Dean&Francis
ISSN 2959-6157

Global Application of Waste Tires as Ecological Slope Reinforcement for Preventing Landslides

Yimo Liu

Abstract:
This study explores the global application of waste tires as an innovative and ecological material for slope reinforcement to prevent landslides. By examining a case study along the Jingxin Expressway in Shanxi Province, China, where waste tires are integrated into slope protection systems, the study demonstrates the practical benefits of using waste tires in landslide prevention. The tires are strategically anchored to slopes using a herringbone skeleton structure and short anchor bolts, absorbing soil pressure and hydraulic stress, while also promoting vegetation growth for further slope stability. This approach not only offers a cost-effective alternative to traditional methods, but also provides an environmentally sustainable solution by repurposing large quantities of waste tires. The study highlights the global potential of this technology, with examples from Brazil, Malaysia, Iran, and other countries that have adapted this solution to their unique climatic and geotechnical conditions. However, the research also identifies environmental concerns regarding the toxicity of synthetic rubbers in tires and the potential heavy metal leaching, which requires further investigation. The study concludes that while the ecological benefits of tire-based slope reinforcement are promising, ongoing research and technological advancements are needed to fully address these risks and enhance the sustainability of the solution.

Keywords: waste tires, slope reinforcement, landslide prevention, ecological application, global practice, environmental risk

1. Introduction

During a visit to Shanxi Province, China, the author had the opportunity to travel along the Jingxin Expressway, a major roadway that spans across the province. As the author journeyed through the re-

ISSN 2959-6157

gion, an unusual and innovative slope structure caught the attention. Both sides of the expressway were lined with an unfamiliar yet striking feature: large stacks of waste tires strategically arranged along the slopes. These tire structures were different from traditional slope stabilization methods, which typically involve concrete blocks, stone walls, or geotextile systems. Intrigued by this unique approach, the author conducted further research into the site to uncover the rationale behind this design.

Through detailed fact-checking and conversations with engineers and local authorities, it was revealed that the technique employed on the Jingxin Expressway involved using discarded waste tires as an innovative solution for slope reinforcement and landslide prevention. The tires were anchored to the slope using a herringbone framework and short anchor bolts, allowing them to bear the pressure of the soil above and mitigate hydraulic stress from rainwater runoff. The integration of vegetation, such as Chinese honey locust trees, within the structure further enhanced the stability of the slope, promoting soil retention and aesthetic value. The tires not only served as a structural barrier but also acted as a medium for water retention, aiding plant growth during dry periods.

Motivated by this unexpected discovery, the author was inspired to investigate the broader implications of this technique, particularly its global applicability and potential for addressing the growing environmental issue of waste tire disposal. This exploration marks the beginning of a deeper investigation into the use of waste tires as an ecological reinforcement material, examining both its feasibility and the environmental risks it may pose.

2. Global Overview of Waste Tires

2.1 The Global Waste Tire Crisis

Globally, 1 billion waste tires are produced annually, creating a severe disposal crisis. Tires are durable and take hundreds of years to decompose naturally, making them one of the most challenging waste streams. Of these, China is the largest producer of waste tires, with an estimated 330 million tires (approximately 10 million tons) generated every year. As a result, China accounts for almost 1/3 of global tire production.

The disposal of waste tires leads to numerous environmental issues:

- Fire Hazards: Waste tire piles are highly flammable and difficult to extinguish, burning for months and releasing toxic fumes into the air. These fires are not only hazardous to human health but also contribute to air pollution.
- Space Occupation: Tires take up significant landfill space due to their size and lack of compressibility. This issue is especially problematic in densely populated regions where land is limited.
- Pollution Risks: Tires contain synthetic rubber, plastics, and various heavy metals, such as zinc, lead, and cadmium, which can leach into the soil and groundwater over time. This poses long-term contamination risks, impacting ecosystems and human health.

2.2 Current Methods of Waste Tire Disposal

Currently, several methods are employed to manage and recycle waste tires:

- Landfilling: Although common, this method is unsustainable due to the long decomposition time of tires and the space they occupy.
- Pyrolysis: Waste tires are subjected to high temperatures to break down into oil, gas, and carbon black, which can be used as alternative fuels. However, this method requires significant energy input.
- Tire Derived Fuel (TDF): Tires are used as an alternative fuel source in industries like cement manufacturing and paper production, offering a cost-effective way to manage waste while generating energy.
- Shredding and Grinding: Tires can be shredded into smaller pieces and repurposed in various applications, such as rubberized asphalt, insulation materials, and construction fill.

Despite these methods, only a fraction of global tire waste is effectively recycled. The challenge remains to find more sustainable and economically viable solutions for large-scale reuse of tires.

2.3 The Potential of Waste Tires in Civil Engineering

Given the widespread issue of waste tire disposal, there has been growing interest in repurposing waste tires for sustainable civil engineering solutions, particularly in the context of slope reinforcement. The potential advantages include:

- Cost-Effectiveness: Waste tires are low-cost, easily available, and free of charge if collected for reuse, making them an affordable material for construction projects, especially in developing nations.
- Structural Benefits: Tires possess unique physical properties, such as flexibility, compressibility, and lightweight, making them suitable for absorbing and distributing the forces that act on slopes. This prevents soil erosion and slope failure.
- Ecological Impact: By integrating vegetation into tire-based slope reinforcement systems, waste tires contribute to soil stabilization, promote water retention, and encour-

age biodiversity in the environment.

3. Application of Ecological Slope Protection Technology Using Waste Tires in the Chinese Context

The Jingxin Expressway, located in Shanxi Province, is a critical infrastructure project that spans 96 kilometers across a region characterized by challenging and varied topography. The roadbed, made primarily of high-fill and semi-fill embankments, requires a reliable and durable method of slope protection to prevent erosion, landslides, and long-term structural degradation. To address these challenges, the initial slope protection design incorporated precast concrete blocks combined with a green plant arch framework. However, the high material costs associated with concrete construction and the relatively limited protective capacity of vegetation during heavy rains led engineers to investigate more affordable and sustainable solutions. This resulted in the adoption of waste tires as an ecological reinforcement material, a strategy that combines both functional performance and environmental sustainability.

3.1 The Role of Waste Tires in Slope Reinforcement

Waste tires, known for their light weight, flexibility, and cost-effectiveness, present several advantages over traditional construction materials. Their malleability allows them to adapt to varying slope angles and contours, while their compressive strength enables them to resist soil pressure effectively. Additionally, waste tires are often discarded and end up in landfills, making them an ideal material for recycling. Using waste tires in slope protection not only provides a cost-effective alternative to concrete but also helps address the growing issue of tire waste. Tires' natural elasticity enables them to absorb and dissipate hydraulic stress caused by rainfall, reducing the impact of water runoff and preventing erosion.

In the case of the Jingxin Expressway, the construction team employed a herringbone skeleton framework to anchor the tires securely to the slope surface using short anchor bolts. This design maximizes the structural integrity of the slope while allowing the tires to disperse soil pressure and hydraulic forces from rainfall. The layout effectively prevents soil erosion and slope failure, even during heavy rains or flooding. By using waste tires in this innovative manner, the project also reduces the demand for traditional materials, thereby decreasing construction costs and the environmental footprint associated with the project.

3.2 The Integration of Vegetation for Enhanced Stability

A key aspect of this ecological slope protection technique is the incorporation of vegetation, specifically Chinese honey locust trees, within the tire framework. The trees are planted within the structure of the tires and the herringbone skeleton, benefiting from both the soil reinforcement provided by the tires and the water-holding capacity of the system. The root systems of the trees play a vital role in enhancing the overall slope stability by binding the soil together, making it more resistant to erosion. This not only stabilizes the slope but also fosters a greener environment.

Furthermore, the vegetation introduces aesthetic value to the slope reinforcement, transforming what would otherwise be a purely functional structure into an attractive landscape feature. The Chinese honey locust trees provide shade, improve biodiversity, and offer habitat for local wildlife, thus contributing to the ecological health of the area.

This combination of waste tires and vegetation creates a self-sustaining system that requires less maintenance than traditional slope protection methods. The trees benefit from the moisture retained by the tires during rainfalls, reducing the need for regular irrigation. As the trees grow, they further stabilize the soil, preventing erosion and reinforcing the slope's resilience to natural disasters such as heavy rains, floods, or earthquakes. This symbiotic relationship between the tires and the trees maximizes the effectiveness of the slope protection system, making it both functional and sustainable.

3.3 Environmental and Ecological Benefits of Tire-Based Slope Protection

In addition to their structural advantages, the use of waste tires in slope reinforcement brings significant environmental benefits. The ecological module created by combining tires, soil, and vegetation forms a natural filtration system that promotes biological water recycling. As rainwater collects in the tires, it is gradually absorbed by the surrounding soil, supplying the plants with much-needed hydration during dry periods. This water retention capability significantly reduces the need for irrigation and maintenance, further lowering the environmental cost of maintaining the slope.

Moreover, this innovative system helps address the growing environmental concern of tire waste. Each year, billions of tires are discarded worldwide, many of which end up in landfills or are burned, causing air and soil pollution. By repurposing these tires as building materials for slope reinforcement, the Jingxin Expressway project

ISSN 2959-6157

provides a valuable example of waste minimization. It also aligns with broader goals of sustainable development by reducing the consumption of new materials, lowering construction costs, and providing an eco-friendly solution to a pressing environmental issue.

The project also demonstrates the potential of waste tire technologies in regions with varying climatic conditions. For example, in areas with high rainfall or flash floods, waste tire-based systems can offer a practical solution to stabilize slopes and reduce the risk of landslides. The ability to recycle tires for practical infrastructure applications could set a precedent for future large-scale infrastructure projects, especially in areas prone to landslide risks and soil erosion.

4. Implementation of Waste Tires in Slope Reinforcement on the Global Level

Globally, the disposal of waste tires poses significant challenges due to their volume and difficult disposal characteristics. The World Business Council for Sustainable Development estimates that approximately 1 billion discarded tires are produced annually, with many accumulating in landfills. Tires are not only difficult to decompose but also prone to fire hazards, as tire piles can burn for months due to their high flammability. This creates a considerable storage and safety risk, making the repurposing of these tires into productive uses an increasingly urgent matter. In response to these environmental challenges, researchers and engineers worldwide have explored ways to recycle and repurpose tires, with significant advancements occurring in the 1980s and 1990s. These early studies primarily came from North America, Europe, and Australia, where tire waste was considered as a resource for construction materials, energy production, and other sectors such as cement and steel industries (Long, 1996; Garga & O'Shaughnessy, 2000; Amari et al., 1999).

4.1 Waste Tires as a Sustainable Solution in Developed Countries

In developed nations, much of the initial research into using waste tires was motivated by a need to reduce landfill waste and minimize environmental hazards. Researchers investigated a variety of approaches, such as using waste tires as an alternative to conventional construction materials. In civil engineering, tires have been used in the form of reinforced earth fills, in which they are interspersed with soil to provide additional stability and strength to embankments and retaining walls. Notable studies, such as those by Long (1996) and Garga & O'Shaughnessy (2000), explored the design and performance of tire-reinforced earth fills in various infrastructure projects.

Additionally, waste tires have been incorporated into energy production methods, serving as alternative fuels in the cement industry and for pyrolysis processes (Amari et al., 1999; Ramos et al., 2011). These innovations illustrate the potential for waste tires to serve as a resource in energy and infrastructure sectors in developed countries, particularly in regions with sophisticated waste management and industrial systems.

4.2 Adaptation of Waste Tire Technologies in Developing Countries

While the technologies for waste tire recycling and reuse were initially developed in industrialized countries, their implementation in developing nations has faced challenges. These regions, especially in Asia and South America, are often characterized by distinct climatic and economic conditions that were not always considered in earlier models. In these countries, landslides, flash floods, and earthquakes pose significant risks to life and property, with steep slopes and heavy rainfall exacerbating the issue. Traditional methods of slope reinforcement, such as rock and concrete retaining walls, gabion walls, and sandbags, are often prohibitively expensive and difficult for local communities to afford.

However, many developing nations have recognized the potential of using waste tires as a cost-effective and sustainable solution for slope stabilization and landslide prevention. The use of tires as a reinforcement material helps alleviate the economic burden on local governments and communities, while simultaneously addressing the environmental challenge of tire disposal.

4.3 Case Studies and Global Applications

A number of studies and projects conducted in developing nations have tailored waste tire technologies to local needs, showcasing the adaptability of these systems to different climatic and geographic conditions.

- Brazil and Canada: A collaborative project between Canadian and Brazilian researchers employed a custom-engineered saw to remove one sidewall from each tire. These tires were interconnected with polypropylene rope, creating a honeycomb structure. This configuration was then filled with compacted soil to create an earth barrier. The system was applied in a hillside slum community that faced severe erosion and landslide risks due to torrential rainfall (Shore, 1999). This innovative application of waste tires demonstrated how recycling materials could serve as a practical and affordable solution to prevent landslides in flood-prone areas.

- Malaysia: In Malaysia, researchers conducted tensile tests on scrap tires and polypropylene rope, exploring the effectiveness of this combination for stabilizing slopes in tropical regions. Field studies were conducted on ramp soil to assess the viability of using waste tires as a reinforcement material in areas with high rainfall and steep slopes (Huat et al., 2008). This research provided valuable insights into the mechanical properties of tire-reinforced soil and how it can be adapted to local conditions in Southeast Asia.
- Iran: In Iran, a study was conducted to examine the stabilizing effect of waste tires on various sand slopes. A simulation test using a steel box filled with sand was used to study how the addition of waste tires influenced the slope's stability. This research demonstrated the potential of tires to reinforce loose soils and improve slope integrity, which is particularly important in regions prone to earthquakes and soil erosion (Hajiazizi et al., 2019).
- Algeria: In Algeria, engineers explored the use of displacement contours and multi-layer configurations in tire-based systems to enhance soil reinforcement on slopes. This research found that by layering tires and adjusting their position relative to the slope's contours, the system provided a stronger foundation and reduced the risk of landslide (Belabdelouahab & Trouzine, 2014). This approach provided a more flexible and adaptable method for different topographical features.
- Indonesia: In Indonesia, empirical data was gathered from gabions constructed from shredded waste tires. The strength and effectiveness of these tire-based gabions were tested for slope stabilization, particularly in regions where conventional retaining walls were not feasible. The study provided valuable data on how shredded tires could be used to create affordable and durable slope protection (Apriyono et al., 2018).

5. Future and Problems

China is the world's largest producer of waste tires, with an annual output of approximately 330 million tires, equivalent to around 10 million tons. This production is projected to grow by 6% to 8% annually, further exacerbating the challenges of waste tire disposal and management. As the global demand for ecological solutions to waste tire disposal continues to rise, China's role in the development and adoption of waste tire recycling technologies will become even more pivotal. Both Chinese and international studies have demonstrated the significant economic and environmental benefits of repurposing waste tires for slope protection and other civil engineering applications. These technologies not only help mitigate the environmental impact of tire disposal but also provide cost-effective solutions for improving slope stability and landslide prevention, particularly in regions with frequent natural disasters.

5.1 The Promise of Waste Tire Recycling

Research on ecological waste tire slope protection technology has revealed that using tires as a reinforcement material for soil stabilization can yield substantial benefits for infrastructure projects. These methods are particularly valuable in regions like China, where landslides and soil erosion due to heavy rainfall and steep terrain are common. Tire-based systems are lightweight, affordable, and highly effective in providing durable protection for vulnerable slopes. Moreover, they contribute to environmental sustainability by reducing the number of tires sent to landfills and repurposing discarded materials into functional structures. As the global focus on sustainable development intensifies, this technology presents a compelling opportunity to address the growing waste tire problem and offer innovative solutions to prevent natural disasters.

However, for this technology to reach its full potential, it is essential that more research be done on its long-term effectiveness, particularly regarding the impact of weathering, temperature changes, and other environmental factors that could affect the performance of tire-based systems over time.

5.2 Unresolved Environmental Concerns

Despite the promise of waste tire recycling, significant environmental concerns remain, particularly related to the potential toxicity of the materials used in tire manufacturing. Tires are composed of synthetic rubber and other chemicals, including heavy metals such as zinc, cadmium, and lead, which are known to be harmful to both soil and water. The long-term effect of these chemicals on the ecosystem is still poorly understood, and there is a growing concern over the release of heavy metals during the process of tire cutting and shredding for recycling. The tires' degradation over time could potentially lead to the leaching of these harmful substances into the surrounding environment, particularly in areas where tires are used in direct contact with soil and water.

As a result, it is essential that more studies be conducted to assess the environmental impact of waste tire-based materials, especially regarding their chemical composition and long-term stability. Further research should focus on understanding the extent to which heavy metals from synthetic rubber can leach into the environment and how this might affect plant life, soil health, and the local water supply.

ISSN 2959-6157

5.3 The Need for Further Research and Technological Innovation

In addition to addressing environmental concerns, there are also several challenges related to the technological advancement of tire-based slope protection systems. For example, there is a need to improve the durability and performance of waste tire materials, particularly in regions with extreme weather conditions or heavy rainfall. While tire-based systems have shown promise in terms of stability and affordability, more work is required to optimize their resilience and long-term sustainability.

Moreover, localization of technology remains an important issue. As waste tire solutions are adapted for use in developing nations, such as Brazil, Indonesia, and Algeria, climatic conditions, soil types, and local infrastructure must be considered. Solutions that work well in one region may need to be modified to account for the unique geographical and environmental conditions in another. This local adaptation is critical to ensuring that tire-based solutions can be effectively used worldwide.

6. Conclusion: A Path Forward

While the use of waste tires for slope stabilization and landslide prevention offers a promising solution to the growing problem of tire waste and environmental degradation, it is clear that there are several key issues that need to be addressed before this technology can be widely adopted. Further research into the environmental impacts, long-term effectiveness, and material innovation of tire-based systems is crucial. In parallel, efforts should be made to develop regulations and standards to ensure that waste tire recycling technologies are implemented in ways that are both environmentally safe and economically viable. With continued innovation and global collaboration, waste tires could play a key role in the sustainable development of infrastructure, paving the way for a more sustainable and resilient future.

References

Amari, T., Themelis, N. J., & Wernick, I. K. (1999). Resource recovery from used rubber tires. *Resources Policy*, *25*(3), 179–188.

Apriyono, A., Sumiyanto, Yanto, & Arif Hidayat, B. (2018). Application of woven waste tires gabion wall as slope reinforcement for preventing landslide in laboratory. *MATEC Web of Conferences, 195*, 3007. https://doi.org/10.1051/matecconf/201819503007

Belabdelouahab, F., & Trouzine, H. (2014). Research and enhancement of used tyres, such as material innovative in Algeria. *Physics Procedia, 55*, 68-74. https://doi.org/10.1016/j.phpro.2014.07.011

Cecchin, A., Lamour, M., Joseph Maks Davis, M., & Jácome Polit, D. (2019). End-of-life product management as a resilience driver for developing countries: A policy experiment for used tires in Ecuador. *Journal of Industrial Ecology, 23*(5), 1292-1310. https://doi.org/10.1111/jiec.12861

Garga, V. K., & O'Shaughnessy, V. (2000). Tire-reinforced earth fill; part 1, construction of a test fill, performance, and retaining wall design. *Canadian Geotechnical Journal, 37*(1), 75-96. https://doi.org/10.1139/t99-084

Hajiazizi, M., Mirnaghizadeh, M., & Nasiri, M. (2019). Experimental study of waste tire-reinforced sand slope. *International Journal of Mining and Geo-Engineering, 53*(2), 183-191. https://doi.org/10.22059/ijmge.2019.256575.594736

Huat, B. B. K., Aziz, A. A., & Chuan, L. W. (2008). Application of scrap tires as earth reinforcement for repair of tropical residual soil slope. *The Electronic Journal of Geotechnical Engineering, 13.*

Long, N.T. (1996) Utilization of used tyres in civil engineering – the pneusol 'tyresoil'. proceedings of 2nd international congress on environmental geotechnic. Osaka, Japan, pp. 809-814.

Ramos, G., Alguacil, F. J., & López, F. A. (2011). The recycling of end-of-life tyres. technological review. *Revista De Metalurgia (Madrid), 47*(3), 273-284. https://doi.org/10.3989/revmetalm.1052

Sienkiewicz, M., Kucinska-Lipka, J., Janik, H., & Balas, A. (2012). Progress in used tyres management in the European union: A review. *Waste Management (Elmsford), 32*(10), 1742-1751. https://doi.org/10.1016/j.wasman.2012.05.010

Su, Y & Zhang, Z. (2022, December 28). *Application and prospect of ecological slope protection technology for used tires.* 2022 China National Civil Engineering Construction Technology Exchange Conference. Beijing, China. https://kns-cnki-net-443.w.bift.edu.cn/kcms2/article/abstract?v=0-LBHIej7QmYBa0aawCSRkSCzQiQyCD4u9OIkkaJixGmaZBuNHb4MZFtCDzit8xCWOMN1MiVxBYYgng61puOTveVfURc3La3mcUwaCRpaRzwuL_wsy09OOi9uLZcjr7xggx6uH8Ah3i4CB2ybdAH3XOyno12fEbE4Sb5sWaN8qrOVjnIiKML3AGP4M2BRrf8l7v6hDoqHwU=&uniplatform=NZKPT&language=CHS

Shore, K. (1999). Stopping landslides in Rio: Recycling scrap tires into retaining walls. *IDRC Reports.*