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Performance Evaluation of Retrofitting of Reinforced Concrete Structures

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Abstract- -Every building is built is to serve for some particular purpose, even after its service life is completed. The structure is required to get repaired in order to keep the structure in serviceable condition so that it fulfills its desire purpose, for which time to time maintenance and repair work are necessary. Every structure is constructed to serve a particular service, after the service structure is subjected to repairs. In order to keep the structure in good condition such that it fulfills its desire purpose, the maintenance and repairs are necessary. The maintenance of structure is done properly and periodically to prevent the structure from defects and hence prevent any repair works. Reinforced concrete is widely used for the construction material for different types of construction of structures. The major failure of rock structures is due to distress and deterioration. Generally, the minor defects in structures such as cracks and leakages are removed with the help of various repair techniques. However, if the defects extend to a considerable damage, rehabilitation is necessary. To keep the building in such a condition so that it provides it intended purpose of construction to improve the strength of the building and service of a building. The purpose of this project is economical structure rather than the reconstruction of the structure and to avoid various types of repairs, cracks, distress and deterioration in the structure. In this project a building taken for study which was 19 years before constructed, but due to poor construction it requires retrofitting. Columns, beams, slabs and walls need to retrofit; it requires increasing strength of the section. Finally, section-enlarging method is used for retrofitting of columns and jacketing method is used for retrofitting of beams. A proposed estimate is calculated with is about Rs. 7,26,827.00/-. Extended life of the building is about 45 years. Annual worth of the extended life period of building is about Rs. 600000/- per year. The experimental results of rebound hammer indicated that the strength of an existing building can be increased by retrofitting the building. Also, quality of concrete is in between Fair to Good for the building. The percentage increase in strength of the building before and after retrofitting is 57.75%. This project has reported on a structural experiment conducted to verify the effectiveness of a retrofitting method for reinforced concrete buildings that uses jacketing method and section- enlarging reinforcing method. Valuation of market is increased by 75% with retrofitting. The life cycle cost of Market is 41,58,563/- Rs.

Keywords: Retrofitting, Repair, Rehabilitation, Retrofitting, Distress, Deterioration, NDT Methods, Rebound Hammer, etc.

1. INTRODUCTION

The maintenance work is done periodically to avoid the building from degrading and hence preventing it from nonfunctioning or ill functioning. The Reinforced cement concrete components are mainly responsible for taking the load and hence are vital elements in any building structure. Retrofitting is the process of repairing existing structures, such as buildings, commercial building structures, bridges, and historic buildings, to make them resistant to seismic forces such as earthquakes, volcanic eruptions, and other natural disasters such as landslides, tsunamis, floods, and thunderstorms. The main objective of retrofitting RCC structural elements is to recover the strength of the deteriorated concrete element structure. It also helps to prevent further damage in concrete elements. The deficiency in the strength of the concrete element could be because of design errors flaws or poor construction workmanship. There could be another reason too for the damage such as the aggression of harmful and hazardous agents.

1.1 Background

Several existing reinforced concrete (RC) buildings fail to conform to current seismic codes, increasing its susceptibility to damage and collapse during earthquakes. A concern for building upgrading and rehabilitation has grown considerably in the last decades. However, there is limited information related to the seismic performance of RC buildings retrofitted with steel jacketing. Once the right methodology of retrofitting is implemented and specified, the required ability to the structure could be returned and it completely depends on the type and seriousness of the damage caused. There are numerous techniques that are utilized in the process of retrofitting such as outside plate bonding, grouting, outer post-tensioning, section extension, and fiber built reinforced polymer materials. The need for rebuilding and restoration of buildings and engineering construction may arise once they are damaged to a point that they are not qualified for general use purpose. The building cannot withstand, with good reliability, a further sequence of the same action or unintended accidental actions and consequently, the chance of lives and thus the raising of any structural and content damage would be not justifiable. An appropriate strengthening replacement that can bring back an adequate magnitude of wellbeing and assurance against such moves is described as retrofitting. Retrofitting of structures implies making changes to a present day building to provide protection from various hazards in future such as high wind flows, flooding and earthquakes.

Figure 1.1: Retrofitting of Existing Building

1.2 Motivations

To exclude the disaster in future calamities like earthquake, the retrofitting plays a key role in the structural fundamentals. When we focus on the global retrofits the first question which comes in our mind. . In easy way we can claim the retrofitting of structure can be dictated as a methodology that is used to continue a structure to last any lateral force such as seismic power forces. Seismic activity makes the seismic force work in to wave form. The seismic powers effect on the building structure is in the form of lateral loading. For prevention of this structure from this lateral loading sacking there are various strategies, which is use for retrofitting. For various kinds of building structure such as masonry stone structure, RC outline frame structure, we use numerous types of methods which are point out as below. Concrete jacketing is considered as the most significant approach for strength reinforcement and fixing of RCC beam.

1.3 Purpose of Retrofitting

As days are passed numerous environmental factors going on that cause impact to the structure. Among all the factors, the most harmful is an earthquake that disturbs the building’s internal structure, and hence the strength and stability of the building structure gradually reduces. As a cause of this, the structure becomes unfit and unsafe for coming future use and may lead to massive loss of life. The magnitude of deterioration which is caused to the concrete component structure occurs at a very fast alarming rate. There has been a confirmation that even when all the specific building construction standards and codes are applied still there has been very high risk of degradation of reinforced concrete element and reinforcement corrosion damage. Corrosion of steel is considered as one of the most serious reason behind the damaging of reinforced concrete element and this could result in formation cracks or minimizing down the effective length and width of the reinforcement, spalling of cover of concrete, and collapse of structure may tend to happen. There are a variety of incidents to be when managing with damages are considered. In situations of any private or government sector like any office building structure or residence construction is damaged to extreme level. Civil Demolishing the building and reconstruct is the new trend preferred by civil engineers. But in the certain cases the important and historic value buildings demolishing them is not a good idea. hence, in this case idea of Retrofitting turns out to be good method. Retrofitting has gone to an extend where all the components and members of the drive to make structures hot proficient and practically fit. This also helps fossil fuel byproducts cutting; make it cheaper and very easy to run structures, as well as addition to beating ventilation helplessly and sogging problems, therefore improvisation of entire environment. Moreover, it can also help in expansion of building versatility, solidness, and flexibility.

1.4 Need of Retrofitting

There are numerous problems that building structural members experience in its entire life and needed to be tackled among them some common problems include:

a) Structural cracks
b) Damage to structural members
c) Excessive loading
d) Errors in design or construction
e) Modification of the structural system
f) Seismic damage
g) Corrosion due to penetration- honeycombs

1.5 Importance of Retrofitting of Buildings

Figure 1.2: Retrofitting of Building

Presently retrofitting is extending its worth out of control in the world, as a considerable part of the recorded, government, and private significant designs plans over a period of time get really old and become weaker. Retrofitting is possibly the best and most ideal option to make a present lacking building structure safe guard against future hazards or other natural god acts. Retrofitting is the methodology of addition of brand-new highlight features to a lot established building structures, structures of legacy, bridges-spans as shown in Figure 1.2, and so on. Retrofitting minimizes the deficiency of harm of old existing design plan during a not-so far future seismic developing movement. It is the restoration of existing designs to make them more resistant to seismic activity, ground movement, and disappointment of soil bed mainly due to seismic activities as well as other characteristic cataclysms, for example, twisters on land, typhoons, and wind loads having high velocity because tempest, snow falling, thunder hails. A few designs plans are significant taking in consideration public, social, or past significant importance. Retrofitting always serves in upgradation of strength and resistivity.

2. LITERATURE REVIEW

Basel E. et. al. [2021] studied benefits of retrofitting school buildings in accordance to LEED v4. Pursuing green building certification for major renovation projects, including schools, had become common due to its associated resource efficiency, reduced operation cost, and enhanced indoor environmental conditions. The perceived renovation costs may discourage professionals from pursuing the Leadership in Energy and Environmental Design (LEED) rating systems.

Ahmed W. et. al. [2021] studied BIM-based techno-economic assessment of energy retrofitting residential buildings in hot humid climate. Buildings in hot humid climates were energy intensive to operate. Energy consumption in Saudi Arabia was almost three times higher than the global average, and one of the major contributors to that was the residential sector. Increasing environmental and economic concerns, in the form of Saudi Vision 2030, mean that the existing unsustainable residential building stock had to be energy retrofitted. This study examined the techno-economic feasibility of retrofitting existing homes in Eastern Province, Saudi Arabia. A Building Information Modelling (BIM)-based retrofit framework had been adopted and investigated on two case studies. Eight Energy Efficiency Measures (EEMs) had been implemented including increasing cooling set point temperature, using energy efficient appliances, replacing conventional lights with more efficient lights, applying window shading, improving glazing type, improving air tightness, using more efficient air conditioning system, and adding envelope insulation. A three-level energy retrofit plan was proposed. Results indicated that annual energy consumption in a villa was reduced by 13.79%, 19.27% and 56.9%, and in the apartment building by 22.84%, 28.85% and 58.5% through a level 1, 2 and 3 retrofit respectively.

Vui V. C. et. al. [2020] studied damage-based seismic retrofitting approach for non-ductile reinforced concrete structures using FRP composite wraps. Applying similar amount of fibre reinforced polymer (FRP) for all plastic hinge locations in a structure was not an ideal approach as damage occurring at these critical locations may vary considerably. Building owners also always want to keep FRP retrofitting cost and associated interruption to a minimum. In this context, the current paper proposes an FRP retrofitting approach, in which FRP is selectively distributed based on the distribution of seismic damage in structures.

Hamida M. et. al. [2019] focused on techno-economic assessment of energy retrofitting educational buildings: A case study in Saudi Arabia. The buildings and construction sector accounts for the majority of the energy consumption in the Kingdom of Saudi Arabia (KSA). For a sustainable future, energy consumption in the sector should be reduced and existing buildings need to be energy retrofitted. A number of studies present energy retrofitting of residential buildings in KSA; however, there was a lack of studies presenting retrofitting of educational buildings.

Gupta N. et. al. [2019] focused a case study on retrofitting of an existing residential building by using shear wall**.** In India, there exists a number of old and existing buildings that were either constructed without taking into account the effects of earthquake forces or that were previously damaged or are likely to be damaged in the near future during the shaking of the ground. There were various ways of retrofitting these buildings so as to mitigate the effect of future earthquake.

Xie H. et. al. [2019] studied big data analysis for retrofit projects in smart cities. This paper aimed to study the potential of using Big Data Analytics (BDA) in smart cities. Based on case studies, this paper scrutinizes the situations when decision makers implement BDA as a tool for smart cities. The paper studied how Internet of Things, Machine to machine, Big Data and Smart Cities Linkages can help to predict and satisfy the needs of retrofitting projects.

Tiwari P. et. al. [2019] reviewed on seismic retrofitting of pure masonry structure. By viewing the latest earthquake in Nepal (25 April 2015), the seismic analysis plays an important role on the construction area. The building demands to build earthquake proof and earthquake resistant. Some building structure which was previously constructed demand to retrofitting. When authors heard the term retrofitting author focused on maintain the previously constructed building through different techniques.

Bandera C. et. al. [2018] focused on energy as a measure of sustainable retrofitting of buildings. This study presented a novel optimization methodology for choosing optimal building retrofitting strategies based on the concept of energy analysis. The study demonstrated that the building energy analysis may open new opportunities in the design of an optimal retrofit solution despite being a theoretical approach based on the high performance of a Carnot reverse cycle. This energy-based solution is different from the one selected through traditional efficient retrofits where minimizing energy consumption was the primary selection criteria. The new solution connects the building with the reference environment, which acts as "an unlimited sink or unlimited sources of energy", and it

adapted the building to maximize the intake of energy resources from the reference environment. The building hosting the School of Architecture at the University of Navarra had been chosen as the case study building.

Sebi C. et. al. [2018] studied Policy strategies for achieving large long-term savings from retrofitting existing buildings. In order to achieve long-term targets for energy savings and emission reductions, substantial savings would be needed from existing buildings. For example, a recent analysis for the USA examines aggressive strategies to cut carbon emissions in half by 2040 and finds that in order to achieve this emission reduction target, more than half of existing buildings would need comprehensive energy efficiency retrofits. Germany is targeting an overall primary energy consumption reduction of 50% in 2050 including increasing building renovation rate to 2% per year. In France, ambitious targets had also been set for existing buildings: 50% reduction of primary energy consumption in 2050 compared to the 2012 level.

Cascone S. et. al. [2018] focused on a comprehensive study on green roof performance for retrofitting existing buildings. Green roofs present a viable solution for increasing rainwater retention while improving the energy performance of both new and existing buildings. Considering the widespread occurrence of existing buildings, it was worthwhile to conduct an in- depth analysis of green roof feasibility for retrofitting these buildings. In such cases, the first constraint was related to structural compatibility. Therefore, the use of lightweight systems should be prioritized to minimize overloading of the existing roof.

Mishra A. et. al. [2017] studied on analysis, design and application of retrofitting techniques in various structures. This research paper was focused on the structures which lack the required strength as per the guidelines of earthquake building code to sustain the seismic force. Suitable retrofitting techniques were suggested after proper analysis and documentation at different sites. The basic idea behind the strength enhancement of structure was based on the concept of improving the flexibility, stiffness, ductility and unity of the structure. The method of retrofitting improved the seismic force sustaining capacity of various components of building without stress concentration at critical points.

Veronica C. et. al. [2017] focused on the experience of international sustainability protocols for retrofitting historical buildings in Italy. The sustainability and efficiency of buildings represents a crucial issue since the building sector was currently responsible for more than 40% of energy consumption and emissions. This concern was extended to historical buildings, as they were typically low-performance constructions usually equipped with ineffective systems.

Gupta G. et. al. [2017] reviewed on seismic retrofitting of structures. Earthquake around the world were single-handedly responsible for the destruction to life and property in large numbers. In order to mitigate such hazards, it was important to incorporate norms that would enhance the seismic performance of structures. This paper represented the change of reinforced concrete structural components which were found to exhibit distress because of earthquake loading. Such unserviceable structures require immediate attention. And it was done by using the shear wall mechanism in the software. It can be used as a seismic retrofitting technique because it can be applied quickly to the surface of the damaged element without the requirement of any special bonding material and also it requires less skilled labor, as compared to other retrofitting solutions presently existing. It had determined that load carrying capacity for beam-column joint retrofitted with shear wall is increased. In this paper author used analytical approach. In this we use STADD Pro V8i software.

Dhanush S. et. al. [2016] analysed retrofitting of existing RC columns by reinforced concrete jacketing using ANSYS and ETABS. Retrofitting was a technique to improve the structural capacities including the strength, stiffness, ductility, stability of a building that was found to be deficient. It could effectively improve the performance of a building. In this paper, an RC building of G+3 will be analyzed and design in ETABS software. Then the number of floors would increase to 3 numbers above the top floor of existing building so that the building becomes G+6 floors and again it is increased by 2 numbers above the top floor of existing building then it becomes G+8.

3.1 RESEARCH METHODOLOGY

This chapter describes the methodology adopted to achieve the aims and objectives of the study, details of the methods used, and the different procedures applied to investigate various methods for retrofitting of construction projects.

3.1 Problem Statement

Every building structure is built to serve some particular function service, after this service life is completed; the structure is subjected to repairs. In order to keep the structure in fair condition such that it fulfills all desire purpose, time to time maintenance and repair work are necessary. The maintaining work of structure is done time to time and properly to avoid the building from degrading and thereby preventing any future repairing works. For different types of construction of structures mostly reinforced concrete is used a construction material. Distress and deterioration are main cause of major failure of rock structures. With the help of various repair techniques, the minor defects in structures such as cracks and leakages are removed. Restoration is really necessary if the damage extend to a considerable damage. The building should be kept in such a condition such that it provides its main purpose of construction to improve the strength of the building and service of a constructed building structure.

Thus, the statement of the Project is,

3.2 Aim of the Study

Retrofitting serves to improve strength, resistivity. The basic aim behind retrofitting or repair works is to extend the service life, enhance the performance of the structure or increase the load-bearing capacity. The major approach to any retrofitting work is to keep into consideration that the main reason of the damage along with the symptoms.

1. To enhance the life of the building after retrofitting.
2. To make reduction cost of new construction,
3. To improvise stability and sustainability in the structure
4. To prepare the building to withstand different weather conditions
5. Strengthening growth and enhancement of the structure.

3.3 Objectives of the Study

1. To study different old buildings,
2. To prepare the questionnaire for the visual inspection of the building,
3. To identify the locations for retrofitting and replacement of items and suggest method of retrofitting,
4. To prepare estimate of retrofitting and replacement as per current DSR of PWD,
5. To find the extended life of the building and annual worth of the extended life period of building.

3.4 Methodology of the Work

The different phases of this project of work are shown in the following Figure3.1. The figure simply describes the experimental strategy of this study step by step.

a) Review the existing literatures on retrofitting of the buildings,
b) Select different old buildings for conducting study with respect retrofitting,
c) Preparing information sheet of building which includes name of owner, location, year of construction, area, drawings, etc.
d) Preparing questionnaire for the visual inspection of the building which includes structural components, doors and windows, water supply and drainage system, etc.
e) Identifying the locations for retrofitting and replacement of items and suggesting method of retrofitting and quantify the replacement of items.
f) Preparing estimate of retrofitting and replacement as per current DSR of PWD,
g) Estimating expenses per unit area,
h) Finding the extended life of the building and annual worth of the extended life period of building,
i) Interpretation of results and conclusion.

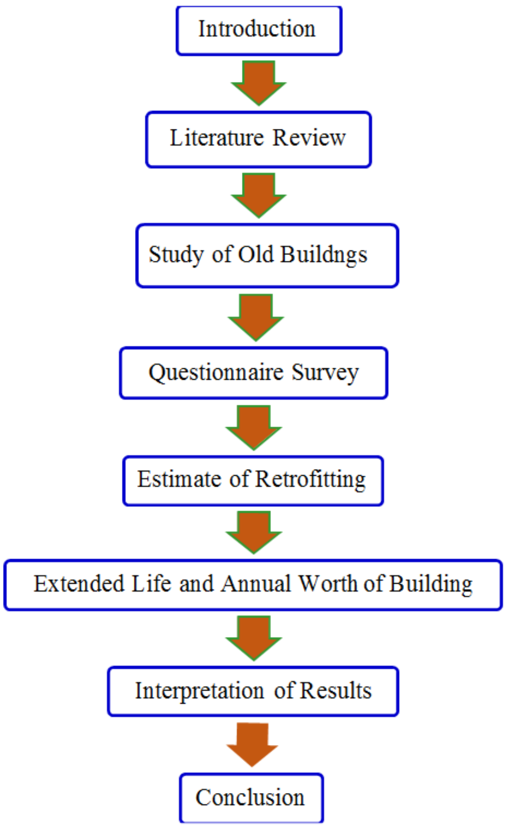

Figure 3.1: Layout of the Project

3.5 Percentage Increase in Strength of Rebound Hammer Test Results before and after Retrofitting

Table 3.1: Percentage Increase in Strength of Rebound Hammer Test Results before and after Retrofitting (Column - Ground Floor)

Sr. No.	Member (Ground Floor)	Avg. Char. Comp. Strength before Retrofitting (MPa)	Avg. Char. Comp. Strength after Retrofitting (MPa)	% Increase in Strength
1	Column C1	14	24	71.43
2	Column C2	16	22	37.5
3	Column C3	10.5	26	147.62
4	Column C4	10	25	150
5	Column C5	16	22	37.5
6	Column C6	12	25	108.33
7	Column C7	25	28	12
8	Column C8	19.5	22	12.82
9	Column C9	9.5	22	131.58
10	Column C9 (A)	15.5	26	67.74
11	Column C10	24	24	0
12	Column C10 (A)	16	22	37.5
13	Column C11	22	25	13.64
14	Column C11 (A)	19	24	26.31
15	Column C12	20.5	22	7.31
16	Column C12 (A)	18	24	33.33
17	Column C13	18.5	22	18.92
18	Column C13 (A)	19.5	25	28.20
19	Column C14	18	25	38.89
20	Column C14 (A)	17.5	25	42.86
21	Column C15	20	25	25
22	Column C15 (A)	22	27.5	25
23	Column C16	15.5	28	80.64
24	Column C16 (A)	22	25	13.63
25	Column C17	9.5	28	194.74
26	Column C18	14.5	28	93.10
27	Column C24	11.5	22	91.30
28	Column C25	19	22	15.79
29	Column C26	14	20	42.86
30	Column C31	13	24	84.62
31	Column C32	11	22	100

3.6 Visual Observation of Market Yard

Table 3.2: Visual Observation of Market Yard

Sr. No.	Description	Current Status	Remarks
1	Foundation Strata	Level Condition	NA
2	Structural Element -Column	Poorly Damaged	Need to be Retrofit
3	Structural Element -Beams	Poorly Damaged and Green Algae	Need to be Retrofit
4	Structural Element -Slab	Green Algae due to excess water	Need to be Retrofit
5	Walls, Plaster and Flooring	Cracks in Walls	Need to be Retrofit
6	Doors and Windows	Corroded	Need to be Retrofit
7	Water Supply System	Broken	Need to be Retrofit

3.7 Survey for Visual Inspection of the Building

Table 3.3: Questionnaire Survey for Visual Inspection of the Building

Sr. No.	Question	Answer
1	Construction Year	2002
2	Age of the building	19 years
3	Front elevation	Poorly Damaged and Green Algae
4	Side elevation	Cracks in Walls
5	Internal Condition	At ground floor level on the landing there was a vertical crack, which was hairline extending upwards within the sloping part of the ceiling.
6	External Condition	Poorly damaged
7	Has previously had major alterations	No
8	Is there any problem of leakage?	Yes. Due to poor quality of construction
9	How many people are live in this apartment?	About 90
10	Is there any falling of ceiling plaster?	Yes, it's already happened.
11	Can you recommend an expert to look into this further?	Yes. We required.

3.8 Locations and Methods of Retrofitting

Table 3.4: Locations and Methods of Retrofitting

Sr. No.	Location for Retrofitting	Methods of Retrofitting
1	Structural Element - Column	Section-Enlarging Reinforcing Method
2	Structural Element - Beams	Jacketing Method
3	Structural Element - Slab	Section-Enlarging Reinforcing Method
4	Walls, Plaster and Flooring	Cavity wall insulation, internal or external insulation, and cladding of external and internal surfaces.
5	Doors and Windows	Replacement high-performance doors and windows
6	Water Supply System	Replacement with PVC pipes

7	Masonry Walls	Grouting

4. RESULT AND DISCUSSION

3.6 Opening Remarks

This chapter describes the performance analysis study on retrofitting of existing building structures. This chapter also shows questionnaire survey, estimate of retrofitting, extended life and annual worth of building.

3.7 Project 1: Market Yard, Nashik

Table 4.1: Detail Information of A Market

Name of Building	Market Yard
Name of Owner	Zilla Parishad, Government of Maharashtra
Type of Building	Commercial Building
Location	Nashik
Type of Structure	RCC G + 1 Structure
Year of Construction	2002
Age of Building	19 Years
Plot Area	254.37 sq. m
Parking Area	15.61 sq. m
Total Built-up Area	170.75 sq. m
Total Carpet Area	150.48 sq. m

Figure 4.1: Market Yard Site

3.8 Visual Observation of Building

Here the first stage of vulnerability assessment is the visual observation. In this stage, the whole building is investigated visually to get the rough idea and condition of the structural condition. In this stage during conducting the visual observation, it is advised to take paper documentations of the building's condition and note down the structural defects observed for future investigation. From the results and conclusion of visual observation, structural investigation is then conducted.

4.4 Visual Observation of Structural Elements

A structural investigation is aspect of a structure's vulnerability evaluation. In structural investigation, the investigator will have to do collection of some data which is related to present existing structural condition for next analysis part. It is advised that the investigator should prepare the necessary equipment's for the investigation to be done. Some of equipment's, writing tools, documentation tools, technical drawing, should be made. All the others equipment's which were related with the structural strength test to be conducted according to the needs of investigation.

Figure 4.2: Visual Observation of Column

Figure 4.3: Visual Observation of Slab

Figure 4.4: Visual Observation of Beams

My project is case Study on Market yard by using rebound hammer test. In which I calculated the life cycle cost of that market yard using retrofitting techniques. I calculated the total cost associated with building design and construction, building operation and maintenance, in addition to the costs associated with building disposal at the end of its life cycle
In that case study
I calculated extended life of the building approximate about **45 years**. Then the Annual Life Cycle Cost for investment calculated as **Rs. 58,147.00/-**
Also I Calculated Average percentage increase in strength of rebound hammer test results before and after retrofitting (Column - Ground Floor) and it was equal to **57.75%**. Seismic Retrofitting is an excellent method for protecting a wide range of structures. It has resulted in a highly reliable technology in recent years.

CONCLUSION

The objective of this research was to study retrofitting of reinforced concrete structures. The study has indicated that objectives of retrofitting of reinforced concrete structures will achieve by proper planning, analysis and design.
The following summarizes the results and conclusions.

1. Retrofitting added strength to the failing building structure, making it more effective and capable of handling static and dynamic loads. Retrofitting a pure masonry construction provides enough seismic structural strength.
2. The estimate of the market is about Rs.7,26,827/- It means that cost per unit area of the retrofitting is Rs. 1219.78/- per sq. m. So retrofitting is the cheapest way to improve the building structural quality. Extended life of the building is about 45 years. Annual worth of the extended life period of building is about
3. The experimental results of rebound hammer indicated that the strength of an existing building can be increased by retrofitting the building. Also, quality of concrete is in between Fair to Good for the building. The percentage increase in strength of the building before and after retrofitting is 57.75%. This Project has reported on a structural experiment conducted to verify the effectiveness of a retrofitting method for reinforced concrete buildings that uses jacketing method and section-enlarging reinforcing method.
4. The market was constructed in year 2002. If it will not retrofit then it may chance of falling of structure due to

poorly damaged of columns and beams. In that case, life of market would be about 5-7 years. Market is also get affected by green algae due to excess water. Green algae decrease the strength of the structural element. Doors and windows get corroded and water supply system is also damaged so team has decided keep the building in such a condition so that it provides it intended purpose of construction to improve the strength of the building and service of a building.

5. When compared to other essential procedures, retrofitting takes less time Retrofitting buildings makes them more versatile and suited for current and future activities, as well as making them more comfortable to resist loading. The key challenge was to attain a required degree of performance at a low cost, which could be accomplished by a thorough examination. Optimization techniques are required to determine the best cost-effective retrofit for a given facility. Professionals in this industry require proper design codes to be published as a code of practice.

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