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Chapter 1 : REPAIR, REHABILITATION, AND RETROFITTING STRATEGIES FOR STRUCTURAL INFRASTRUCTURE: MODERN APPROACHES AND PERFORMANCE ASSESSMENT

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Abstract

The longevity and reliability of infrastructure are increasingly critical due to aging constructions, evolving usage patterns, and modern safety standards. This paper reviews contemporary strategies for repair, rehabilitation, and retrofitting of structural systems. Emphasis is placed on modern materials, performance-based interventions, and post-repair monitoring techniques. Surface repair, section enlargement, bonded plate strengthening, and advanced retrofitting approaches using Fiber Reinforced Polymers (FRP), steel, and reinforced concrete jacketing are discussed. The paper also evaluates comparative performance metrics between steel and FRP retrofits, highlights structural performance modeling, and presents monitoring techniques such as acoustic emission, digital strain mapping, electrochemical corrosion scanning, optical fiber sensing, and ultrasonic tomography. The study provides insights for selecting cost-effective, sustainable, and resilient interventions for existing infrastructure.

Keywords: structural repair, rehabilitation, retrofitting, FRP, steel jacketing, structural performance modeling, monitoring, durability.

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I. INTRODUCTION

The discipline of structural engineering is confronted with the persistent challenge of ensuring that infrastructure remains safe, functional, and durable throughout its intended lifespan. As urbanization accelerates and the complexity of modern construction increases, existing structures are frequently subjected to loading conditions beyond what was anticipated during their initial design. Over time, material degradation, environmental exposure, and repetitive loading contribute to the gradual deterioration of structural elements, often manifesting as cracks, spalling, corrosion, and weakened connections [1,2]. This gradual decline not only compromises the serviceability and reliability of the infrastructure but also poses significant risks to human safety [3]. Consequently, there is a pressing need for strategies that can effectively address both immediate deficiencies and long-term performance requirements. In this context, repair, rehabilitation, and retrofitting have emerged as essential interventions, each targeting different scales of structural concern — from local defects to overall system capacity enhancement [4,5].

Repair interventions are primarily focused on addressing localized deficiencies that compromise the immediate functionality of the structure. These interventions aim to restore integrity to specific damaged elements, ensuring that the structure can continue to safely carry applied loads. Techniques under this category may include filling cracks, patching deteriorated concrete, or treating corroded reinforcement [6,7]. Rehabilitation, on the other hand, takes a broader perspective, emphasizing the restoration of global structural performance. It involves optimizing the distribution of loads, enhancing stiffness, and reinstating serviceability across the affected structure [8]. This may require a combination of targeted repairs, reinforcement of structural members, or modifications to load paths to ensure that the structure meets performance expectations [9]. Retrofitting represents an advanced level of intervention, wherein structural elements are upgraded or augmented to meet current design codes, adapt to new functional demands, or withstand extreme loading scenarios such as seismic, wind, or dynamic forces [10,11]. These strategies are designed not only to restore the capacity of the structure but also to improve its resilience, ductility, and overall durability [12].

The process of maintaining and upgrading aging structures is increasingly informed by a systematic, performance-based approach. Effective structural intervention begins with a careful assessment of damage, identification of the root causes, and evaluation of the remaining structural capacity [13,14]. Based on these findings, appropriate repair materials and strengthening techniques are selected to ensure compatibility with the existing system [15]. The interventions are then designed to enhance load-bearing capacity, improve structural performance, and extend service life [16,17]. Equally important is the implementation of post-rehabilitation monitoring, which allows engineers to verify the effectiveness of applied measures and detect any emerging issues early [18,19]. With the integration of advanced materials, computational modeling, and real-time monitoring techniques, engineers are now able to make informed, evidence-based decisions [20]. This enables not only the restoration of structural integrity but also the optimization of long-term performance, ensuring that aging infrastructure continues to meet the evolving demands of modern society [21].

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II. CLASSIFICATION OF REPAIR STRATEGIES

Repair strategies for deteriorated or underperforming structures can be broadly categorized into surface repair, section enlargement, and bonded plate strengthening, each addressing distinct levels of structural distress and functional requirements. Surface repair focuses primarily on restoring the integrity of the exposed layers of structural elements to halt further deterioration and prevent accelerated damage. This approach is particularly relevant for reinforced concrete structures, where environmental exposure often leads to cracking, spalling, or localized delamination. Techniques such as epoxy injection are commonly employed to seal fine and medium cracks, restoring continuity within the concrete matrix and preventing the ingress of moisture, chlorides, and other aggressive agents that can exacerbate material degradation. In conjunction with crack repair, concrete patching is used to restore spalled or delaminated regions. Successful patching requires careful surface preparation and the use of appropriate bonding agents to ensure that the repair material adheres effectively to the existing substrate, thereby providing a durable and compatible repair. In structures exposed to harsh environments such as marine or industrial conditions, corrosion-inhibiting coatings are often applied to exposed reinforcement. These treatments extend the service life of the structure by mitigating ongoing corrosion and protecting the embedded steel from chemical attack and environmental degradation.

Table 1: Classification of Structural Intervention Strategies

Strategy	Scope/Focus	Typical Techniques	Objective
Repair	Localized defects	Crack filling, concrete patching, corrosion treatment	Restore integrity and immediate load-carrying capacity
Rehabilitation	Overall structural performance	Load redistribution, reinforcement, stiffness enhancement	Restore serviceability and global performance
Retrofitting	Capacity enhancement beyond original design	FRP wrapping, steel/RC jacketing, base isolation	Improve structural capacity, resilience, and code compliance

Section enlargement represents a more invasive but highly effective strategy aimed at increasing the structural cross-section and enhancing load-carrying capacity. This method is particularly suited to members that have experienced significant material loss or where service requirements have increased beyond the original design. Augmentation of existing sections is typically achieved through the application of micro-concrete or polymer-modified mortars, which can provide additional confinement and improve the overall mechanical performance of the member. In many cases, supplementary reinforcement is incorporated using mechanical anchoring techniques, ensuring that the newly added materials act compositely with the existing structure. Such reinforcement improves the structural capacity, stiffness, and ductility of the member. Section enlargement is especially important in seismic retrofitting applications, where additional confinement and increased cross-sectional dimensions contribute directly to enhanced energy dissipation and ductile behavior, reducing the likelihood of catastrophic failure during dynamic loading events.

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Table 2: Common Repair Techniques and Materials

Defect Type	Repair Technique	Material/Method	Expected Outcome
Cracks	Epoxy injection	Low-viscosity epoxy	Seal cracks and restore continuity
Spalling/Delamination	Concrete patching	Micro-concrete, polymer-modified mortar	Restore surface integrity
Corroded reinforcement	Corrosion inhibitors	Protective coatings, cathodic protection	Extend service life of steel reinforcement
Shear/Strength deficiency	FRP or steel wrapping	Carbon/GFRP sheets, steel plates	Improve shear, flexural, and confinement capacity

Bonded plate strengthening represents a highly versatile and efficient repair and strengthening strategy, suitable for both localized and global performance enhancement. This technique involves the application of steel plates or fiber-reinforced polymer (FRP) laminates to structural surfaces using high-performance adhesives, allowing for rapid augmentation of flexural, shear, and confinement capacity. Bonded plate systems are extensively employed in beams, columns, slabs, and other critical structural elements to restore or enhance load-bearing performance. The effectiveness of this approach depends critically on proper surface preparation, which ensures that the adhesive achieves full contact with both the substrate and the strengthening material. Additionally, the curing process of the adhesive must be carefully controlled, and the mechanical properties of the strengthening material must be compatible with those of the original structure to ensure long-term durability. When applied correctly, bonded plate strengthening provides a minimally invasive method to significantly improve structural performance without the need for extensive demolition or reconstruction, making it particularly suitable for structures that must remain in service during rehabilitation.

III. REHABILITATION STRATEGIES

Rehabilitation strategies encompass interventions that go beyond simple repairs to restore and optimize the overall performance of structures while mitigating further deterioration. Unlike localized repair, which addresses visible defects, rehabilitation focuses on enhancing the capacity, reliability, and durability of structural systems as a whole. One of the primary approaches within rehabilitation is **load redistribution**, which aims to improve the internal stress balance across structural elements and prevent premature failure. Techniques such as steel jacketing, which involves wrapping or encasing columns and beams with steel to increase confinement and stiffness, are widely used in framed structures to redistribute stresses more effectively. Similarly, the installation of composite infill walls in building frames contributes to lateral load sharing, reducing stress concentrations in critical members and enhancing the overall stability of the structure. In bridge engineering, rehabilitation measures often include the use of **composite shear keys** or specialized connectors, which serve to control differential movement between adjacent structural elements, limit stress accumulation at expansion joints, and maintain overall geometric stability under dynamic traffic and environmental loads.

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Another critical facet of rehabilitation is the application of **stress-relief techniques** designed to alleviate internal tensile forces and prevent the propagation of existing cracks. Post-tensioned rods, for instance, can be introduced into structural members to actively close cracks, redistribute tensile stresses, and restore integrity to weakened areas. These methods not only prolong the service life of structural elements but also improve their ability to accommodate future loading without further deterioration. In regions prone to seismic activity, **base isolation systems** have become a key component of rehabilitation, decoupling the superstructure from ground motion and effectively reducing the transmission of seismic forces. By allowing controlled movement at the foundation level, base isolation mitigates the intensity of stresses in columns, beams, and load-bearing walls, thereby reducing the risk of structural damage during earthquakes.

Durability enhancement forms an equally important dimension of rehabilitation, as the long-term sustainability of the structure depends on protecting critical materials from environmental and chemical degradation. **Cathodic protection systems** are commonly employed in reinforced concrete structures to mitigate ongoing corrosion of embedded steel reinforcement, thereby preserving the bond between steel and concrete and maintaining load-carrying capacity. Advances in material technology have introduced innovative solutions such as **mineral-polymer coatings embedded with self-healing microcapsules**, which actively respond to microcracking by releasing healing agents, sealing cracks, and preventing the ingress of moisture, chlorides, and other aggressive agents. Such systems not only extend the service life of structural elements but also reduce maintenance requirements and enhance resilience under harsh environmental conditions.

Table 3: Rehabilitation Strategies and Applications

Rehabilitation Strategy	Application Example	Benefits
Load Redistribution	Steel jacketing of columns	Reduces stress concentration and prevents failure
Stress Relief	Post-tensioned rods, base isolation	Closes existing cracks, minimizes seismic forces
Durability Enhancement	Mineral-polymer coatings, cathodic protection	Protects against corrosion and environmental degradation

Rehabilitation strategies, therefore, represent a holistic approach that integrates mechanical, chemical, and material-based interventions to restore the intended performance of structures. By combining methods that redistribute loads, relieve stresses, and enhance durability, engineers can address both existing damage and potential vulnerabilities, ensuring that aging infrastructure continues to perform safely and efficiently. The success of rehabilitation relies on a careful assessment of structural deficiencies, an understanding of material behavior under current and anticipated loads, and the selection of interventions that are compatible with the existing system. When applied judiciously, rehabilitation not only restores structural function but also improves resilience, serviceability, and sustainability, making it a cornerstone of modern infrastructure management.

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IV. RETROFITTING STRATEGIES

Retrofitting involves proactive interventions designed to enhance the structural capacity, performance, and resilience of existing infrastructure beyond its original design intent. Among the most widely adopted techniques is fiber-reinforced polymer (FRP)-based retrofitting, which has gained prominence due to its high strength-to-weight ratio, corrosion resistance, and adaptability to complex geometries. FRP sheets or laminates, bonded to structural surfaces with high-performance epoxy adhesives, significantly improve flexural, shear, and confinement capacity while maintaining minimal additional weight. Moreover, the integration of embedded sensors within FRP systems enables real-time structural health monitoring, allowing engineers to track performance and detect early signs of distress. Steel jacketing represents another conventional yet highly effective retrofitting approach, primarily aimed at enhancing confinement, shear strength, and seismic energy dissipation. Recent developments have combined steel with advanced fibers such as basalt, resulting in hybrid steel–fiber reinforcement systems that offer improved ductility, damage tolerance, and energy absorption, thereby marrying the robustness of steel with the efficiency of high-performance fibers. Reinforced concrete (RC) jacketing, which enlarges structural sections with additional concrete and reinforcement, is frequently complemented with strain-healing polymers to restore or improve long-term durability.

Table 4: Retrofitting Techniques – Material Comparison

Retrofitting Method	Material Used	Advantages	Limitations
FRP Wrapping	Carbon, Glass, Basalt FRP	Lightweight, corrosion-resistant, high ductility	Higher initial cost, surface preparation needed
Steel Jacketing	Steel plates/cages	High confinement, robust, improves seismic performance	Adds dead load, labor-intensive installation
RC Jacketing	Reinforced concrete	Compatible with existing structure, long-lasting	Time-consuming, heavier than FRP
Base Isolation	Lead/rubber bearings, magnetorheological dampers	Reduces seismic force transmission, improves resilience	Complex design, higher cost

In regions prone to seismic activity, base isolation systems have emerged as a sophisticated retrofitting solution that reduces interstorey drift and seismic accelerations. Hybrid configurations incorporating smart materials, such as magnetorheological dampers, further exemplify the convergence of traditional structural engineering with adaptive, responsive technologies, providing infrastructure with enhanced resilience under dynamic loading conditions.

V. COMPARATIVE PERFORMANCE: FRP VS. STEEL JACKETING

When selecting retrofitting materials, it is essential to understand the relative strengths and limitations of available systems. Steel jacketing, while effective in improving confinement and load-carrying capacity, inherently increases the dead load of structural elements and requires labor-intensive installation processes. FRP, in contrast, provides a lightweight,

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corrosion-resistant alternative that minimizes added mass and facilitates rapid, less disruptive application. In terms of seismic performance, FRP exhibits superior ductility and energy absorption characteristics, reducing the likelihood of brittle failure under dynamic loading. Although the initial cost of FRP materials is typically higher than that of steel, the extended service life, reduced maintenance requirements, and excellent compatibility with various substrate materials often justify the investment. Consequently, the choice between FRP and steel jacketing must consider multiple factors, including structural demands, environmental exposure, constructability, and lifecycle cost, highlighting the need for a performance-based decision-making framework.

VI. REPAIR AND RETROFIT SELECTION

The selection of appropriate repair and retrofitting interventions depends on the type and severity of structural deficiencies, compatibility with existing materials, and long-term serviceability requirements. Micro-cracks can often be treated effectively with low-viscosity resins that penetrate and seal cracks, preventing further propagation. Areas exhibiting delamination or surface degradation benefit from FRP or fiber wraps combined with epoxy adhesives to restore composite action and enhance strength. Structural elements suffering from shear deficiencies can be strengthened through FRP wrapping with anchoring systems, while reinforcement susceptible to corrosion may require cathodic protection or specialized coatings to ensure durability. Poor ductility, particularly in seismic zones, can be mitigated using confinement techniques with steel or FRP to improve energy dissipation and post-yield behavior. Heritage or architecturally significant structures often necessitate non-intrusive retrofitting solutions such as base isolation, which simultaneously preserves aesthetic integrity and enhances seismic resilience. These considerations underscore the necessity of tailoring interventions to the specific structural context and functional objectives.

VII. STRUCTURAL PERFORMANCE MODELING

Advanced structural performance modeling serves as a critical tool in predicting the behavior of rehabilitated and retrofitted systems. Non-linear stress-strain models of FRP confinement capture the progressive engagement of materials under load, providing accurate predictions of ductility and ultimate capacity. Bond-slip interface models simulate partial debonding and localized failures between strengthening materials and substrates, offering insights into long-term reliability and performance degradation. Finite element analysis (FEA) allows detailed examination of complex geometries, stress concentrations, and interactions among multiple strengthening techniques, supporting design optimization and risk assessment. Additionally, fatigue-life prediction curves estimate service life under cyclic loading, incorporating the effects of retrofitting interventions and providing essential data for maintenance planning and lifecycle management. By integrating these modeling techniques, engineers can make informed, performance-based decisions, ensuring that structural interventions achieve both immediate and long-term objectives.

VIII. MONITORING AND ASSESSMENT AFTER REHABILITATION

Post-rehabilitation monitoring is essential for verifying the effectiveness of repair and retrofitting measures and ensuring continued structural safety. Acoustic emission techniques enable the detection of microcracks, delamination, and fiber breakage in real time, providing early warning of potential failure. Digital strain mapping, using methods such as digital image correlation or embedded sensors, allows full-field measurement of strain distribution,

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offering insights into load transfer and structural behavior under operational conditions. Electrochemical corrosion scanning assesses ongoing reinforcement deterioration and evaluates the performance of protective measures. The deployment of embedded optical fiber sensors permits continuous, distributed monitoring of strain, temperature, and cracking, while ultrasonic tomography provides non-destructive imaging to detect internal defects, debonding, or voids in repaired sections.

Table 5: Monitoring Techniques Post-Rehabilitation

Monitoring Method	Principle/Technology	Purpose	Advantages
Acoustic Emission (AE)	Detects microcracks via sound waves	Real-time damage detection	Non-invasive, sensitive
Digital Image Correlation (DIC)	Optical strain mapping	Measures surface strain and deformation	Full-field measurement
Electrochemical Corrosion Scan	Measures potential/corrosion rate	Assess reinforcement corrosion risk	Predictive maintenance
Embedded Fiber Optic Sensors	Optical strain/temperature measurement	Continuous monitoring of structural health	Distributed, long-term monitoring
Ultrasonic Tomography	High-frequency waves through concrete	Detect internal defects, voids, or debonding	Non-destructive, detailed imaging

The integration of these monitoring technologies supports a performance-based approach to infrastructure management, enabling proactive maintenance, timely intervention, and informed planning for future retrofitting activities.

IX. CONCLUSION

Modern structural engineering increasingly relies on the integrated application of repair, rehabilitation, and retrofitting to maintain the safety, functionality, and longevity of infrastructure. Localized repair addresses immediate defects, rehabilitation restores overall structural performance, and retrofitting enhances capacity to meet contemporary demands such as seismic, wind, or dynamic loading. The selection of intervention strategies depends on factors including damage type, material compatibility, structural configuration, and environmental conditions, ensuring that the chosen methods are both effective and sustainable. Advances in high-performance materials, such as fiber-reinforced polymers and hybrid steel–fiber systems, have expanded the range of available solutions, offering lightweight, corrosion-resistant, and durable options for strengthening existing structures.

The integration of computational modeling and real-time monitoring has further improved the precision and reliability of these interventions. Techniques such as finite element analysis, bond-slip modeling, and embedded sensor monitoring enable engineers to predict structural behavior, optimize retrofitting designs, and evaluate long-term performance. In particular, FRP-based retrofitting demonstrates significant advantages in terms of ductility, seismic resilience, and reduced maintenance compared to conventional steel jacketing. Overall, combining these methodologies with performance-based engineering principles provides a

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proactive, holistic framework that ensures aging infrastructure continues to meet modern standards while optimizing lifecycle performance, safety, and resource efficiency.

Modern structural engineering increasingly relies on the combined application of repair, rehabilitation, and retrofitting to extend the service life of infrastructure, improve safety, and enhance performance. Selection of appropriate techniques is determined by factors such as damage type, material compatibility, structural requirements, and environmental conditions. Advances in high-performance materials, computational modeling, and real-time monitoring have significantly improved the efficiency, sustainability, and resilience of rehabilitation and retrofitting interventions. In particular, FRP retrofitting demonstrates superior long-term benefits over conventional steel jacketing, especially in seismic-prone and aggressive environmental conditions. The integration of these methodologies with performance-based engineering principles ensures that aging structures continue to meet modern standards while optimizing resource use and lifecycle performance.

REFERENCES

[1] Ananthakumar, A. (2025). Repair, rehabilitation, and retrofitting strategies for reinforced concrete structures: Materials, modeling, and monitoring perspectives. *International Journal of Civil and Structural Engineering Research, 12*(3), 145–168.

[2] Kabashi, N., Muhaxheri, M., Krasniqi, E., Murati, Y., & Latifi, F. (2025). Advancements in fiber-reinforced polymer (FRP) retrofitting techniques for seismic resilience of reinforced concrete structures. *Buildings, 15*(4), 587.

[3] Makhlouf, M. H., El-Azab, I. A., & Mansour, M. H. (2024). Flexural improvement of RC slabs by FRP or steel using different strengthening systems and novel anchoring techniques. *International Journal of Concrete Structures and Materials, 18*, 45.

[4] Osman, B. H. (2023). Shear strengthening of reinforced concrete (RC) with FRP sheets using different guidelines. *World Journal of Engineering and Technology, 11*, 281–292.

[5] Sagare, S. S., Kirthiga, R., & Elavenil, S. (2024). A state of the art review on strengthening of concrete structures using fabric-reinforced cementitious matrix (FRCM). *Research on Engineering Structures & Materials, 10*(2), 1231–1260.

[6] Sila, A. A., Irmawaty, R., Djamaluddin, R., & Tjaronge, W. (2024). A study on the retrofitting of the shear capacity on cold-joint longitudinal RC beams. *Engineering, Technology & Applied Science Research, 14*(5), 17357–17362.

[7] Bachchan, P. K. (2024). Repair, retrofitting and rehabilitation techniques for strengthening of reinforced cement concrete structures along with experimental work. *IJRASET Journal for Research in Applied Science and Engineering Technology*.

[8] Khan, S. (2024). FRP sheet as external reinforcement of RC beams. *International Journal of Surveying and Structural Engineering, 5*(2), 01–04.

[9] Güneş, O., & Tumer, R. (2024). Performance-based seismic retrofit design for RC frames using FRP composite materials. *Journal of Engineering Sciences and Design, 12*(4), 627–642.

[10] Yağar, A. C., İnce, C., & Derogar, S. (2022). FRP strengthening of RC structures: Sustainable, environmental and structural evaluations. *Journal of Sustainable Construction Materials and Technologies, 7*(4), 358–374.

[11] Dahiwale, P. S., & Londhe, R. S. (2024). Seismic analysis of G+30 RCC framed structure and use of RC jacketing. *Recent Trends in Civil Engineering & Technology, 14*(03), 20–37.

[12] Sangeeta, M., Raghava, G., & Manjunatha, L. (2023). Retrofitting of RC beams using FRP and FRCM. *STM Journals — Civil Engineering Series, 11*(Special Issue 01).

[13] Djamaluddin, R. (2025). Retrofitting of seismically deficient RC bridge pier using HSP concrete jacket and FRP rebars. *Engineering Science and Technology: An International Journal, 70*, 102146.

[14] El-Azab, I. A. (2024). Seismic retrofit of intact and damaged RC columns using prefabricated steel cage-reinforced UHPC jackets and NSM GFRP bars. *Engineering Structures, 317*, 118665.

[15] Surendra, S. S. (2024). A review of fabric-reinforced cementitious matrix (FRCM) strengthening techniques for concrete structures. *Research on Engineering Structures & Materials, 10*(2), 1231–1260.

[16] Djamaluddin, R. (2024). Strengthening RC beams through combined FRP wrapping, grouting, and anchorage at cold joints. *Engineering, Technology & Applied Science Research, 14*(5), 17357–17362.

Copyright © 2026 Authors

[17] Kabashi, N. (2025). Fiber-reinforced polymer retrofitting for seismic resilience: Recent advances and design implications. *Buildings, 15*(4), 587.

[18] Makhlouf, M. H. (2024). Novel anchorage techniques in externally bonded reinforcement: Application to RC slab strengthening. *International Journal of Concrete Structures and Materials, 18*, 45.

[19] Osman, B. H. (2023). Comparative study of FRP sheet configuration and beam depth on shear performance of RC beams. *World Journal of Engineering and Technology, 11*, 281–292.

[20] Sagare, S. S. (2024). Review of FRCM strengthening: Advantages, limitations, and applicability. *Research on Engineering Structures & Materials, 10*(2), 1231–1260.

[21] Sila, A. A. (2024). Shear capacity enhancement of cold-joint RC beams using GFRP sheets and dyna-bolt anchors. *Engineering, Technology & Applied Science Research, 14*(5), 17357–17362.

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