# ENHANCING STRUCTURAL INTEGRITY AND RESILIENCE: A SYSTEMATIC APPROACH FOR RETROFITTING DESIGN OF A TWO-STORY HOSPITAL BUILDING IN KARACHI

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***Abstract-*** This paper presents a case study on the structural assessment and retrofitting design of a two-story hospital building in Karachi, Pakistan, constructed in 1992. To overcome this, a systematic approach was adopted, involving site visits, data gathering, the creation of as-built drawings, and detailed analysis and design using ETABS software. The assessment revealed vulnerabilities in the existing structure, particularly in the columns, which necessitated retrofitting measures. The retrofitting design included the incorporation of shear walls and the increase in column and beam sizes to enhance the building's seismic resilience. The successful completion of this project underscores the importance of a systematic approach in ensuring the structural integrity and resilience of existing buildings, especially in earthquake-prone regions. By prioritizing the preservation of human life and the enhancement of building safety, this study contributes to a more resilient built environment.

***Keywords-*** Seismic Resilience, Structural Assessment, Retrofitting Design, Non-Destructive Testing.

## 1 Introduction

The devastating earthquake that struck the Northern region of Pakistan in 2005, commonly known as the Kashmir Earthquake [1], brought about significant destruction and loss of life. This natural disaster not only impacted the effective areas but also highlighted the need for a structured assessment and retrofitting of existing buildings to ensure their resilience against future earthquake events [2].

The impact of the earthquake on the existing buildings was catastrophic. Many structures including hospitals suffered expensive damage or collapsed entirely the lack of proper seismic design and retrofitting measures in these buildings exacerbated the destruction and resulted in the loss of critical healthcare facilities when they were needed the most.

In light of this, the present paper focuses on a case study involving a two-story hospital building in Karachi, constructed in 1992. The hospital has a ground floor and two upper floors, with existing column sizes measuring 6 in x 18 in and beam sizes measuring 6 in x 27 in. The scope of the project includes creating as-built drawings, making architectural notifications as requested by the client, conducting a retrofitting design of the structure, and outlining the methodology for implementing the retrofitting measures.

## 2 Research Methodology

The structural assessment and retrofitting design of the two-story hospital building involved a systematic approach to ensure successful project execution. A site visit was conducted to gather the necessary site data and details for creating accurate as-built drawings. This involved documenting the existing conditions of the building, including its architecture and structural elements. The Ferro Scanning test was conducted to identify the existing steel in the existing structural elements.

Using the gathered data, as-built architecture and structure drawings were created in Revit [3]. These drawings served as a baseline for the retrofitting design process.

The model was analyzed and designed in the Etabs software using the ELF procedure. This analysis considered seismic forces and other relevant loadings to ensure the retrofitting design could withstand potential earthquakes. Based on the analysis and design outputs, final structure drawings and details were prepared. A comprehensive methodology report was prepared to outline the execution of the project.

# 3 Case Study

This case study revolves around the hospital in Karachi, established in 1992, according to the building code of Pakistan (BCP-2007), the Karachi region lies under the seismic zone 2B [4]. The structural system of the building is comprised of a Reinforced Concrete frame system (RCC column beam framing). Hollow block masonry has been used for infill wall panels along with seismic stiffeners.

## *3.1 Site Visit and Data Gathering*

To assess the building's integrity, a team of senior structural engineers and architects carried out a visual inspection of the existing building. A conditional survey by visual inspection was based on ACI 201.1R-08 which serves as a Guide for Conducting a Visual Inspection of Concrete in Service and ACI 364.IR-07 which is used for the guide of evaluation of concrete structures before rehabilitation [5, 6]. In Figure 1, on-site investigations and measurements of visible cracks have been found at the slab (Figure 1a) and existing beam (Figure 1b), the cracks observed are due to a combination of factors, including the seismic activity and the overloading. [9].

a) b)

*Figure 1: Observed structural cracks, a. Existing roof slab, b. Existing concrete beam.*

## *3.2 Creation of As-Built Drawings*

One of the main challenges encountered was the absence of original construction drawings. To address this, a team of architects was engaged to create as-built architectural drawings of the building. For the preparation of structural drawings with exact steel reinforcement in the existing concrete elements, a ferro scanning test was conducted by professionals. The objective of the test is to determine the diameter of the steel bars, concrete cover, and spacing between the bars in beams, columns, and slabs. The equipment used consists of a rebar detection system named Profometer made by Proceq SA, Switzerland. For rebar detection, the profilometer was slid over the surface of the existing structural elements. The provided beams are of size 6 in x 30 in and flexural cracks were observed in the beams. Columns size consists of 8 in x 18 in with minor torsional cracks were observed.

### *3.3 Structural Analysis and Design*

An analytical model of the existing building was developed within ETABS software, incorporating the two additional stories and precise steel reinforcement details obtained from the ferro-scanning report. This model was subjected to the existing loads and boundary conditions to assess its structural integrity. While the model demonstrated adequate performance under existing loads, the introduction of proposed additional stories and their corresponding loads revealed signs of failure in specific structural elements. Notably, the columns exhibited a demand-to-capacity ratio exceeding acceptable limits, necessitating immediate attention in the retrofitting design process. To address this, an iterative design process was employed to incrementally increase the column and beam sizes until the building successfully passed all post-analysis checks including drift and torsional building checks.

*Table 1 Drift limits before retrofitting*

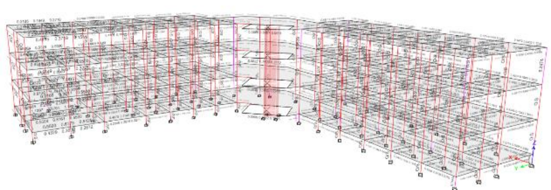
| Storey Level | Storey Elevation (ft) | R | $\Delta_s$Ex (in) | $\Delta_s$Ey (in) | $\Delta_m$Ex (in) | $\Delta_m$Ey (in) | Storey Drift % Ex | Storey Drift % Ey |
|---|---|---|---|---|---|---|---|---|
| 4 | 36 | 5.5 | 1.99211 | 1.481328 | 7.6696 | 5.7031 | 1.46 | 1.23 |
| 3 | 25 | 5.5 | 1.490297 | 1.061036 | 5.7376 | 4.0850 | 2.16 | 1.60 |
| 2 | 14 | 5.5 | 0.750679 | 0.513921 | 2.8901 | 1.9786 | 2.06 | 1.41 |
| 1 | 3 | 5.5 | 0.044387 | 0.030012 | 0.1709 | 0.1155 | 0.47 | 0.32 |

The initial structural analysis revealed that the maximum average drift in the x and y directions exceeded the allowable limit of 2%, reaching 2.16% and 1.60%, respectively as shown in Table 1, with a fundamental time period of 1.001 seconds.

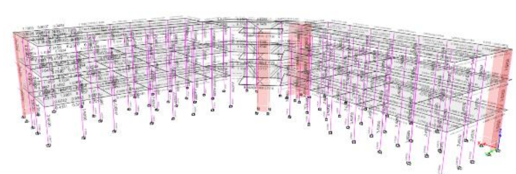
*Table 2 Drift limits after retrofitting*

| Storey Level | Storey Elevation (ft) | R | $\Delta_s$Ex (in) | $\Delta_s$Ey (in) | $\Delta_m$Ex (in) | $\Delta_m$Ey (in) | Storey Drift % Ex | Storey Drift % Ey |
|---|---|---|---|---|---|---|---|---|
| 4 | 36 | 5.5 | 0.604753 | 0.385042 | 2.3283 | 1.4824 | 0.59 | 0.40 |
| 3 | 25 | 5.5 | 0.40392 | 0.249321 | 1.5551 | 0.9599 | 0.64 | 0.41 |
| 2 | 14 | 5.5 | 0.18294 | 0.108501 | 0.7043 | 0.4177 | 0.50 | 0.29 |
| 1 | 3 | 5.5 | 0.01044 | 0.00789 | 0.0402 | 0.0304 | 0.11 | 0.08 |

The implementation of retrofitting measures, including the addition of shear walls, effectively reduced the building's drift limits to 0.64% and 0.41% in the x and y directions, respectively as shown in Table 2. This reduction, coupled with a decreased time period of 0.441 seconds, indicates a substantial improvement in the building's seismic performance. The analysis and design process adhered to the guidelines outlined in the Building Code of Pakistan (BCP-2007), with an importance factor of 1.25 assigned to the hospital building.



a)



b)

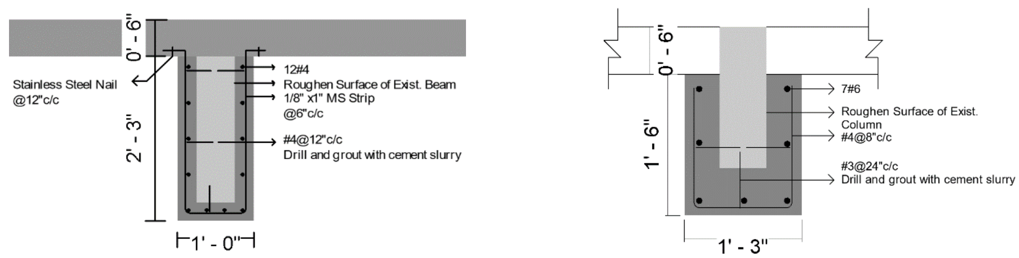
*Figure 2: Structural analysis and design in etabs, a. O/S sections before retrofitting, b. Pass sections after retrofitting*

After the final analysis and design (Figure 2a), we determined the new column and beam sizes 15 in x 18 in and 12 in x 33 in as shown in Table 3. To control the drift, we considered the inclusion of 9 in-thick shear walls.

*Table 3 Member sizes*

| Sr. No | Members | Existing Sizes before Retrofitting (in) | New Sizes after Retrofitting (in) |
|---|---|---|---|
| 1 | Slab | 6 | 6 |
| 2 | Beam | 6 x 30 | 12 x 33 |
| 3 | Column | 8 x 18 | 15 x 18 |
| 4 | Shear walls | Not provided | 9 |

M/s strips were employed as a substitute for conventional stirrups. M/s strips, also known as steel straps or flat bars, are thin, flat steel elements used to confine concrete and enhance its ductility and shear strength [9]. In this context, they were strategically placed within the column and beam reinforcement to improve the stability of the columns to withstand lateral loads and seismic forces as shown in Figure 3. This choice was likely made due to the ease of installation and the potential for M/s strips to provide a more uniform distribution of confinement compared to traditional stirrups.




a) b)

*Figure 3: Retrofitting details, a. Retrofitting detail of beam, b. Retrofitting detail of column*

## 4 Conclusion

This case study underscores the importance of a systematic approach to structural assessment and retrofitting, particularly in the absence of original construction drawings. By utilizing a combination of site visits, data collection, the creation of as-built drawings, and advanced analysis and design tools, the structural integrity and resilience of existing buildings can be significantly enhanced. This approach not only ensures the safety of occupants but also contributes to a more resilient built environment in regions prone to seismic activity.

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