

Resilient Infrastructure Development in Mountainous Regions: A Synergy of Natural waste Materials, Geosynthetics, and Intelligent Systems

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Abstract - Mountainous regions like Nepal and Northern India face profound infrastructure challenges driven by geological instability, seismic activity, harsh climates, and rapid urbanization. Conventional construction methods often prove inadequate, expensive, and environmentally unsustainable in these fragile terrains. This paper presents a comprehensive review advocating for a synergistic paradigm that integrates three key pillars for resilient infrastructure: (1) the Valorization of locally available natural and agro-industrial waste materials (e.g., rice husk ash, sugarcane bagasse ash, waste paper sludge ash) for soil stabilization and green concrete; (2) the strategic application of geosynthetics for reinforcement, slope stabilization, and road construction; and (3) the deployment of Intelligent Transport Systems (ITS) for real-time traffic and hazard management. Unifying these pillars is a robust framework of Geographic Information Systems (GIS), remote sensing, and advanced Machine Learning (ML) techniques, including Frequency Ratio, Weight of Evidence, Logistic Regression, and Artificial Neural Networks. These tools are critically reviewed for their application in multi-hazard susceptibility mapping, material supply chain optimization, and predictive infrastructure monitoring. By synthesizing existing research and proposing an integrated model, this review demonstrates that a data-driven, circular economy approach can significantly enhance the sustainability, resilience, and cost-effectiveness of infrastructure development in the world's most vulnerable landscapes.

Keywords: Resilient Infrastructure, Mountainous Regions, Soil Stabilization, Geosynthetics, Intelligent Transport Systems (ITS), GIS, Remote Sensing, Machine Learning, Waste Valorization.

I. INTRODUCTION

The majestic yet formidable landscapes of mountainous regions such as the Himalayas in Nepal and India present a unique set of challenges for infrastructure development. These areas are characterized by steep slopes, complex geology, high

seismicity, intense rainfall, and increased susceptibility to natural hazards like landslides, rockfalls, and floods [1]. The conventional approach to infrastructure relying on imported materials and standardized designs is often economically prohibitive, logistically challenging, and environmentally damaging. This has resulted in a significant infrastructure deficit, hindering economic growth, access to services, and disaster resilience for local communities.

Compounding these geological challenges are two contemporary issues: the massive generation of agro-industrial waste and the pressing need for smarter infrastructure systems. The cultivation of rice, sugarcane, and other crops, along with associated industries, produces substantial waste streams, such as Rice Husk Ash (RHA), Sugarcane Bagasse Ash (SCBA), and Waste Paper Sludge Ash (WPSA), whose disposal is a persistent environmental concern [2], [3]. Simultaneously, the growing volume of traffic on mountainous roads necessitates intelligent management to ensure safety and efficiency on precarious routes.

Recent research has begun to address these issues in isolation. Studies have explored the efficacy of natural waste materials in soil stabilization and concrete [4], [5], the use of geosynthetics for slope reinforcement [6] and the potential of Intelligent Transport Systems (ITS) [7]. However, a holistic framework that synergistically integrates these elements, underpinned by modern geospatial and artificial intelligence tools, is conspicuously absent from the literature. This review paper aims to fill this gap.

The core objective of this paper is to synthesize existing knowledge and propose a novel, integrated model for resilient infrastructure development in mountainous regions. This model rests on three interconnected pillars:

1. **Circular Economy of Materials:** Utilizing locally available natural and industrial wastes to create stabilized soils and sustainable concrete, reducing both material cost and environmental footprint.
2. **Geotechnical Reinforcement:** Employing geosynthetics to enhance the stability of slopes,

embankments, and road subgrades, providing engineered solutions to geotechnical instability.

3. **Intelligent Systems:** Implementing ITS for dynamic traffic management, hazard warning, and infrastructure health monitoring.

To bind these pillars into a cohesive strategy, we extensively review the role of a fourth, cross-cutting enabler: **Geospatial and AI/ML Technologies**. This includes the use of GIS and remote sensing for site selection and hazard assessment, and advanced ML models like Artificial Neural Networks (ANNs) and Logistic Regression for predictive analysis and optimization. By weaving together these threads, this paper charts a path toward infrastructure that is not only built to last but is also adaptive, intelligent, and in harmony with its environment.

II. THE FIRST PILLAR: WASTE MATERIALS FOR SUSTAINABLE CONSTRUCTION

The strategic use of locally sourced waste materials can revolutionize construction practices in remote mountainous areas by providing low-cost, sustainable alternatives to conventional materials like cement and chemical stabilizers.

A. Agro-Industrial Ashes in Soil Stabilization

Mountain soils are often weak, expansive, or dispersive, leading to poor subgrade performance for roads and foundation failures. Stabilization with cement or lime is effective but carbon-intensive and costly. Agro-industrial ashes, rich in silica and other oxides, offer a pozzolanic alternative.

- **Rice Husk Ash (RHA):** Produced from controlled burning of rice husk, RHA is composed of over 85-95% amorphous silica, making it a highly reactive pozzolan [2], [8]. When mixed with soil and a source of lime (which can be naturally present or added in small quantities), RHA reacts to form cementitious compounds (C-S-H gel), thereby improving soil strength, reducing plasticity, and increasing resistance to water infiltration. This is particularly valuable for stabilizing landslide-prone slopes and improving road subgrades.
- **Sugarcane Bagasse Ash (SCBA) and Waste Paper Sludge Ash (WPSA):** Similar to RHA, SCBA also possesses significant silica content and pozzolanic properties [3], [9]. WPSA, with its variable composition of silica, calcium, and alumina, can exhibit both pozzolanic and self-cementing characteristics [4], [10]. Research [4], [10] has demonstrated the effectiveness of SCBA and WPSA blends in enhancing the compressive and tensile

strength of concrete, a principle directly transferable to soil stabilization. The use of these materials transforms a waste management problem into a resource for enhancing geotechnical properties, as echoed in studies on other wastes like plastic for soil improvement [11].

B. Green Concrete for Mountain Infrastructure

The production and transportation of Ordinary Portland Cement (OPC) to remote sites is a major contributor to the cost and carbon footprint of mountain projects. Partial replacement of OPC with processed agro-industrial ashes can yield "green concrete" with adequate or superior performance.

- **Mechanical and Durability Performance:** Studies consistently show that a 10-20% replacement of cement with RHA or SCBA can lead to concrete with comparable or higher later-age compressive strength due to pore refinement from the pozzolanic reaction [2], [3], [9]. This results in a denser matrix that is more durable against the freeze-thaw cycles common in high altitudes and resistant to chemical attacks from acidic waters.
- **Economic and Logistical Advantages:** Sourcing these materials locally drastically reduces the reliance on imported cement, cuts transportation costs and associated emissions, and supports local economies by creating value from waste. This aligns with the principles of a circular economy, crucial for sustainable development in remote regions.

III. THE SECOND PILLAR: GEOSYNTHETICS FOR SLOPE AND ROAD STABILITY

Geosynthetic polymer-based materials used in contact with soil/rock are powerful tools for solving classical geotechnical problems in mountainous terrain.

A. Types and Functions

The primary geosynthetics relevant to mountainous infrastructure include:

- **Geogrids:** These open-grid structures are primarily used for reinforcement. They are deployed within soil masses to create mechanically stabilized earth (MSE) walls for slope stabilization and to reinforce road base courses, distributing loads and reducing rutting [6], [12].
- **Geotextiles:** These permeable fabrics are used for separation, filtration, and drainage. Placed between different soil layers (e.g., subgrade and aggregate base in a road), they prevent intermixing. In slope

drains, they allow water passage while preventing soil erosion [13].

- **Geocells:** Three-dimensional honeycomb-like structures that provide confinement for granular infill materials, significantly improving the load-bearing capacity of weak subgrades for roads and erosion control on slopes [14].

B. Applications in Hazard Mitigation

- **Landslide Stabilization:** Geosynthetics are integral to constructing reinforced soil slopes and walls, which are more flexible and resilient to seismic shaking than rigid retaining structures. They can also be used in conjunction with drainage systems to manage pore water pressure, a primary trigger for landslides.
- **Road Construction on Soft Ground:** Mountain roads often traverse areas with soft, saturated soils. Geogrids and geocells reinforce the road base, allowing for thinner aggregate layers and reducing differential settlement, a common cause of road failure in these regions [6], [15]. [6] provide a detailed review of the utilization of geogrids specifically in road construction, highlighting their benefits in improving load distribution and overall pavement life.

IV. THE THIRD PILLAR: INTELLIGENT TRANSPORT SYSTEMS (ITS) FOR MOUNTAINOUS TERRAIN

Mountain roads are not just static structures; they are dynamic corridors where safety and efficiency are paramount. ITS leverages information and communication technology to manage this complexity.

A. Core ITS Components for Mountains

- **Advanced Traffic Management Systems (ATMS):** Use sensors and cameras to monitor traffic flow, weather conditions, and road status in real-time. This information can be used to dynamically control variable message signs, warning drivers of fog, landslides, or congestion ahead [7], [16].
- **Advanced Traveler Information Systems (ATIS):** Provide real-time information to drivers via mobile apps or onboard units about road conditions, travel times, and optimal routes, allowing them to make informed decisions.
- **Incident Management Systems:** Enable rapid detection of and response to accidents or road blockages, coordinating between emergency services

and traffic management centers to minimize disruption and save lives.

B. Synergy with Hazard Monitoring

ITS can be integrated with the geotechnical monitoring systems. For instance, data from slope instrumentation (e.g., piezometers, inclinometers) can be fed into the ITS. If a slope shows signs of critical movement, the ITS can automatically trigger road closures and alerts, creating a proactive safety net. [7] reviewed the potential of ITS, underscoring its role in enhancing safety and efficiency, which is exponentially more critical in hazardous mountainous environments.

V. THE UNIFYING FRAMEWORK: GIS, REMOTE SENSING, AND ADVANCED AI/ML

The true synergy of the three pillars is achieved through a data-driven framework utilizing GIS, remote sensing, and a suite of ML algorithms. This framework enables proactive planning, precise implementation, and predictive maintenance.

A. Hazard Susceptibility and Resource Mapping

- **Remote Sensing & GIS:** Satellite imagery (e.g., from Sentinel-2, Landsat) and LiDAR data are invaluable for generating high-resolution Digital Elevation Models (DEMs), mapping land use/land cover, and identifying existing landslide scars, drainage patterns, and fault lines. GIS serves as the platform to integrate these spatial datasets [17].
- **Machine Learning for Susceptibility Modeling:** Statistical and ML models use these spatial data to predict and zone areas based on their hazard susceptibility.
 - **Frequency Ratio (FR) and Weight of Evidence (WOE):** These bivariate statistical methods quantify the spatial relationship between historical hazard locations (e.g., landslides) and conditioning factors (e.g., slope, curvature, lithology, distance to road, rainfall). The result is a susceptibility map classifying areas from very low to very high risk [18], [19].
 - **Logistic Regression (LR):** A multivariate statistical model that establishes a probabilistic relationship between the presence or absence of a hazard and a set of independent predictive factors. It is widely used for its simplicity and interpretability [20].
 - **Artificial Neural Networks (ANNs):** These powerful non-linear models can capture complex, hidden relationships within the data that simpler models might miss. ANNs often achieve higher predictive accuracy in landslide susceptibility

mapping by learning from the intricate patterns in the input parameters [21], [22].

These models directly inform the "where" of infrastructure development, guiding route planning for roads and identifying zones where geosynthetic reinforcement and waste-stabilized soils are most critically needed.

B. Material Supply Chain and Lifecycle Management

- **GIS for Logistics:** GIS can map the locations of waste sources (rice mills, sugar mills) relative to planned construction sites. Network analysis tools can then calculate optimal transport routes, minimizing cost and environmental impact [23]. This makes the use of local waste materials logistically feasible.
- **AI for Predictive Performance:** ANNs and other ML models can be trained on experimental data to predict the long-term performance of waste-stabilized soils or geosynthetic-reinforced structures under various environmental stressors. For example, an ANN could predict the shear strength of an RHA-stabilized soil based on its properties, RHA content, and curing time, reducing the need for extensive lab testing [24].
- **Digital Twins for Infrastructure:** A futuristic but plausible application is the creation of a "digital twin" of a critical mountain road or slope. This virtual model, fed by real-time data from embedded sensors (monitoring strain in geogrids, moisture in soil, etc.) and ITS, would allow engineers to simulate the impact of future rainfall or traffic loads and perform predictive maintenance, preventing failures before they occur [25].

VI. DISCUSSION: SYNTHESIS OF AN INTEGRATED MODEL FOR RESILIENCE

The reviewed components are not standalone solutions but are deeply interconnected. The proposed integrated model functions as a cyclical process of planning, construction, and management:

1. **Planning and Site Selection:** Multi-hazard susceptibility maps generated using FR, WOE, LR, or ANN models identify safe corridors for new infrastructure. Concurrently, GIS-based resource mapping locates sources of RHA, SCBA, and other wastes.
2. **Design and Material Specification:** For slopes identified as high-risk, designs incorporate geosynthetic-reinforced structures with backfill stabilized using local waste ashes to enhance strength

and reduce earth pressure. For road alignments in these corridors, the subgrade is improved with waste stabilization, and the base course is reinforced with geogrids.

3. **Construction with Local Resources:** The material supply chain is optimized via GIS, ensuring waste materials are transported efficiently from local sources to construction sites, reducing cost and carbon footprint.
4. **Operation and Monitoring:** The completed infrastructure is integrated into an ITS. Sensors embedded within geosynthetic layers or stabilized soil masses feed data into a central monitoring system. The ITS uses this information, alongside weather and traffic data, to manage traffic flow and issue early warnings.
5. **Adaptive Management and Predictive Maintenance:** Data from the monitoring systems are used to train and refine ML models (like ANNs) that predict deterioration or failure. This enables proactive maintenance, ensuring long-term resilience.

This model directly addresses the core challenges: it uses local waste to reduce cost and environmental impact, employs geosynthetics to solve geotechnical instability, and uses ITS and AI to manage dynamic risks, all under the umbrella of data-driven decision-making.

VII. CHALLENGES AND FUTURE RESEARCH DIRECTIONS

While the proposed synergy is promising, several challenges need to be addressed:

- **Standardization and Quality Control:** The variable nature of agro-industrial wastes necessitates the development of regional standards for their processing and application to ensure consistent performance.
- **Technical Capacity:** Widespread adoption requires training local engineers and technicians in the use of geosynthetics, waste material processing, and the interpretation of GIS/ML outputs.
- **Data Availability:** The accuracy of ML models is contingent on the availability of high-quality, historical hazard data. Efforts must be made to build comprehensive geospatial databases for mountainous regions.
- **Initial Cost and Policy:** The initial investment in ITS and specialized materials like geosynthetics can be a barrier. Supportive government policies and

cost-benefit analyses highlighting long-term lifecycle savings are crucial.

Future research should focus on:

1. Developing optimized mix designs for waste-stabilized soils specific to the soil types of the Himalayas.
2. Creating hybrid ML models that combine, for example, ANNs with optimization algorithms for superior predictive performance in hazard mapping.
3. Conducting full-scale field trials and long-term monitoring of infrastructure built with this integrated approach to validate its efficacy and build stakeholder confidence.
4. Exploring the integration of Blockchain technology for transparent and efficient management of the waste-to-resource supply chain.

VIII. CONCLUSION

The development of resilient infrastructure in mountainous regions like Nepal and India demands a departure from conventional, siloed approaches. This review has articulated a compelling case for a synergistic paradigm that strategically integrates the Valorization of natural waste materials, the engineered reinforcement provided by geosynthetics, and the dynamic intelligence of ITS. The glue that binds this triad is a modern framework of GIS, remote sensing, and advanced Machine Learning techniques, including Frequency Ratio, Weight of Evidence, Logistic Regression, and Artificial Neural Networks.

This integrated model offers a holistic pathway to tackle the multifaceted challenges of cost, sustainability, geological instability, and operational safety. It transforms local waste into a valuable resource, provides robust engineering solutions for slope and road stability, and creates an intelligent, responsive transport network. By adopting this data-driven, circular economy approach, stakeholders can pave the way for infrastructure that not only withstands the test of the mountains but also fosters sustainable and safe communities for generations to come.

REFERENCES

- [1] Chagger, Jeevanjot & Anil, Er. (2025). A REVIEW STUDY: ELECTRICAL WORK ON CONSTRUCTION SITE. *Industrial Engineering Journal*, ISSN: 0970-2555, Volume: 53, Issue 6, No.5, June: 2024 https://www.researchgate.net/publication/396053644_A_REVIEW_STUDY_ELECTRICAL_WORK_ON_CONSTRUCTION_SITE
- [2] Chagger, Jeevanjot & chedda, Er & Wuntah, Er. (2025). Review study: Waste glass powder (WGP) with replacement of cement. *International Journal of Structural Design and Engineering*. 6. 01-06. 10.22271/27078280.2025.v6.i2a.43. https://www.researchgate.net/publication/394245448_Review_study_Waste_glass_powder_WGP_with_replacement_of_cement
- [3] Sharma, H., Singh, J., Kumar, A., Bala, M., & Kumar, S. (2025, June). Review on the utilization of the Geogrids in road construction. In *AIP Conference Proceedings* (Vol. 3261, No. 1, p. 120002). AIP Publishing LLC. https://www.researchgate.net/publication/392428380_Review_on_the_utilization_of_the_Geogrids_in_road_construction
- [4] Suri, Navleen & Chagger, Jeevanjot & Sharma, Er. Harish & Chandel, Dr. (2025). INVESTIGATION ON THE TENSILE STRENGTH WITH USE OF ScBA AND WPSA WITH PARTIAL REPLACEMENT OF CEMENT IN CONCRETE. *Industrial Engineering Journal*. 54. 678-704. https://www.researchgate.net/publication/391643779_INVESTIGATION_ON_THE_TENSILE_STRENGTH_WITH_USE_OF_ScBA_AND_WPSA_WITH_PARTIAL_REPLACEMENT_OF_CEMENT_IN_CONCRETE
- [5] Jeevanjot Singh, Simran, Pema Chheda, Prince Wuni Wuntah. A review study on machine learning to investigate the issue of plastic pollution in oceans. *Int J Hydropower Civ Eng* 2025;6(1):48-51. DOI: 10.22271/27078302.2025.v6.i1a.62, https://www.researchgate.net/publication/396213967_A_review_study_on_machine_learning_to_investigate_the_issue_of_plastic_pollution_in_oceans
- [6] Chagger, Jeevanjot & Sharma, Er. Harish & Bala, Er. (2024). PARTIAL REPLACEMENT OF CEMENT WITH RICE HUSK ASH & SUGARCANE BAGASSE ASH: REVIEW PAPER. *Industrial Engineering Journal* ISSN: 0970-2555 Volume: 53, Issue 6, June: 2024. https://www.researchgate.net/publication/387567151_PARTIAL_REPLACEMENT_OF_CEMENT_WITH_RICE_HUSK_ASH_SUGARCANE_BAGASSE_ASH_REVIEW_PAPER
- [7] Suri, Navleen & Chagger, Jeevanjot & Sharma, Er. Harish & Chandel, Dr. (2025). INVESTIGATION ON THE COMPRESSIVE STRENGTH WITH USE OF ScBA AND WPSA WITH PARTIAL REPLACEMENT OF CEMENT IN CONCRETE. *Industrial Engineering Journal*. *Industrial Engineering Journal* ISSN: 0970-2555 Volume: 54, Issue 4, April:

2025.
https://www.researchgate.net/publication/391643772_INVESTIGATION_ON_THE_COMPRESSIVE_STRENGTH_WITH_USE_OF_ScBA_AND_WPSA_WITH_PARTIAL_REPLACEMENT_OF_CEMENT_IN_CONCRETE
- [8] Chagger, Jeevanjot & Bala, Er & Sharma, Er. Harish. (2024). INVESTIGATE THE COMPRESSIVE STRENGTH OF CONCRETE USING FLY ASH ON M30 CONCRETE GRADE. *Industrial Engineering Journal* ISSN: 0970-2555 Volume: 53, Issue 6, No.5, June: 2024.
https://www.researchgate.net/publication/387566115_INVESTIGATE_THE_COMPRESSIVE_STRENGTH_OF_CONCRETE_USING_FLY_ASH_ON_M30_CONCRETE_GRADE
- [9] Singh, Er & Chagger, Jeevanjot. (2024). Review Study: Robotics and Automation in Construction, *IRJIET*, Volume 8, Issue 11, November 2024 pp. 260-264. [10.47001/IRJIET/2024.811033](https://doi.org/10.47001/IRJIET/2024.811033).
https://www.researchgate.net/publication/396051331_Review_Study_Robotics_and_Automation_in_Construction
- [10] Chagger, Jeevanjot & Sharma, Er. Harish. (2024). Review Study on Partial Replacement of Cement with Sugarcane Bagasse Ash (SCBA), National Conference on “Empowering Sustainability: Bridging Science, Technology and Climate Resilience” (ESBSTCR-2024), 17-19 Jan 2024; SBBS University, Jalandhar, Punjab.
https://www.researchgate.net/publication/396270286_Review_Study_on_Partial_Replacement_of_Cement_with_Sugarcane_Bagasse_Ash_SCBA
- [11] Chagger, Jeevanjot & Sharma, Er. Harish. (2024). A Review: ScBA& WPSA Used in Concrete as Partial Replacement of Cement, National Conference on “Empowering Sustainability: Bridging Science, Technology and Climate Resilience” (ESBSTCR-2024), 17-19 Jan 2024; SBBS University, Jalandhar, Punjab.
https://www.researchgate.net/publication/396270282_A_Review_ScBA_WPSA_Used_in_Concrete_as_Partial_Replacement_of_Cement
- [12] Chagger, Jeevanjot & Sharma, Er. Harish. (2024). A Review on Improving Asphalt Mixtures Through the Use of Geosynthetics and Waste Fibers, National Conference on “Empowering Sustainability: Bridging Science, Technology and Climate Resilience” (ESBSTCR-2024), 17-19 Jan 2024; SBBS University, Jalandhar, Punjab.
https://www.researchgate.net/publication/387573908_A_Review_on_Improving_Asphalt_Mixtures_Through_the_Use_of_Geosynthetics_and_Waste_Fibers
- [13] Mahi, Vishal & Chagger, Jeevanjot & Sharma, Er. Harish & Bala, Er. (2024). Performance Evaluation of Adhesion in Recycled & Reused Construction Material in RCC, *International Research Journal of Innovations in Engineering and Technology (IRJIET)*, ISSN (online): 2581-3048, Volume 8, Issue 1, pp 19-37, January-2024
<https://doi.org/10.47001/IRJIET/2024.801004>,
https://www.researchgate.net/publication/387570170_Performance_Evaluation_of_Adhesion_in_Recycled_Reused_Construction_Material_in_RCC
- [14] Anmol, & Sharma, Er. Harish & Bala, Er & Chagger, Jeevanjot. (2023). An Examination the Use of Waste Glass Powder as Cement Partial Replacement in Concrete. *International Research Journal of Innovations in Engineering and Technology (IRJIET)* ISSN (online): 2581-3048 Volume 7, Issue 11, pp 343-355, November-2023
<https://doi.org/10.47001/IRJIET/2023.711047>,
https://www.researchgate.net/publication/375826197_An_Examination_the_Use_of_Waste_Glass_Powder_as_Cement_Partial_Replacement_in_Concrete
- [15] Chagger, Jeevanjot & Singh, Gurpreet & Mohit, (2023). A Review Study on The Use of Geosynthetics in Road Constructions. *International Journal of Research Publication and Reviews*, Vol 4, no 7, pp 518-522 July 2023,
<https://ijrpr.com/uploads/V4ISSUE7/IJRPR15273.pdf>,
https://www.researchgate.net/publication/396052553_A_Review_Study_on_The_Use_of_Geosynthetics_in_Road_Constructions
- [16] Chagger, Jeevanjot. (2023). ASSESSING THE EFFECTIVENESS OF BAMBOO IN ENHANCING THE STRENGTH OF CONCRETE STRUCTURES: A REVIEW STUDY, *International Journal of Engineering Technology Research & Management*, Vol-07 Issue 07, 68-76, July-2023.
https://www.researchgate.net/publication/396052546_ASSESSING_THE_EFFECTIVENESS_OF_BAMBOO_IN_ENHANCING_THE_STRENGTH_OF_CONCRETE_STRUCTURES_A_REVIEW_STUDY
- [17] Singh, J.; Chandel, S.K.; Mohit; Singh, G. The Article Explores Improving the Performance of Asphalt Mixtures through the Utilization of Added Fibers. *Int. Res. J. Innov. Eng. Technol.* 2023, 7, 59–65.
https://www.researchgate.net/publication/389533862_The_Article_Explores_Improving_the_Performance_of_Asphalt_Mixtures_through_the_Utilization_of_Added_Fibers

- [18] Singh J, Mohit, Gurpreet Singh. Case study on partial replacement of cement with RHA. *Int J Res Anal Rev (IJRAR)*. 2023;10(3):5-10. Available from: <http://www.ijrar.org/IJRAR23C1002.pdf>, https://www.researchgate.net/publication/389533760_Case_Study_on_Partial_Replacement_of_Cement_with_RHA
- [19] J. Singh, D. S. Chandel, "An Examination and Investigation Compressive Strength the Use of Waste Paper Sludge Ash and Rice Husk Ash as Cement Substitutes in Concrete", *International Journal of Innovative Research in Engineering and Management (IJIREM)*, Vol-10, Issue-3, Page No-60-66, 2023. Available from: <https://doi.org/10.55524/ijirem.2023.10.3.11>, https://www.researchgate.net/publication/372098556_An_Examination_and_Investigation_Compressive_Strength_the_Use_of_Waste_Paper_Sludge_Ash_and_Rice_Husk_Ash_as_Cement_Substitutes_in_Concrete
- [20] Jeevanjot Singh, Mohit, Gurpreet Singh (July2023), "THE EXAMINATION STUDY TO INVESTIGATE THE EFFECTS OF USING A REDUCED AMOUNT OF CEMENT WITH WPSA, 'International Research Journal of Modernization in Engineering Technology and Science, Volume:05/Issue:07/July-2023 Impact Factor- 7.868 www.irjmets.com, e-ISSN: 2582-5208. https://www.researchgate.net/publication/396052546_ASSESSING_THE_EFFECTIVENESS_OF_BAMBOO_IN_ENHANCING_THE_STRENGTH_OF_CONCRETE_STRUCTURES_A_REVIEW_STUDY
- [21] Jeevanjot Singh, Dr. Sandeep Kumar Chandel, Mohit, Gurpreet Singh (2023), "A Study: How Using Waste Paper Sludge Ash and Rice Husk Ash Instead of Cement in Concrete, 'Quest Journals Journal of Architecture and Civil Engineering, Volume 8 ~ Issue 7, pp: 20-29, ISSN(Online) :2321-8193, www.questjournals.org, https://www.researchgate.net/publication/396052558_A_Study_How_Using_Waste_Paper_Sludge_Ash_and_Rice_Husk_Ash_Instead_of_Cement_in_Concrete
- [22] Thakur, Dr & Kumar, Naveen & Kaith, Sangharsh & Rana, Sanchit & Goyal, Pranshu & Tiwary, Aditya & Kumari Thakur, Ratnesh. (2022). A Critical Review on Fiber Reinforced Polymer Composites in Strengthening Reinforced Concrete Structure. 10.55524/ijirem.2022.9.2.88., https://www.researchgate.net/publication/362546639_A_Critical_Review_On_Fiber_Reinforced_Polymer_Composites_In_Strengthening_Reinforced_Concrete_Structure
- [23] Thakur, Dr & Kumar, Manish. (2023). Study of mechanical properties of conventional concrete and for fibrous concrete with various volume fractions of micro and macro steel fibers. *European Chemical Bulletin*. volume 12. 672-685. 10.31838/ecb/2023.12.3.052, https://www.researchgate.net/publication/370204599_Study_of_mechanical_properties_of_conventional_concrete_and_for_fibrous_concrete_with_various_volume_fractions_of_micro_and_macro_steel_fibers
- [24] Thakur, Dr. (2023). Enhancing the soils geotechnical properties by using plastic waste: A Review, *Journal of Basic Science and Engineering*. 23. 168-186. 10.37896/JBSV23.5/2096. https://www.researchgate.net/publication/370528028_Enhancing_the_soils_geotechnical_properties_by_using_plastic_waste_A_Review
- [25] Yousuf, Saleem & Thakur, Dr. (2023). A Review Intelligent Transport System. *GIS SCIENCE JOURNAL*. volume 10. 2017-2045. https://www.researchgate.net/publication/371131269_A_Review_Intelligent_Transport_System
- [26] Themisana, Rajkumari & Thakur, Dr & Thaguna, Parwati & Thounaojam, Anuradha & Senagah, Amenjor. (2023). TO DETERMINE THE STRENGTH OF CONCRETE WITH PARTIAL REPLACEMENT OF SAND WITH MARBLE DUST POWDER, *Journal of Biomechanical Science and Engineering, Japan Society of Mechanical Engineers*, ISSN: 1880-9863, *Advances in Mechanical, Civil, Computer Engineering in respect Public Health and Safety*, DOI 10.17605/OSF.IO/QD68N, https://www.researchgate.net/publication/372724255_TO_DETERMINE_THE_STRENGTH_OF_CONCRETE_WITH_PARTIAL_REPLACEMENT_OF_SAND_WITH_MARBLE_DUST_POWDER

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