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Seismic Retrofitting of a Building using Steel Bracing and Concrete Jacketing (with Case Study: A 5 Storey Building at Ibadan, Nigeria)

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ABSTRACT: Seismic retrofitting is a crucial intervention for enhancing the resilience of existing buildings in seismically active regions. This study focuses on the retrofitting of a three-storey commercial building in Ibadan, Nigeria, utilizing steel bracing and concrete jacketing techniques. Although Ibadan is not traditionally classified as a high-seismic zone, recent global and regional studies highlight the need to evaluate the potential impact of seismic loads on structures. This paper methodology entails retrofitting design, including assessment of existing structural conditions, selection of appropriate retrofitting techniques, numerical modelling using ETABS software, and a comparative analysis of retrofitted and unretrofitted models, also key structural response parameters such as base shear capacity, inter-storey drift, lateral displacement, and stiffness degradation were evaluated. The study further considers soil-structure interaction (SSI) effects, given the implications of seismic loading on foundation bearing capacity and ground settlement. The results expressed that retrofitting significantly enhances the structural integrity of the building, reducing lateral displacements and improving seismic resistance, and reveals that while the soil's bearing capacity is sufficient under normal conditions, seismic loading could induce reductions in soil strength, emphasizing the importance of long-term ground improvement measures. The study concludes that steel bracing and concrete jacketing provide effective solutions for improving seismic resilience. Recommendations include implementing regular structural health monitoring, adopting performance-based design approaches, and considering soil stabilization techniques to ensure sustained structural stability under potential seismic events.

KEYWORDS: structural response, integrity, seismic resilience, bearing capacity, retrofitting

1. INTRODUCTION

Recent structural distress and collapse in Nigerian urban centers, notably in cities like Ibadan and Lagos, have underscored the inadequacy of older buildings in withstanding modern loading demands. Many structures constructed before the adoption of contemporary codes were primarily designed for gravity loads, neglecting lateral force resistance and dynamic load considerations. This has heightened the risk of progressive failures, especially as buildings age and usage patterns evolve to include higher occupancies and increased live loads. Seismic retrofitting emerged as vital strategy for addressing these deficiencies, providing a cost-effective means of strengthening existing buildings without necessitating total demolition. Retrofitting involves the addition of new structural elements or the enhancement of existing ones to improve the lateral stiffness, strength, and ductility of a structure. Common retrofitting techniques include steel bracing, concrete jacketing, shear wall installation, and fiber-reinforced polymer (FRP) wrapping. These methods aim to enhance the structure's response to lateral and dynamic loads, thereby improving serviceability and occupant safety. The primary objectives of this study are:

- To assess the existing structural performance of the selected building.
- To determine the critical structural members requiring retrofitting.
- To propose and model appropriate steel bracing and concrete jacketing configurations.
- To evaluate and compare key response parameters, including base shear, inter-storey drift, and displacement, before and after retrofitting.
- To analyze soil-structure interaction under seismic excitation.
- To offer recommendations for adopting similar retrofitting strategies in Nigerian urban centers.

1.1: A resilient system is expected to resist an extreme event with minimal deformation or damages and also has capability to quickly recover to its initial state and functionality, that is, the design must include possibilities of occurrence of such events by considering environmental factors and other critical forces that could impact the structural systems during the life cycle.

Resilience is characterized by four Rs, which are Robustness: having adequate stiffness Redundancy: sufficient reactive forces to ensure stability and equilibrium state Recover quickly: limit states parameter (design within tolerable limits) Resourcefulness: Adequate strain energy for structural responses

Therefore, structures are designed with sufficient tolerance against failure by providing adequate safety factor to the ultimate stress (σ_u) to define the design (or, permissible) stress which enables performance with respect to the characteristics Rs of resilient structure. Principle of least action is a variational principle and when applied to action of a mechanical system can be used to obtain the equations of motion for that system, and the motin parameters, such as acceleration and displacement. The principle state that physical fields and particles will sometimes take extreme values (ie, maxima or minima). Similarly, structures are object designed to remain at rest and in static equilibrium during load application ie, action of applied forces (a maxima value) must not change the equilibrium state and displacement can only be within permissible limit (or, minimal value)

$F = ma \approx 0$ (static equilibrium), implies $d \approx 0$ (minimal displacement)

Thus, action of force describes the work-done as follows,

$W = F \times d$, and if $d \approx 0$ then $W = F \times d \approx 0$ (or virtual work)

In structural system constraints are employed ro restraint motion of rigid body system, and ensure that the system remains at rest (ie, $d \approx 0$). When the rest position becomes impossible the system becomes unstable. Instability is critical structural condition that describes "lack of fitness" and integrity associated with reduced strain energy of the structural system

2. LITERATURE REVIEW

2.1. Mayer et al (2023) in their study on resilience and systems, a building structure case study, indicated that the resilience of building structures as plain technical/ physical/engineering systems or complex sociotechnical systems exposed to perturbation and change, has become increasingly important as natural effect and disaster are on the increase. Existing resilience frameworks are focused mainly on the responses of building system to perturbation events and their functional recovery. The study applied resilience system interpretation framework, which defines resilience in cross-discipline environmental as adaptation and adaptive systems to analyze actual and conceptual building structure systems. The system framework using modern control systems theory, defines resilience as ability of the system state and form to return to their initial or other suitable states or forms through active feedback mechanism. A simple smrf office building structure system is utilized to simulate the system state and form return abilities that are demonstrated by the system functional recovery time and functional recovery curve shape respectively. The framework provided a practical roadmap for resilience design and building of structures that effectively respond to perturbation while dynamically adapting to change in order to avoid obsolescence as well as increase the building useful life. Silva et al (2020), in their study on modeling structural performance and risk for enhanced building resilience and reliability, identified that performance-based regulations and standards adopted by AECO (Architecture, Engineering, Construction and Operation) sector stakeholders are more sophisticated, which include future events, changes, needs or the uses to prepare adequately, minimizing impacts and capitalizing on opportunities leading to business continuity throughout the whole building projects life cycle. The paper employed building structures as an empirical case study to determine effect of technical performance and risk engineering can be programmed defensively towards higher resilience and reliability.

Research study by Haikal and Muca in 2018 on evaluation of seismic retrofitting methods for seven story building in Stockholm, indicated that building's response to lateral loads (eg, seismic or wind induced) can improve significantly through strategic application of steel bracing and concrete jacketing. The work showed that combining global retrofitting interventions such as steel bracings with local strengthening methods (eg, concrete jacketing) could dramatically enhance structural stiffness and reduce displacement, even in low seismic zones, while environmental conditions of the location differ from Ibadan, the core principles of structural enhancement remain relevant. Buildings decreased strength with period of load application, environmental response or evolving functional demands can benefit from targeted interventions that are contextually adapted to local materials, labor skills and cost constraint. Bansal (2018), investigated structural retrofitting in historic buildings and expressed that retrofitting is modification process after manufacturing or construction and also presently there are many historic buildings that have potential for future use and presently may not meet expected structural requirement, and performance standards. Most significant aspect of retrofitting is associated with structural refurbishment which aids for increase strength, stability and safety. Through case examples, the paper aims to bring out the trends in retrofitting and techniques that are being adopted in contributing to sustainable future of historic buildings. Structural retrofitting techniques employed at the Hearst Greek theatre exemplify how historic buildings can be structurally rehabilitated to become sustainable resource for future generation

2.2. Seismic retrofitting involves the modification and strengthening of existing structures to improve their performance under lateral and dynamic loads. The selection of appropriate retrofitting techniques depends on the structural configuration, identified deficiencies, intended performance objectives, and socio-economic factors. Retrofitting interventions may be classified as:

- Global retrofitting techniques: Affecting the entire structural behavior.
- Local retrofitting techniques: Targeting individual deficient members.

2.2.1: Several retrofitting strategies have been developed and widely implemented globally, including:

Steel Bracing: Steel bracing systems enhance the lateral load-resisting capacity of RC frame structures by introducing diagonal or cross bracing members, which form a truss mechanism within the structural frame. This reduces lateral displacement, increases stiffness, and redistributes seismic forces. Common configurations include X-bracing, K-bracing, and V-bracing, each offering unique structural and architectural benefits. Steel bracing is relatively easy to install using locally available materials and is well-suited for external application, minimizing disruption to building operations.Concrete Jacketing: Concrete jacketing involves encasing existing structural members—particularly columns and beams—with additional reinforced concrete to increase their axial, shear, and flexural capacities. The technique enhances member confinement, improves ductility, and restores deteriorated or under-designed sections. It is especially valuable in cases where reinforcement corrosion or inadequate detailing has been identified. Jacketing is practical in Nigerian urban centers, where concrete and reinforcement materials are readily available and affordable.

Shear Walls: Shear walls act as vertical cantilevers that resist lateral loads through in-plane shear and flexural action. Incorporating shear walls significantly increases a structure’s lateral stiffness and reduces inter-storey drift. In retrofitting applications, shear walls can be added to building cores, along stairwells, or externally, *though careful analysis is required to avoid introducing torsional irregularities or stress concentrations.*

Fiber-Reinforced Polymer (FRP) Wrapping: FRP wrapping involves externally applying high-strength composite materials around columns, beams, or joints to improve axial, shear, and flexural capacities. These materials, such as carbon fiber or glass fiber composites, offer high strength-to-weight ratios and ease of installation. However, their application in Nigeria remains limited due to cost and the need for skilled labor.

Base Isolation: Base isolation techniques decouple a structure from ground motion by inserting flexible bearings at the foundation level. This shifts the structure’s fundamental period, reducing seismic forces transmitted to the superstructure. While highly effective, base isolation is complex and cost-intensive, making it more suitable for high-importance or newly constructed buildings in the Nigerian context.

3. METHODOLOGY

3.1 Description of the Case Study

The case study structure is a five-storey reinforced concrete (RC) commercial building located in Ibadan, Oyo State, Nigeria. The building has a plan dimension of 25 m × 16 m with five suspended floors supported by RC columns and beams. It was originally designed for modest occupancy but currently supports higher live loads due to commercial activities.

Field assessment revealed several structural deficiencies:

- Cracks in load-bearing columns and beams.
- Excessive floor deflections.
- Corrosion of reinforcement.
- Inadequate lateral load-resisting systems.

3.2 Seismic Data and Parameters

Although Ibadan is a region of low recorded seismicity, global seismic trends and urban structural distress necessitated seismic assessment using Eurocode 8 (EC8) guidelines. The adopted seismic parameters are:

- Peak Ground Acceleration (PGA): 0.05g (Ibadan region)
- Soil Type: Class C (medium dense soil)
- Importance Factor (γI): 1.0
- Behavior Factor (q): 3.0 for RC frames
- Damping Ratio (ξ): 5%

3.3 Seismic Load Estimation (Eurocode 8)

Seismic base shear was determined using the lateral force method of analysis per EC8:

Seismic Mass

Total load per floor: w = (DL + LL) = 6.5 kN/m²

Total seismic weight: W = 11.75 × 400 = 4700 kN

Mass (m) = $\frac{w}{g} = \frac{4700x5}{9.81} \approx 2395.6$ tonnes

Design Ground Acceleration $S_d(T)$

Using EC8 Spectral Shape

$S_d(T) = a_g . S . \{ 1 + \frac{T}{T_B} (n - 1)\}, \quad for \ \ 0 < T \leq T_B$

But for simplicity in equivalent static method, we approximate:

$$S_d\,(T) = \ a_g\,.S/q$$

- Soil factor S =1.2
- a_g= 0.04g = 0.392 m/s²
- q=3.0

$$S_d\,(T) = \frac{0.392\ x\ 1.2}{3.0} = 0.157 m/s^2$$

Design Base Shear Fb

$$F_b = S_d(T)\,.m\,.\gamma I$$

$$F_b = 0.157\ x\ 2396.96\ x\ 1.0 = 376.3kN$$

Lateral Load Distribution

The lateral force at each floor F_i is distributed as:

$$Fi = Fb \times \frac{(w_i \times h_i)}{\Sigma(w_i \times h_i)}$$

3.4 Structural Modelling and Analysis

A three-dimensional RC frame model of the building was developed using ETABS v18. The analysis stages included:

- Bare Frame Model: Original unretrofitted building.
- Retrofitted Frame Model:
  - External X-type steel bracing at selected bays.

- Concrete jacketing of critical columns (C1 to C6) based on observed deficiencies.

Loading Conditions:

- Dead Load (DL): 3.5 kN/m²
- Live Load (LL): 2.5 kN/m²
- Seismic Load: as per EC8 design spectrum

Load Combinations (per EC8):

- 1.35DL + 1.5LL
- 1.0DL + 1.0LL ± 1.0E
- 0.9DL ± 1.0E

3.5 Retrofitting Configurations

Steel Bracing:

- X-bracing system using ISA 60 × 60 × 6 mm steel angles.
- Applied externally along the longitudinal and transverse frames up to the 5th storey.

Concrete Jacketing:

- 150 mm thick reinforced concrete jacket around critical columns.
- Additional 12 mm diameter rebars at 150 mm c/c with 8 mm stirrups at 100 mm c/c.

Material Properties:

- Existing Concrete: fck=20 $f_{\{ck\}}$ = 20fck=20 MPa
- Jacketing Concrete: fck=30$f_{\{ck\}}$ = 30fck=30 MPa
- Steel Reinforcement: fy=460f_y = 460fy=460 MPa

3.6 Performance Evaluation Parameters

Key response parameters evaluated:

- Base Shear (kN)
- Inter-storey Drift (mm)
- Storey Displacement (mm)
- Plastic Hinge Formation
- Column Axial and Flexural Capacity

Comparative assessment of retrofitted vs unretrofitted models was conducted to establish the effectiveness of the interventions.

4.0 RESULTS AND DISCUSSION

The structural performance of the case study building was evaluated through numerical modelling in ETABS using Response Spectrum Analysis based on Eurocode 8 (EC8). The comparative performance of the unretrofitted and retrofitted models was assessed using critical response parameters including base shear, storey displacement, inter-storey drift, and plastic hinge formation.

4.1 Base Shear Capacity

The total base shear capacity of the building increased substantially after retrofitting. In the X-direction, the base shear improved from 684.26 kN (unretrofitted) to 912.34 kN (retrofitted), representing a 33.3% increase. Similarly, in the Y-direction, base shear increased from 698.45 kN to 926.71 kN, a 32.7% improvement.

Table 4.1 Base Shear Comparison

Direction	Unretrofitted (kN)	Retrofitted (kN)	% Increase
X	684.26	912.34	33.3%
Y	698.45	926.71	32.7%

The increase is attributed to the enhanced lateral stiffness provided by the steel bracings and the increased axial and flexural strength of columns from concrete jacketing.

4.2 Storey Displacement

The maximum lateral displacement at the top storey reduced notably in both principal directions after retrofitting. In the X-direction, the displacement decreased from 28.5 mm to 16.3 mm (42.8% reduction). In the Y-direction, displacement reduced from 27.2 mm to 15.8 mm (41.9% reduction).

Table 4.2 Maximum Top Storey Displacement

Direction	Unretrofitted (mm)	Retrofitted (mm)	% Reduction
X	28.5	16.3	42.8%
Y	27.2	15.8	41.9%

4.3 Inter-Storey Drift

According to Eurocode 8, the allowable inter-storey drift is 0.004 × storey height (15 m × 0.004 = 60 mm). The maximum inter-storey drift recorded for the unretrofitted model was 66.2 mm, exceeding the permissible limit. After retrofitting, the drift was reduced to 38.4 mm, well within acceptable limits.

Table 4.3 Maximum Inter-Storey Drift

Model	Maximum Drift (mm)	Allowable (mm)	Status
Unretrofitted	66.2	60	Unsafe
Retrofitted	38.4	60	Safe

The reduction in drift enhances overall lateral stability, preventing excessive sway and serviceability problems.

4.4 Plastic Hinge Formation

In the unretrofitted model, plastic hinges formed predominantly at beam-column joints and column bases at lower storeys under seismic excitation, indicating a high collapse risk. The retrofitted model demonstrated a significant reduction in hinge formation, with most hinges limited to beams and avoiding primary load-bearing columns.

Table 4.4 Plastic Hinge Formation Summary

Model	Critical Column Hinges	Beam Hinges	Status
Unretrofitted	9	14	Collapse-prone

Model	Critical Column Hinges	Beam Hinges	Status
Retrofitted	2	18	Stable

4.5 Effect of Concrete Jacketing

The application of concrete jacketing on distressed columns resulted in:

- Increase in axial capacity by 41.5%.
- Increase in flexural moment capacity by 34.6%.
- Enhanced confinement, delaying plastic hinge formation.

This significantly improved vertical load stability and lateral force resistance, particularly in columns at critical ground and first-floor levels.

4.6 Soil-Structure Interaction and Bearing Capacity

The ultimate bearing capacity under seismic conditions is calculated using EC8-modified Terzaghi's bearing capacity equation:

$$qu = c'Nc + \gamma DfNq + 0.5\gamma BN\gamma$$

where:

- $c' = 20$ kN/m² (cohesion of sandy clay soil)
- $\gamma = 18$ kN/m³ (unit weight of soil)
- $Df = 1.8$ m (foundation depth)
- B= 16 m
- $Nc, Nq, N\gamma$ = Bearing capacity factors from EC8

For seismic conditions, these factors are adjusted using reduction factorsRq and $R\gamma$

$$q_u seismic = qu \cdot Rq$$

Assuming Rq=0.85 (based on EC8 seismic soil adjustments):

$$q_u seismic = (15 \times 5.14) + (16 \times 1.5 \times 1.5) + (0.5 \times 18 \times 6 \times 0.8) \times 0.85 = 274.8\ kN/m^2$$

The applied seismic stress on the soil from the structure is:

$$q_{applied} = \frac{W_{strucuture}}{A_{foundation}}$$

$$q_{applied} = \frac{5000}{400} = 12.5Kn/m^2$$

Since $q_{applied} \ll q_u^{seismic}$, the soil bearing capacity is sufficient under seismic loads, indicating no immediate risk of bearing failure.

Seismic-Induced Settlement Analysis

Even when the soil has adequate bearing capacity, seismic shaking can still cause settlement. The total settlement (SSS) is estimated using seismic settlement equations from EC8:

$$S = Cs \cdot \frac{q_{applied}}{E_S}$$

- Cs = Seismic settlement coefficient (0.3 for Type C soils)
- Es = Soil modulus of elasticity (35 MPa = 35000 kN/m² for stiff clay)

$$S = 0.3. \frac{12.5}{35000} = 0.094mm$$

This is very low settlement, confirming that no significant seismic settlement will occur under expected conditions.

Summary of Findings

- Retrofitting increased base shear capacity by over 30%.
- Storey displacement and inter-storey drift significantly reduced.
- Plastic hinge formation at critical points minimized.
- Axial and flexural capacity of columns improved.
- Soil-structure interaction analysis confirmed foundation adequacy under seismic excitation.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This study has demonstrated the effectiveness of seismic retrofitting using steel bracing and concrete jacketing in improving the structural performance of a five-storey RC commercial building in Ibadan. Although the region is considered seismically low-risk, increasing urban wind loads, traffic-induced vibrations, and structural aging necessitate proactive strengthening interventions.

The key conclusions drawn from this research are as follows:

- Base shear capacity of the retrofitted building increased by over 30% in both principal directions.
- Storey displacement and inter-storey drift were significantly reduced, with maximum drift falling within Eurocode 8 allowable limits after retrofitting.
- Plastic hinge formation at critical load-bearing columns was drastically reduced, ensuring improved ductility and energy dissipation.
- Concrete jacketing enhanced column axial capacity by 41.5% and flexural capacity by 34.6%, effectively restoring deteriorated members.
- Soil-structure interaction analysis confirmed that seismic-induced stress levels in the foundation remained within safe bearing capacity limits following retrofitting.
- The combined application of external steel X-bracing and concrete column jacketing offers a reliable, practical, and economically viable seismic retrofit solution for mid-rise RC frame structures in urban Nigerian contexts.

The numerical simulation results confirm that targeted retrofitting interventions can significantly improve the lateral stiffness, strength, and overall seismic resilience of existing RC buildings, preserving their functionality and safety.

5.2 Recommendations

Based on the findings of this research, the following recommendations are proposed:

- Structural health assessments and retrofitting studies should be conducted for aging commercial buildings in Ibadan and other urban centers in Nigeria, regardless of their seismic zoning classification.

- The combination of steel bracing and concrete jacketing should be considered a primary retrofit option for mid-rise RC frame buildings exhibiting lateral instability or structural distress.
- Seismic provisions in the Nigerian Building Code should be reviewed and updated to incorporate mandatory retrofitting guidelines for existing structures, supported by regionally calibrated seismic hazard maps.
- Training programs and technical workshops should be organized for local engineers and contractors to promote awareness and practical knowledge of seismic retrofitting techniques.
- Further research should be conducted on low-cost, non-invasive retrofitting options suitable for densely populated, commercially active urban areas in Nigeria.
- Future studies should explore experimental validation of numerical models through shake-table testing and full-scale structural retrofitting case implementations.

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