IJSREAT-0000626_T

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A REVIEW ON STUDY OF MULTI-TIERED REINFORCED FLY ASH WALL

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Abstract: The demand for taller retaining walls is on the rise due to the rapid expansion of urban infrastructure and the increasing constraints on available space. However, conventional methods of construction become prohibitively costly as wall height increases. Multi-tiered walls, which incorporate offsets at various heights, present a promising solution to this challenge. As walls grow taller, they experience heightened stress, elevating project costs and construction complexity. By strategically placing offsets at intervals along the wall, construction becomes more manageable, and stress levels decrease, thereby enhancing wall stability.

This study offers an understanding of multi-tiered reinforced retaining walls constructed using fly ash, a sustainable alternative material derived from coal combustion byproducts. The research delves into the structural performance and stability of these innovative retaining systems, offering potential solutions for sustainable infrastructure development. Factors such as external stability, internal stability, and deformation characteristics are meticulously analyzed to evaluate structural integrity and long-term performance. Additionally, the study investigates the incorporation of geosynthetic reinforcement to bolster overall stability and load-bearing capacity.

Through the optimization of reinforcement configurations and material properties, the study aims to maximize the structural efficiency and resilience of multi-tiered retaining systems. Extensive sensitivity analyses pinpoint critical design parameters, facilitating the development of robust design guidelines and recommendations for practical implementation. The study's findings advance sustainable infrastructure practices by showcasing the feasibility and effectiveness of multi-tiered reinforced fly ash retaining walls. Leveraging innovative analysis techniques, engineers and designers can refine the design and construction of retaining structures, fostering resilient and environmentally conscious infrastructure development.

Key Word: *Fly ash, Multi-tiered Wall, Geosynthetics, Reinforced earth, offset*

1. Introduction

Reinforced earth retaining walls serve the purpose of containing soil masses, particularly when these materials lack inherent vertical stability. These structures are pivotal in maintaining distinct ground levels and mitigating lateral earth pressure resulting from elevation changes. Geosynthetic-reinforced soil (GRS) walls have become increasingly prevalent in civil engineering applications. In certain scenarios, these walls are configured in tiers rather than as single entities, a decision influenced by considerations such as wall stability, construction limitations, drainage requirements, and aesthetic concerns along the wall's height.

Designing walls with tier configurations presents greater complexity compared to single walls, as upper and lower tiers interact concerning wall deformation and reinforcement loads. Fly ash, a byproduct of coal combustion finds versatile applications in civil engineering, including roads, railways, and dam embankments. Its utilization extends to structural fill in low-lying areas for residential development and mine filling. Additionally, fly ash has been utilized in constructing embankments for roads and highway bridges, as well as in backfill materials behind retaining walls.

Reinforced soil techniques involve integrating tensile elements into the soil to enhance stability and regulate deformation. Crucially, these reinforcements must intersect potential failure surfaces within the soil mass. As strains develop in the soil, corresponding strains occur in the reinforcements, generating tensile forces that restrict soil movements and enhance shear strength. This interplay between soil and reinforcement underscores the effectiveness of reinforced soil as a structural solution.

1.1 Reinforced Earth Retaining Wall

The incorporation of reinforced earth represents a recent advancement in the realm of foundation and earth-retaining structure design and construction. This innovative material comprises soil that has been fortified by various tensile elements, including metal rods or strips, nonbiodegradable fabrics such as geotextiles, and geogrids. While the concept of reinforcing soil is centuries old, its systematic application in modern construction is relatively recent.

The concept of reinforcing soil bears striking similarities to reinforcing concrete, as both materials utilize reinforcement to withstand tension stresses induced by applied loads. In concrete, bond stresses prevent pullout, whereas, in soil, friction stresses arise based on the angle of friction between the soil and reinforcement. The fundamental principle of reinforced earth finds historical precedent in the use of materials like straw, bamboo rods, and similar alternatives, which have long been employed to reinforce primitive mud bricks and walls in traditional housing construction.

The three primary components of reinforced earth include [list components]. Figure 1.1 illustrates these fundamental components of a reinforced earth wall, showcasing the interplay between soil and reinforcement elements in this innovative construction technique.

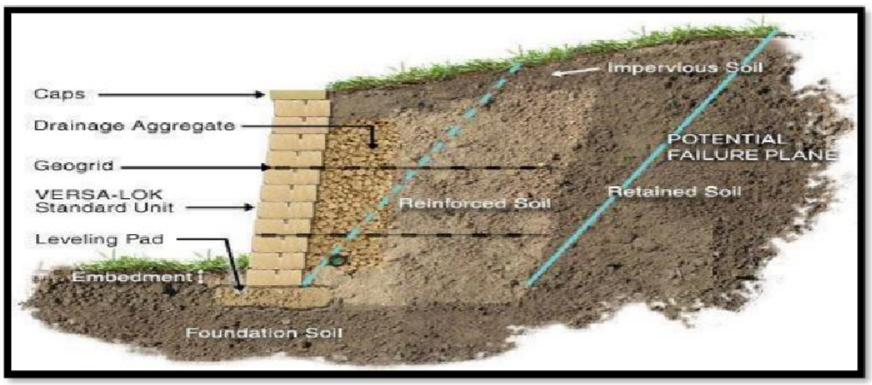


Figure 1.1 Reinforced Earth Retaining Wall

1.2 Multi-Tiered Reinforced Wall

Multi-tiered walls present an innovative approach to earth-retaining structures, incorporating offsets at specific heights to address the challenges posed by increased wall height. As walls grow taller, they experience heightened stress levels, leading to escalated project costs and construction complexities. To balance aesthetics and economics, multi-tiered walls are increasingly favoured, particularly in the context of high walls. By introducing offsets between adjacent tiers, tensile stresses in the reinforcement of lower tiers can be mitigated. This offsetting strategy not only enhances construction manageability but also reduces stresses on the wall.

Prior research on multi-tiered walls has underscored the effectiveness of offsets in bolstering wall stability. In the realm of reinforced soil walls, dividing the structure into multiple sections or tiers yields what is termed a multi-tiered reinforced soil retaining wall (MRSRW). These walls offer a practical solution, particularly when dealing with height requirements. Figure 1.2 provides a visual representation of a multi-tiered retaining wall, highlighting its various components and the strategic placement of offsets to optimize structural integrity and performance.

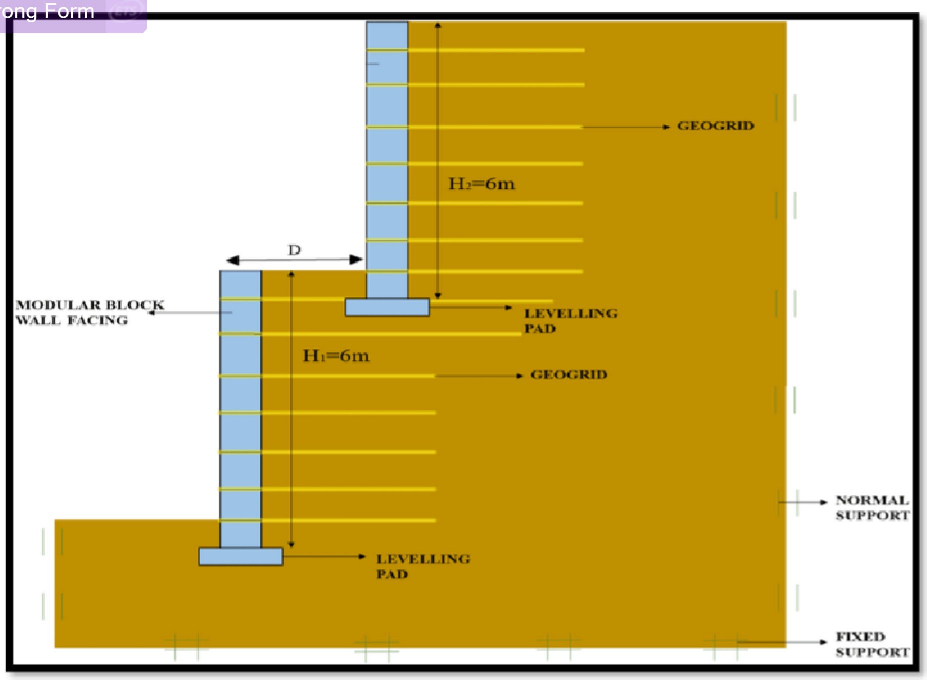


Figure 1.2 Multi-tiered retaining wall with different components

1.3 Fly Ash

Fly ash is the finely divided residue resulting from the combustion of pulverized coal, transported from the combustion chamber by exhaust gases. Several key characteristics should define fly ash:

- Non-hazardous: Fly ash should exhibit non-hazardous properties concerning ignitability, corrosivity, reactivity, and toxicity.

- Potential for Improvability: It should demonstrate a high potential for enhancing its properties, including workability and performance, through the addition of suitable additives.
- Compatibility: Fly ash should be compatible with other construction materials and maintain consistency in its properties.
- Economic Feasibility: Economically, it should offer low unit costs and high quality, resulting in savings on construction costs. It should be usable as produced without necessitating costly processing, readily available, easy to handle and store, and exhibit long-term performance stability.

1.4 Soil Reinforcement

Soil reinforcement employs mechanical methods to stabilize weak soils, utilizing fibrous materials such as [illegible] and geonets), whether natural or synthetic, with randomly distributed fibres. Various functions are performed by soil reinforcement:

- Separation: Geosynthetics, positioned between two dissimilar materials, uphold the integrity and functionality of both materials.
- Filtration: Geosynthetics enable liquid flow across their plane while retaining fine particles on their upstream side.
- Reinforcement: Geosynthetics generate tensile forces aimed at maintaining or enhancing the stability of the soil-geosynthetic composite.
- Stiffening: Geosynthetics generate tensile forces aimed at controlling deformations within the soil-geosynthetic composite.
- Drainage: Geosynthetics facilitate liquid flow within the plane of their structure.

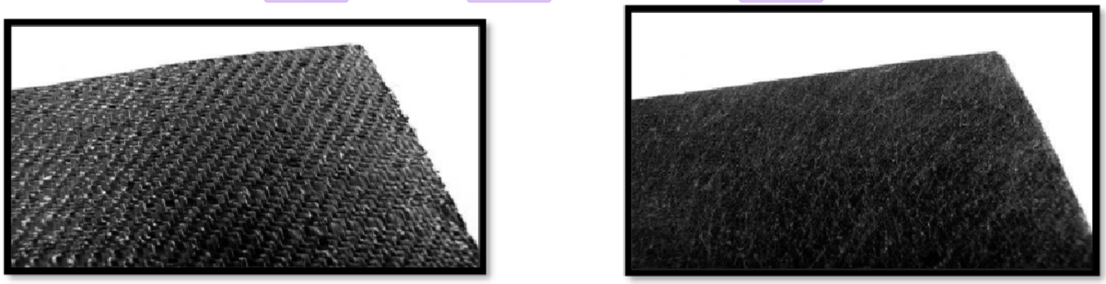
1.4.1 Geogrid

Geogrids constitute a rapidly expanding sector within geosynthetics. Unlike woven, nonwoven, or knitted textile fabrics, geogrids consist of polymers fashioned into a highly open, grid-like structure, featuring large apertures between individual ribs in both transverse and longitudinal directions. They can be stretched in one, two, or three directions to enhance their physical properties. Manufactured using standard textile manufacturing methods on weaving or knitting machinery, or by bonding rods or straps together via laser or ultrasonic methods. While geogrids find numerous specific applications, their primary function is almost exclusively as reinforcement materials. Figure 1.3 illustrates the configuration of a geogrid.

Figure 1.3 Geogrid

1.4.2 Geotextile

Geotextiles are permeable fabrics that, when employed in conjunction with soil, serve various functions such as separation, filtration, reinforcement, protection, or drainage. Generally crafted from polypropylene or polyester, geotextile fabrics are available in two primary forms: woven, resembling mail bag sacking, and nonwoven. Figure 1.4 illustrates different types of geotextiles: (a) woven geotextile and (b) nonwoven geotextile.



(a) (b)

Figure 1.4 Different Types of Geotextiles

2. Literature Review

Ankita Kumar *et al* (2019) performed a parametric study on a multi-tiered model fly ash wall. The various stages such as the multi-tiered wall model of fly ash and reinforcement, and experimental program include loading setup and procedure. Good quality fly ash and jute geotextile are used as per standards to build the wall model. Loading setup includes the loading frame and other measurement devices. The relationship between different design parameters is carried out such as reinforcement length, reinforcement spacing, offset distance etc. The horizontal displacement of the wall is reduced to a greater percentage when there is inclusion of reinforcement as compared to unreinforced walls. The offset distance is increased When there is an addition of reinforcement. settlement of the wall is also reduced due to the provision of reinforcement. The critical offset distance is also found for unreinforced and reinforced walls.

K. Jagdish *et al* (2018) performed the numerical analysis of multi-tiered walls, the author described the various failure patterns of the multi-tiered wall by analyzing the internal and external stability. Poorly graded sand used with the inclusion of reinforcement for the wall modelling. Types of failure such as sliding overturning, bending and settlement. The distribution surcharge load is calculated for each separate tier by using geo5 modelling software Slope stability analysis of the wall is carried out by the bishops' method. After it is concluded that the increase in the resistance to pullout the reinforcement length should be minimal, the overturning behaviour of the wall is dependent on its geometry and load intensity is dependent on the offset distance between the wall.

Bhattacharjee *et al* (2015) performed the finite element numerical analysis of multi-tiered retaining walls by using the ANSYS software comparison between the single and multi-tiered wall models done with and without inclusions of reinforcement. The main objective of the research was to study the different design parameters of multi-tiered walls and their major role in controlling the effect of different forces as compared to single-tiered walls. The material used for the construction of the model is concrete backfill soil as gravel material and geogrid reinforcement with suitable desired properties. it was observed from the study that the lateral displacement is maximum at the offset junction or the mid-height of the wall. The displacement decreased with an increase in tier offset. The upper wall acts as a surcharge on the lower tier which increases deformation in the middle. The maximum lateral pressure acts at the base of the wall and decreases with an increase in height. The addition of reinforcement holds the surrounding soil and transfers the stresses partially to the facing and soil mass. The vertical stress is higher in unreinforced walls as compared to reinforced walls.

A. Abedi *et al* (2019) performed the experimental investigation on a multi-tiered wall for the determination of lateral pressure and horizontal as well as vertical deflection. The design and geometry consideration of tiered walls is taken into account as important to carry out the performance against different failure conditions such as settlement lateral deformation etc. The materials used for making the model are poorly graded sandy soil as retained backfill concrete and geogrid reinforcement for filling. A small loading frame is used to apply the load It is concluded that when the tier width and the number of tiers get increased there is a decrease in the horizontal deformation and settlement of the wall. The number of reinforcement layers can provide the best interaction between the upper and lower tiers to reduce the lateral deformation and increase the bearing capacity of the wall.

According to Leonard *et al*. (1972), untreated pulverized coal ash devoid of cementing additives was effectively employed as structural fill material. Despite its inherent variability, the ash could be satisfactorily compacted by ensuring that moisture content remained below the optimum level determined through standard laboratory tests and that the percentage of fines (particles passing the No.200 sieve) did not exceed 60%.

Kumar *et al*. (1999) present findings from laboratory investigations conducted on specimens of silty sand and pond ash reinforced with randomly distributed polyester fibres. The study's results indicate that incorporating fibres into the soils leads to notable enhancements in several key properties. Specifically, the inclusion of fibres results in increased peak compressive strength, CBR (California Bearing Ratio) value, peak friction angle, and ductility of the specimens. The study concludes that the optimal fibre content for both silty sand and pond ash falls within the range of approximately 0.3 to 0.4% of the dry unit weight. This optimal range ensures the most significant improvements in the mechanical properties of the reinforced soils, highlighting the effectiveness of polyester fibre reinforcement in enhancing soil performance.

Bera *et al*. (2007) conducted a comprehensive study on the compaction characteristics of pond ash, employing three distinct types of pond ash. The research delved into the effects of various compaction-controlling parameters, including compaction energy, moisture content, layer thickness, mould area, tank size, and specific gravity, on the dry density of pond ash. The study revealed that the maximum dry density and optimum moisture content of pond ash fall within the respective ranges of 8.40–12.25 kN/m3 and 29–46%. Additionally, the degree of saturation at the optimum moisture content was observed to range from 63% to 89%. To facilitate practical application, an empirical model was developed through multiple regression analyses to estimate the dry density of pond ash, accounting for compaction energy, moisture content, and specific gravity.

Furthermore, linear empirical models were devised to estimate the maximum dry density and optimum moisture content in the field at any given compaction energy. These empirical models serve as valuable tools for engineers involved in field compaction control, offering preliminary estimates of maximum dry density and optimum moisture content for pond ash utilization in various engineering applications.

Bera *et al (2009)* investigated the shear strength response of reinforced pond ash through a series of unconsolidated undrained (UU) triaxial tests conducted on both unreinforced and reinforced pond ash samples. The study focused on analyzing the effects of confining pressure (σ3), number of geotextile layers (N), and types of geotextiles on the shear strength response of pond ash. The results revealed that the normal stress at failure (σ1f) exhibited an increasing trend with rising confining pressure. Specifically, the rate of increase in normal stress at failure (σ1f) was found to be highest for samples reinforced with three layers of geotextiles. Moreover, the corresponding percentage increase in σ1f was approximately 103% when the number of geotextile layers increased from two to three. Furthermore, as the confining pressure increased, the increment in normal stress at failure (Δr) also increased, reaching a peak value at a certain threshold confining pressure. Beyond this threshold, Δr remained relatively constant. The threshold value of confining pressure was found to be dependent on factors such as the number of geotextile layers, dry unit weight (γd) of pond ash, type of geotextile used, and the specific characteristics of the pond ash itself. This study provides valuable insights into the behaviour of reinforced pond ash under shear loading conditions, shedding light on the influence of various parameters on its shear strength response.

Ghosh *et al*. (2010) present laboratory test results focusing on Class F Pond ash both in its untreated form and stabilized with varying percentages of lime (4%, 6%, and 10%) and PG (0.5% and 1.0%). Their study aims to assess the suitability of stabilized pond ash for road base and sub-base construction. Standard and modified Proctor compaction tests were conducted to elucidate the compaction characteristics of the stabilized pond ash. Additionally, bearing ratio tests were performed on specimens compacted at maximum dry density and optimum moisture content obtained from standard Proctor compaction tests and cured for durations of 7, 28, and 45 days. Both un-soaked and soaked bearing ratio tests were conducted to evaluate the material's behaviour under different conditions. The paper underscores the influence of lime content, PG content, and curing period on the bearing ratio of stabilized pond ash. To facilitate practical application, an empirical model was developed through multiple regression analysis to estimate the bearing ratio for stabilized mixes. Furthermore, a linear empirical relationship was established to estimate the soaked bearing ratio from the un-soaked bearing ratio of stabilized pond ash. The experimental findings suggest that pond ash-lime-PG mixes exhibit promising potential for use as road base and sub-base materials, indicating the viability of incorporating stabilized pond ash into infrastructure construction projects.

Kumar *et al*. (1998) conducted laboratory investigations focusing on specimens of silty sand and pond ash reinforced with randomly distributed polyester fibres. Their study yielded significant findings regarding the impact of fibre inclusion on various mechanical properties of the specimens. The test results indicated that incorporating fibres into the soils led to notable enhancements in several key parameters. Specifically, the inclusion of fibres resulted in increased peak compressive strength, CBR (California Bearing Ratio) value, peak friction angle, and ductility of the specimens. Based on their analysis, Kumar et al. concluded that the optimal fibre content for both silty sand and pond ash fell within the range of approximately 0.3 to 0.4% of the dry unit weight. This optimal range of fibre content ensured the most substantial improvements in the mechanical properties of the reinforced soils, highlighting the effectiveness of polyester fibre reinforcement in enhancing soil performance.

Kumar *et al.*(2012) examined the effectiveness of reinforced earth retaining walls as a modern construction technique, which has gained prominence due to its simplicity, cost-effectiveness, and expedited construction compared to traditional reinforced concrete and gravity retaining walls. The researchers noted the widespread adoption of this technique worldwide. The study focused on a specific application of reinforced earth retaining walls in alleviating congestion on National Highway-2 at the Kalindi Kunj crossing near Sarita Vihar, New Delhi. To address this issue, a flyover was constructed along the Badarpur-Ashram direction, and the approach road was supported by a reinforced retaining wall featuring friction polymeric ties (geosynthetic material) as reinforcement. Notably, instead of conventional earth, pond ash sourced from the nearby Badarpur thermal power plant was utilized as backfill material. The paper delves into various aspects of the construction process, including the properties of geosynthetic reinforcement and pond ash backfill material, design details, and the methodology employed for constructing the reinforced approach embankments. Kumar et al. conclude the suitability of geosynthetic material as reinforcement and pond ash as a backfill material for the retaining wall, shedding light on their efficacy in this particular application.

S. Adhana *et al.* (2011) conducted a parametric investigation on reinforced fly ash slopes employing various geosynthetics. The laboratory experiments aimed to assess the stability of steep slopes comprised of fly ash filling material, both with and without reinforcement, on soft foundations. Two types of reinforcement were utilized in the experiments: (a) a three-dimensional circular geocell strip, crafted from waste plastic bottles with a diameter of 5 cm and a height of 1 cm, and (b) a polyester geogrid strip measuring 4.5 cm in width and 0.3 mm in thickness. The properties of the geocell and geogrid strip were thoroughly characterized. During the experiments, load and settlement were measured, and load-settlement curves were generated from the data. The results indicated that the load-carrying capacity of the geocell exceeded that of the geogrid strip. Additionally, while the deformation of the geocell was slightly greater than that of the geogrid strip, it remained within acceptable limits. Furthermore, the study involved the evaluation of a Finite Element Method (F.E.M.), providing additional insights into the behaviour of reinforced fly ash slopes. These findings contribute to a deeper understanding of the performance of different reinforcement techniques in stabilizing steep slopes composed of fly ash material, offering valuable guidance for engineering applications in slope stability and reinforcement design.

Mohammad Al-Barqawi *et al.* (2021) provided an extensive overview of polymer geogrids, focusing on the relationships between material properties, design considerations, and structural performance. The review begins by introducing the fundamental properties of geogrids and discussing the methodologies used to determine these properties through various testing methods. Additionally, the authors delve into the process of designing reinforcement for specific structures, as well as the potential failure modes associated with geogrids. Present advancements and current insights into geogrid materials, highlighting their diverse applications. They critically analyze different geogrid systems, examining both their physical and chemical characteristics and assessing how these properties influence short- and long-term performance. Furthermore, the review explores approaches to characterizing the mechanical behaviour of geogrids, with a focus on recent advancements in computational methods. These computational techniques offer valuable insights into the performance of geogrid materials in real-world scenarios. Finally, the review discusses recent applications of geogrids, including their use in remote sensing of subgrade conditions and their incorporation into composite materials. By synthesizing existing knowledge and recent developments, provide a comprehensive overview of polymer geogrids and their evolving role in geotechnical engineering applications.

3. Conclusions

From the summarized literature, it's evident that numerous experimental and analytical studies have been conducted to address various challenges and mitigate the shortcomings associated with backfill materials for reinforced earth walls, parameters of multi-tiered walls, and geosynthetic reinforcement for earth walls. The following conclusions can be drawn.

- Fly ash can be used as backfill material for retaining walls with different geosynthetic reinforcement
- Parameters of the multi-tiered walls such as offset, reinforcement length and reinforcement spacing affect the performance and stability of wall.
- Various geosynthetic reinforcements can be use to enhance the performance and strength of retaining wall.

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Article Error You may need to remove this article.

Sp. This word is misspelled. Use a dictionary or spellchecker when you proofread your work.

Missing "," You may need to place a comma after this word.

Article Error You may need to use an article before this word.

Sp. This word is misspelled. Use a dictionary or spellchecker when you proofread your work.

Hyph. You may need to add a hyphen between these two words.

S/V This subject and verb may not agree. Proofread the sentence to make sure the subject agrees with the verb.

P/V You have used the passive voice in this sentence. Depending upon what you wish to emphasize in the sentence, you may want to revise it using the active voice.

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Proofread This part of the sentence contains a grammatical error or misspelled word that makes your meaning unclear.

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Prep. You may be using the wrong preposition.

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Confused You have used **a** in this sentence. You may need to use **an** instead.

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