

Variation of Ground Acceleration with Increase in Lateral Distance

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Abstract

Ground acceleration induced by dynamic loading decreases with increasing lateral distance from the source because of wave attenuation and energy dissipation through the ground. Accurate estimation of ground acceleration at different distances is essential for evaluating the safety and performance of nearby structures, particularly in blasting, seismic, and heavy construction activities. This study presents a simplified linear attenuation model for estimating ground acceleration at greater lateral distances using limited measured data. The model is based on initial ground acceleration values of 6.867 m/s^2 (0.7 g) at a lateral distance of 0.10 km and 6.860 m/s^2 at 0.15 km . The observed reduction in acceleration between these two points was used to establish a linear rate of attenuation, which was subsequently employed to estimate ground acceleration at larger distances. Using this approach, the predicted ground acceleration at 1.5 km was found to be approximately 6.671 m/s^2 , while the estimated value at 15 km was 4.781 m/s^2 . The results indicate a gradual decrease in ground acceleration with increasing lateral distance, demonstrating the influence of wave propagation and attenuation on vibration intensity. Although the proposed model is based on a simplified linear assumption, it provides a practical and computationally efficient method for preliminary estimation of ground motion where extensive field measurements are unavailable. The methodology can assist engineers and researchers in conducting initial vibration hazard assessments, planning infrastructure projects, and evaluating the potential effects of dynamic loads on surrounding structures. Future work should incorporate nonlinear attenuation relationships and field validation to improve the accuracy and applicability of the proposed estimation model under varying geological and loading conditions.

Keywords: Ground acceleration, lateral distance, ground motion attenuation, dynamic loading, seismic wave propagation, ground vibration, linear attenuation model, vibration analysis, geotechnical engineering, structural safety, seismic hazard assessment

INTRODUCTION

Ground acceleration is one of the most significant parameters used to evaluate the effects of dynamic loading on soil and structural systems. It represents the intensity of ground motion generated by sources such as earthquakes, blasting operations, pile driving, heavy machinery, traffic loads, and other vibration-producing activities such as construction. An accurate estimation of ground acceleration is essential for assessing the safety, stability, and serviceability of buildings, bridges, dams, tunnels, pipelines, and other critical infrastructures. Excessive ground acceleration can lead to structural damage, soil settlement, slope instability, and failure of engineering components, making its prediction an important aspect of geotechnical and structural engineering [1–3].

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The propagation of vibration waves through the ground is influenced by several factors, including the characteristics of the vibration source, soil type, geological conditions, damping properties, and distance between the source and point of

observation. As seismic or vibration waves travel through the ground, their energy gradually dissipates because of geometric spreading and material damping, resulting in a reduction in ground acceleration with an increasing lateral distance. Understanding this attenuation behavior is essential for predicting vibration levels at locations where direct measurements are unavailable.

Several empirical and analytical attenuation models have been developed to estimate ground motions at different distances. These models generally require extensive field measurements, detailed geological information, and sophisticated computational techniques. However, such data are often unavailable during the preliminary stages of engineering projects. Consequently, simple estimation methods that can provide reasonable predictions using limited measured data are required.

In this study, a simplified linear attenuation approach was proposed to estimate ground acceleration as a function of lateral distance. The methodology utilizes measured ground acceleration values of 6.867 m/s^2 (0.7 g) at 0.10 km and 6.860 m/s^2 at 0.15 km to establish the rate of decrease in acceleration with distance. Based on this relationship, the ground acceleration was estimated at larger lateral distances, including 1.5 km and 15 km . The calculated values illustrated a progressive reduction in acceleration as the vibration waves propagated away from the source.

Although the proposed method assumes a linear variation in ground acceleration with distance, it provides a straightforward and computationally efficient framework for preliminary vibration assessments. This approach can be useful in the planning and design stages of engineering projects where rapid estimation of ground motion is required, and comprehensive field investigations are not feasible. The findings also emphasize the importance of considering attenuation effects when evaluating the impact of dynamic loading on nearby structures. Future research should validate the proposed model using field measurements and compare its predictions with established nonlinear attenuation relationships to improve its accuracy and applicability under different geological and loading conditions.

LITERATURE REVIEW

Ground acceleration is a fundamental parameter in earthquake engineering and vibration analysis because it quantifies the intensity of the ground motion experienced by structures during dynamic loading. It plays a significant role in the seismic design of buildings, bridges, dams, tunnels, and other critical infrastructures. The propagation of seismic waves through soil and rock is accompanied by attenuation due to geometric spreading and material damping, resulting in a gradual reduction in ground acceleration with increasing distance from the vibration source [1].

According to Kramer [1], the characteristics of ground motion are governed by the earthquake source, wave propagation path, and local site conditions. As seismic waves travel through different geological formations, their energy dissipates, causing a reduction in the peak ground acceleration (PGA), peak ground velocity (PGV), and spectral acceleration. These attenuation characteristics are fundamental to ground motion prediction and seismic hazard assessment.

Chopra [2] emphasized that ground acceleration is the principal parameter used in dynamic structural analyses. Earthquake-induced inertia forces acting on structures are directly proportional to ground acceleration; therefore, an accurate prediction of acceleration at various distances is essential for evaluating structural safety and serviceability. Dynamic response analysis has become an indispensable component of modern earthquake resistant designs.

Several empirical attenuation relationships have been developed using strong motion records. Boore et al. [3] proposed equations for estimating the horizontal response spectra and PGA based on earthquake data collected in western North America. Their study demonstrated that ground acceleration decreases with increasing source-to-site distance and is significantly influenced by the earthquake magnitude and local geological conditions.

Campbell [4] developed empirical attenuation relationships for PGA, PGV, and spectral acceleration considering fault mechanisms, earthquake magnitudes, and site conditions. The study indicated that attenuation follows a nonlinear trend rather than a simple linear decrease, particularly at larger distances, where wave energy is substantially dissipated.

Abrahamson and Silva [5] further improved attenuation prediction by incorporating the rupture distance, fault mechanism, and local soil conditions into empirical response spectral relationships. Their attenuation equations have been widely adopted in probabilistic seismic hazard analyses because of their improved prediction accuracy across different geological environments.

Joyner and Boore [6] analyzed numerous strong motion records and observed a systematic reduction in the PGA with increasing distance from the seismic source. Their findings established one of the earliest empirical relationships between source distance and ground motion intensity, providing the basis for several modern ground motion prediction equations.

Douglas [7] reviewed numerous ground motion prediction equations developed worldwide and concluded that attenuation behavior varies according to the tectonic setting, regional geology, earthquake magnitude, source mechanism, and local site conditions. The study highlighted that no single attenuation model is universally applicable, and regional calibration is often necessary to obtain reliable predictions of the ground motion.

Das [8] explained that soil properties, such as the shear modulus, damping ratio, density, and stratification, significantly influence the transmission and attenuation of vibration waves. Soft soil deposits may amplify certain frequencies, whereas dense soils and rock formations generally exhibit lower amplification and greater energy dissipation characteristics.

The seismic design recommendations provided in IS 1893 (Part 1):2016 [9] recognize ground acceleration as the primary parameter for determining the seismic forces acting on structures. The code recommends considering seismic zonation, response spectra, local site effects, and soil conditions when estimating the design ground motion.

Bolt [10] explained the physical mechanisms responsible for earthquake generation and wave propagation, emphasizing that seismic energy decreases continuously because of material damping and geometric spreading. Similarly, Aki and Richards [11] presented the theoretical basis of quantitative seismology and demonstrated that attenuation depends on the wave type, propagation path, and subsurface material properties. Seed and Idriss [12] further showed that the soil stiffness and damping characteristics significantly influence the dynamic response of soil deposits subjected to seismic loading. Bommer and Abrahamson [13] discussed the evolution of probabilistic seismic hazard analysis and emphasized the importance of reliable attenuation models for predicting design ground motions.

Although sophisticated nonlinear attenuation relationships are available, many engineering projects lack sufficient field measurements to effectively apply these advanced models. Under such conditions, simplified empirical methods provide a practical alternative for the preliminary estimation of ground acceleration. In this study, we adopted this approach by developing a simplified empirical attenuation model using measured ground acceleration values at two lateral distances. The developed model predicts the variation in ground acceleration with increasing lateral distance and provides an efficient estimation technique for preliminary engineering analyses where detailed field investigations are unavailable.

METHODOLOGY

The objective of this study was to estimate the variation in ground acceleration by increasing lateral distance from the vibration source using a simplified empirical approach. The initial measured ground acceleration values were 6.867 m/s^2 (0.7 g) at a lateral distance of 0.10 km and 6.860 m/s^2 at 0.15 km ,

respectively. The difference in acceleration between these two locations was 0.007 m/s^2 for an increase of 0.05 km in lateral distance.

Assuming a linear attenuation of ground acceleration with distance, the reduction in acceleration was extrapolated to estimate the ground acceleration at greater distances. Based on this assumption, the estimated ground acceleration at 1.5 km was calculated to be 6.671 m/s^2 . The same attenuation trend was further extended to estimate the ground acceleration at 15 km , resulting in a value of 4.781 m/s^2 .

To establish an empirical mathematical model, the lateral distance and corresponding ground acceleration values were normalized and averaged. A power-law relationship was developed using normalized parameters. The model constant was determined to be 0.411 , resulting in an estimated attenuation coefficient of 0.0082 . Using the developed empirical relationship, the residual ground vibration at larger distances was evaluated, and the corresponding ground acceleration was estimated to be approximately 0.056 m/s^2 at a distance of 400 km from the epicenter Tables 1–3.

At $0.10 \text{ km} = 6.867 \text{ m/sec}^2$ (0.7 g)

$0.15 \text{ km} = 6.860 \text{ m/sec}^2$.

We have to find the ground acceleration at a distance of 2 km

As the distance from the fault surface (0.05 km) increases, the ground acceleration decreases by $6.867 - 6.860 = 0.007 \text{ m/sec}^2$.

At 1 km , the ground acceleration decreases by 0.007

Suppose we have to find the ground acceleration at 1.5 km . The increase in distance with respect to $0.15 \text{ km} = 1.5 - 0.15 = 1.35 \text{ km}$ is an increase in lateral distance, for which ground acceleration is decreased by $\frac{0.007 \times 1.35}{0.05} = 0.189 \text{ m/sec}^2$ is decreased on the ground. Hence, at 1.5 km , ground acceleration $= 6.860 - 0.189 = 6.671 \text{ m/sec}^2$.

Suppose at 15 km distance we have to find ground acceleration increase in distance with respect to $1.5 \text{ km} = 15 - 1.5 = 13.5 \text{ km}$ for $0.15 \text{ km} = 6.860 \text{ m/sec}^2$. $1.6 \text{ km} = 6.671 \text{ m/sec}^2$.

As $1.5 - 0.15 \text{ km} = 1.35 \text{ km}$ increases

As the lateral distance of 1.35 km increases, the ground acceleration decreases by $6.860 - 6.671 = 0.189 \text{ m/sec}^2$.

$$1 \text{ km} \quad \frac{0.189}{1.35}$$

For a 13.5 km increase $\frac{0.189 \times 13.5}{1.35} = 1.89 \text{ m/sec}^2$

Hence, for $1.5 \text{ km} = 6.671$

$15 \text{ km} = (6.671 - 1.89) = 4.781 \text{ m/sec}^2$.

At $0.15 \text{ km} = \text{ground acceleration} = 6.860 \text{ m/sec}^2$.

At $1.5 \text{ km} = 6.671 \text{ m/sec}^2$.

As the lateral distance increased by 1.35 km , the ground acceleration decreased by 0.189 m/s .

$$1 \text{ km} \quad \frac{0.189}{1.35}$$

Table 1. Formation of model.

S.N.	Lateral distance l in km	Ground in m/sec ² f
(1)	0.15	6.860
(2)	1.50	6.671

Table 2. Formation of model $\frac{l}{l_{\max}}$ (x) and $\frac{f}{f_{\max}}$ (y)

S.N.	$\frac{l}{l_{\max}}$ (x)	$\frac{f}{f_{\max}}$ (y)	xy	x ²
(1)	0.10	1.000	0.10	0.01
(2)	1.000	0.972	0.972	1.000
Σ	1.10	1.972	1.072	1.010

Table 3. Formation of model $\frac{1}{\frac{l}{l_{\max}}}$ and $\frac{f}{f_{\max}}$

S.N.	$\frac{1}{\frac{l}{l_{\max}}}$	$\frac{f}{f_{\max}}$
(1)	10.000	1.000
(2)	1.000	0.972
Average	5.50	0.986

Corresponding to $0.986 \approx 1.000$

$$\frac{1}{\frac{l}{l_{\max}}} = 10.00 \text{ Average value } 5.50$$

$$\text{Power } \frac{5.50}{10} = 0.55$$

$$\text{Hence, } \frac{f}{f_{\max}} = x \left[\frac{1}{\frac{l}{l_{\max}}} \right]^{0.55}$$

$$\begin{aligned} 0.986 &= x [5.50]^{0.55} \\ &= x [2.4] \\ x &= 0.411 \end{aligned}$$

$$\text{Hence, } \frac{f}{f_{\max}} = 0.411 \left[\frac{1}{\frac{l}{l_{\max}}} \right]^{0.55}$$

$$\begin{aligned}
&= 0.411 \left[\frac{1}{\frac{400}{1.50}} \right]^{0.55} \\
&= 0.411 \left[\frac{1}{267} \right]^{0.55} \\
&= 0.411 [0.004]^{0.55} \\
&= 0.411 \times 0.02 = 0.0082 \\
F &= 0.056 \text{ m/sec}^2.
\end{aligned}$$

Hence, at 400 Km same vibration of the ground is felt.

$$\frac{l}{l_{\max}}$$

RESULTS AND DISCUSSION

The results indicate that the ground acceleration decreases continuously with increasing lateral distance owing to the attenuation of the vibration energy during wave propagation. The measured acceleration reduced slightly from 6.867 m/s² at 0.10 km to 6.860 m/s² at 0.15 km. By applying the proposed empirical model, the estimated ground acceleration decreased to 6.671 m/s² at 1.5 km and further to 4.781 m/s² at 15 km.

The developed model demonstrated that the rate of attenuation became more significant over longer distances. The empirical power-law formulation provides a convenient means of estimating ground acceleration when direct field measurements are unavailable. The attenuation coefficient obtained from the normalized data represents the reduction in the vibration intensity with increasing distance.

The predicted ground acceleration of approximately 0.056 m/s² at 400 km indicates that only very low-amplitude ground vibrations would remain at such a large distance from the source. This behavior is consistent with the general principle of seismic wave attenuation, where the vibration energy decreases because of geometric spreading and material damping.

Although the proposed model provides a simple estimation technique, it is based on limited measured data and assumes uniform attenuation patterns. In practice, ground acceleration is influenced by several factors, including soil properties, geological formations, wave frequency, source characteristics, and damping effects. Therefore, the model should be considered suitable for preliminary engineering assessments rather than detailed seismic hazard evaluations.

CONCLUSION

A simplified empirical model was developed to estimate the ground acceleration at different lateral distances using limited measured data. The analysis demonstrated that the ground acceleration decreased progressively as the distance from the vibration source increased. The estimated values were 6.671 m/s² at 1.5 km and 4.781 m/s² at 15 km, confirming the attenuation of the vibration energy during wave propagation. The developed power-law model yielded an attenuation coefficient of approximately 0.0082 and predicted a residual ground acceleration of approximately 0.056 m/s² at 400 km.

The proposed methodology is computationally simple and can be applied for the preliminary estimation of ground vibrations in engineering projects where field measurements are limited. However, because the model is derived from only a few observations and assumes simplified attenuation behavior, further validation using extensive field measurements and established nonlinear ground motion

prediction equations is recommended. Incorporating site-specific soil conditions, geological characteristics, and dynamic loading parameters will improve the accuracy and reliability of future ground acceleration prediction models.

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