

Research Paper

Retrofitting design of Kathmandu University library building after Gorkha earthquake 2015

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ARTICLE INFORMATION

Article history:

Received: 19 January, 2016

Received in revised form: 29 February, 2016

Accepted: 11 March, 2016

Publish on: 26 September, 2016

Keywords:

Major shock
 Aftershock
 Damages on KU library
 Safety requirements
 Seismic risk
 Retrofitting

ABSTRACT

The major earthquake on April 25, 2015 (7.8 M_w) and the aftershock on May 12, 2015 (7.3 M_w) caused severe damages on Kathmandu University (KU) Library. Disaster prevention of the library building is necessary to restore its strength and reduce seismic risk. Retrofitting approach can be employed to strengthen the building and increase its seismic capacity. Seismic retrofit is an effective technique by which the building can be strengthened to improve its seismic performance without affecting its aesthetics value and architectural identity. To achieve public safety by considering use of various materials and structural stability, retrofitting is economically applied to meet functional and structural requirements of the building. This pro-active disaster mitigation technique has been effective in modifying the existing structure for strengthening to improve its structural performance.

1. Introduction

This is a case study for Retrofitting Design of Kathmandu University Central Library Building (Block#3) after Gorkha Earthquake 2015. The building lies south to the Administrative Building of Kathmandu University, located at Dhulikhel, Kavrepalanchwok (**Fig. 1**). The strong earthquake on April 25, 2015 (7.8 M_w moment magnitude) originated at Barpak of Gorkha District and the largest aftershock with the magnitude of 7.3 M_w (United States Geological Survey) affected the building to great extent leading to the structural failure of the building. This building is an Ordinary Moment Resisting Frame (OMRF) covering an area of 888.31 sq.m.

The reinforced concrete building is (G+2) storey high.



Fig. 1. Location of KU Central Library. Google image. Kathmandu University, Dhulikhel, Nepal- Google Maps. Dec. 8 2010. Web. Dec 11 2015. www.cimpa-icpam.org.

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Note: Discussion on this paper is open until March 2017.

Due to lack of soil test reports of library building, the soil type is assumed as soft rock i.e. medium soil based on the reports of recently conducted soil tests in the vicinity of the building. Response spectra are specified for three types of founding strata namely rock and hard soil, medium soil and soft soil in fifth revision section of IS 1893 (Part I): 2002. The identification of soil type is important for determining spectral acceleration. According to **Fig. 1** of IS 1893 (Part I): 2002; Criteria for Earthquake Resistant Design of structures, Part 1: General Provisions and Buildings [CED 39: Earthquake Engineering], the district is assumed to lie on earthquake zone V, the severest one, so the effect of earthquake is predominant compared to wind load. Before the earthquake, the ground floor of the building was used as library whereas the upper two floors were used for educational purpose. After the occurrence of earthquake, only ground floor is accessible. The damages are found heavy so the building needs to be strengthened through retrofitting. It is emphasized that the building will satisfy the functional and structural need after retrofitting. During retrofitting analysis of the building, seismic effect was considered whereas earthquake loading was ignored in the initial design and detailing of the structure.

Retrofitting means strengthening later. Strengthening an RC element may be defined as an intervention to increase the original strength and stiffness of the RC element (Júlio et al., 2003). It is intended to provide not only increased strength, so as to prevent collapse, but also increased stiffness and ductility to give increased protection against damage to non-structural building components (Sugano, 1981).

Therefore, retrofitting refers to modifying a structure, which means making changes to the systems inside the building or even the structure itself at some point after its initial construction and occupation. Apart from improving the performance of the building, retrofitting is also done with the expectation of improving amenities for the building's occupants ("Reducing Carbon Footprint", 2016). It reduces the vulnerability of damage to an existing structure during/ after recent earthquake or during the event of future earthquake. The steps encompass condition assessment of the structure, evaluation for seismic forces, selection of retrofit strategies and construction (Sengupta, n.d., para. 1).

The need for retrofitting arises due to any of the following reasons: (1) building not designed to code, (2) subsequent updating of code and design practice, (3) subsequent upgrading of seismic zone, (4) deterioration of strength and aging (5) modification of existing structure (6) change in the use of the building, etc. (Handbook on Seismic Retrofit of Buildings, 2007). Factors like economy, aesthetics, architectural identity and duration

of project determine whether or not retrofitting should be opted. The cost of retrofitting should not exceed 35 % of the cost of reconstructing the building.

Various Indian Standard codes were used as per the requirements in the retrofitting analysis works. Majorly the codes used were IS 15988: 2013 Seismic Evaluation and Strengthening of existing Reinforced Concrete Buildings, IS 1893: 2002: Criteria for Earthquake Resistant Design Structures, IS: 875 (Part I, II)-1987: Code of Practice for Design Loads for Buildings and Structures and IS 456: 2000: Code of Practice for Plain and Reinforced Concrete.

2. Building Assessment

The performance of building is to be accessed in order to determine the safety of existing structures against various loads including earthquake load. Visual inspection is the most important tool in the study of the actual condition of a building. Study of drawings is another source of information. A systematic seismic evaluation is needed to determine whether a building requires retrofitting or not. Evaluation is required to estimate the strength of the existing structure, so that the need, extent, strategy and system of retrofitting can be decided. So the existing building was accessed for determining its present condition (Singh and Paul, 2006).

2.1 Rapid Visual Assessment

Initially, the Rapid Visual Assessment (RVA) was carried out for the seismically vulnerable library building to identify if the building requires further evaluation for assessment of its seismic vulnerability. RVA is designed to be implemented without performing any calculations. RVA was used to assess the seismic damageability (structural vulnerability) of the building and seismic rehabilitation needs. The purpose of the Rapid Visual Assessment (RVA) was also to determine the adequacy of the structural facility to withstand the expected earthquake (Singh and Paul, 2006a).

Rapid visual assessment showed structural failure of large numbers of columns; clearly evident by shear cracking, concrete spalling and exposure of longitudinal reinforcements. The building was damaged severely by frequent earthquakes and aftershocks. The main reasons adding to the structural failure of the building were soft storey effect, captive and short column effect, pounding effect, brick cladding, irregular load path and excessive load in the roof.

Rapid Visual Assessment was done as per the MSK Intensity Scale as well as The New European Intensity

Scale. The following evaluation was done in order to determine the recommended action for strengthening the building:

- *Seismic zone V*- MSK Intensity IX or higher
- *Reinforced Concrete Frame type*: C
- *Grade of damage to building*: Many(15 ± 5) to (55 ± 5 %) of grade 3
Few (15 ± 5 %) % of grade 4 (rest of grade 2)
(Singh and Paul, 2006b).

According to the relationship between seismic zone, building type and damage grade; it was recommended to evaluate in detail for the need of retrofitting.

2.2 Detailed Vulnerability Assessment

A detailed evaluation was made for the library building as it was found deficient in initial assessment. The performance of the building was evaluated with regard to strength and ductility.

Detailed analytical method evaluates the damage on the basis of energy capacity of the structure and expresses as percentage of total damage on a Storey-by-Storey basis. Forces resulting from elastic analysis demand of the building were compared with strength (Capacity) to provide a demand-capacity ratio (DCR) for actions at different parts of the structure (**Table 1**). In its simplest form, a ratio greater than 1 implies failure (Priestely et al., 1996).

Table 1. DCR check for different components of the structure.

Check	DCR	Remarks
Moment of Resistance of beam in hogging	0.39	Check satisfied
Moment of Resistance of beam in sagging	0.47	Check satisfied
Beam Shear Capacity	0.78	Check satisfied
Column Flexural Capacity	2.48	Check not satisfied
Column Shear Capacity	0.71	Check satisfied

Since only column flexural capacity does not satisfy the check (>1); columns had to be retrofitted.

3. Structural Analysis

Structural modeling of the building was done using a general purpose finite element program (FEM) SAP 2000.v16 (Computer and Structures, Inc. (Structural and Earthquake Engineering Software, 2015).

FEM is the dominant discretization technique in structural mechanics for dividing a complex problem into

small elements through mesh generation techniques. The basic concept in the physical interpretation of the FEM is the subdivision of the mathematical model into disjoint (non-overlapping) components of simple geometry called finite elements or elements for short. The response of each element is expressed in terms of a finite number of degrees of freedom characterized as the value of an unknown function, or functions, at a set of nodal points ("Introduction to Finite Element Modeling", n.d., para. 2).

Creation and modification of the model, execution of the analysis, checking and optimization of the design and its display were all done through this sophisticated, intuitive and versatile user interface. The following analysis procedure was followed:

- 1) First step included setting up geometry to assigning restraint, including defining material and members, section properties, assigning members, defining load cases and assigning load magnitudes (**Fig. 2**).
- 2) In second step, the model was run on defined load combination(s) using model analysis method. This was the solving step.
- 3) In the third step, the main options were displaying the deformed shape (**Fig. 3**), the member forces (**Figs. 4 and 5**), bending moments (**Fig. 6**) and torsion; printing the results; designing the structural members and checking the safety of a design and lastly, modifying the structure if needed.

Following were the input parameters for simulating the building model in SAP2000.

Material Properties

Concrete: M15

Steel: Fe415

Section Properties

Restraint: Fixed

Column: Square (240*240)

Rectangular (360*240)

Plinth Beam: 240*400

Floor Beam: 240*600

Slab: Thickness 100 mm

Masonry Infill wall: Exterior (360 mm)

Interior (240 mm)

Diaphragm: Rigid

After modelling the building, 13 load combinations considering Dead Load (DL), Live load (LL), earthquake force in X-direction (EQ_x) and earthquake force in Y-direction (EQ_y) were defined (As per IS 1893 (Part 1):2002 Clause 6.3.1.2). The model was run on defined

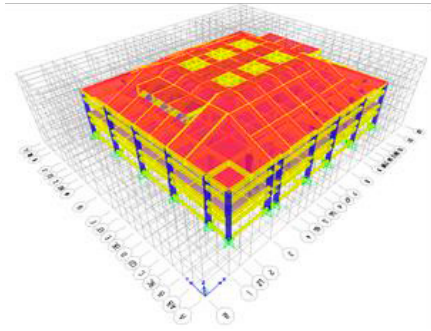


Fig. 2. 3D Model of building for analysis in SAP.

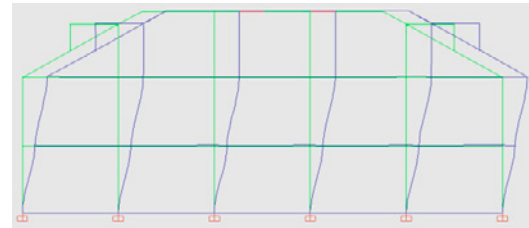


Fig. 3. Deformed shape at XZ, Y=27m, Axis G-G. Load combination: EQx. (SAP 2000 v.16).

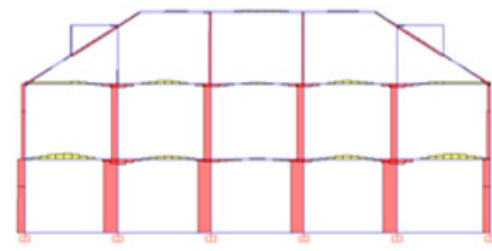


Fig. 4. Axial Force diagram at XZ, Y = 27m, Axis G-G. Load combination: 1.5D.L +1.5L.L.

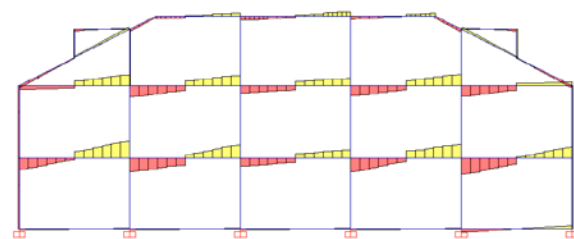


Fig. 5. Shear Force diagram at XZ, Y=27m, Axis G-G. Load combination: 1.5D.L +1.5L.L (SAP 2000 v.16).

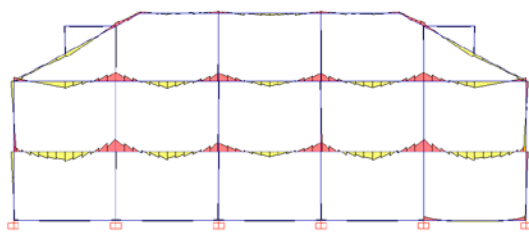


Fig. 6. Bending Moment diagram at XZ, Y=27 m, Axis G-G. Load combination: 1.5D.L +1.5L.L. (SAP 2000 v.16).



Fig. 7. Cracks seen in masonry infill wall.

load combinations. The deformed shape, axial force, shear force and bending moment as shown in **Figs. 3, 4, 5** and **6** respectively were then displayed under the defined load combinations.

The structure was analyzed under envelope type load combination which superimposes the maximum moment, shear, axial, and torsional response on a single design process from all the load combinations (Abell, 2012). The performance of structure was determined by the demand/capacity ratio (D/C) or PMM ratio. It is the sum of the axial force demand/capacity ratio and the bending moment demand/capacity ratio (Whittle et al., 2012).

4. Seismic Analysis

During rapid visual assessment of the building, large numbers of cracks was seen in masonry infill walls and some columns had undergone structural failure as well.

During detailed analysis in SAP2000, 142 columns out of 168 columns failed which is 84.5 % of total columns.

Figures 7, 8 and **9** show both structural and non-structural damages as seen in the building.

The seismic analysis of building was performed to determine the fundamental natural period of vibration (T_a), base shear and lateral force.

The approximate T_a , in seconds, of a moment-resisting frame building without brick infill panels was estimated by the empirical expression:

$$T_a = 0.075 * h^{0.75} \text{ for RC frame} \quad [1]$$

(IS 1893(Part I); 2002 Clause 7.6.1).

where, h is the height of the building.

The times period of the building was calculated as 0.5341 seconds.

Seismic Coefficient method basically consists of calculation of base shear V_b , given by the following equation:

$$V_b = \alpha_h * W \quad [2]$$

$$\alpha_h = \frac{Z}{2} * \frac{I}{R} * \frac{S_a}{g}; \frac{I}{R} \leq 1.0 \quad [3]$$

(IS 1893 (Part I): 2002 Clause 6.4.2)

where,

V_b = Base shear

α_h = Design horizontal seismic coefficient

Z = Zone factor for MCE (maximum Considered Earthquake) condition given in IS 1893 (Part 1): 2002, Clause 6.4.2 Table 2.

R = Response reduction factor given in IS 1893 (Part 1): 2002, Clause 6.4.2 **Table 7**.

S_a = Spectral acceleration depending upon the period of vibration and damping as given in IS 1893 (Part 1): 2002.

g = Acceleration due to gravity.

I = Post disaster importance factor depending on the life and function of the structure, historical value or economic importance as given in IS 1893 (Part 1): 2002

Table 6.

W = Total Seismic weight
(Shah et al., 2005)

The value of S_a/g is obtained from the graph below:

(Site dependent design spectra modified from (Seed *et al.*, 1976) and specified by ATC-3 (Dobrey et al., 2000)).

where,

S1= Rock, or Hard Soil

S2=Medium Soil

S3=Soft Soil

The value of S_a/g is obtained from the graph (**Fig. 10**).

The value depends on time period (T) and soil type.

Assuming Medium Soil,

Assuming Nepal lies in zone V, $Z=0.36$

$I=1.5$

$S_a/g=2.5$ for $T_a=0.5355$ sec

For existing building:

For reinforced frame, $R=3$

$\alpha_h=0.225$

$V_b=0.225*16729.227=3764.076$ kN

For retrofitted building:

For reinforced frame, $R=5$

$\alpha_h=0.135$

$V_b=0.135*17360.993=2343.734$ kN

After calculating the base shear V_b , the distribution of earthquake force on different floors was determined as follows:

$$Q = \frac{W_i * h_i^2}{\sum (W_i * h_i^2)} * V_b \quad [4]$$

Table 2. Calculation of Storey Shear.

Building Status	Weight(W_i) kN	Lateral Force (Q_i) kN	Storey Shear kN
Before retrofitting	16729.227	3764.076	3764.076
After retrofitting	17360.993	2343.734	2343.734

Table 3. Inter-Storey Drift of Existing Building.

Storey	Displacement (mm)	Storey Drift (mm)
Roof	49.43	0.34
2nd floor	49.09	24.72
1st floor	24.37	24.37
Plinth	0	0

Maximum drift= 24.72 mm

Maximum drift permitted= $0.004*4200=16.8$ mm (Not O.K.)

Table 4. Inter-Storey Drift of Retrofitted Building.

Storey	Displacement (mm)	Storey Drift (mm)
Roof	11.18	0.13
2nd floor	11.05	5.08
1st floor	5.97	5.97
Plinth	0	0

Maximum drift= 5.97 mm

Maximum drift permitted= $0.004*4200=16.8$ mm (O.K)

(IS 1893(Part I): 2002 Clause 7.7.1)

where,

I = from 1 to n

n = number of storey in the building at which the mass is located

Q_i = Horizontal force acting at any floor i .

W_i = Weight of i^{th} storey assumed to be lumped at i^{th} floor.

h_i = Height of the i^{th} floor from the base of frame.

The design storey shear in any storey is distributed to the various elements of the vertical lateral force resisting system in proportions to their rigidities considering the rigidity of the diaphragm (**Table 2**), (Shah, 2005).

Inter-story drift of building structures is defined as relative translational displacement between two consecutive floors (GB50011, 2010). The joint displacement for each storey was obtained from SAP2000 v.16 under the action of lateral load due to earthquake is listed in tabular form and storey drift is computed (**Tables 3** and **4**). The maximum drift calculated is checked with maximum permitted displacement ($0.004*h$) to ensure lateral stability of the

Table 5. Need for Retrofitting according to PMM value.

P	M2	M3	PMM Ratio	Status
31.43	0.20	12.53	0.13	<1;OK
151.20	58.37	130.70	2.60	>1;not OK

Table 6. Results (column size 240*240).

	Size	A _s	PMM ratio	Remarks
Before Retrofitting	240*240	2060.88	3.5	>1(not ok)
After Retrofitting	440*440	4629.164	0.7	<1(ok)

building (As per IS 1893 (Part I); 2002 clause 7.11.1).

5. Retrofitting

Considering the architectural, aesthetics, functional and economic aspects of the building retrofitting was proposed as a viable option for strengthening it.

During SAP2000 analysis columns were identified to have failed in flexure. Reinforced Concrete Jacketing as per the guidelines provided by the code *IS 15988:2013* was, therefore, proposed for strengthening these columns.

Jacketing was carried out by the addition of concrete layers, longitudinal bars and closely spaced ties. It increases flexural strength, shear strength and ductility of the column as well as provides increased seismic capacity of the moment resisting framed structure. (Waghmare, 2011). The cross-section of the column was increased by providing a jacket of minimum thickness 100mm on each side (**Fig. 10**). The concrete strength in jacket was 20 MPa; greater than existing by 5 MPa [As per IS15988: 2013]. The column with increased cross-section was subjected to further analysis in SAP2000 until PMM ratio was within safe limit. A member with PMM value greater than one was indicated as an overstressed member and required retrofitting (**Table 5**).

The area of longitudinal reinforcement to be provided for PMM ratio to be within safe limit after increasing the column cross-section was obtained from SAP2000. The area of steel in existing section was then subtracted from this area to obtain the longitudinal reinforcement which was to be provided in jacket. The area of concrete and steel obtained in jacket were then increased by 3/2 and 4/3 respectively to account for losses. (As per IS 15988: 2013 Clause 8.5.1.1)

Closely spaced transverse reinforcement was provided in the jacket to increase the shear strength and ductility of the column.

From IS 13920:1993 the design shear force for columns was taken maximum of

- Calculated factored shear force as per analysis
- Factored shear force given by (**Fig. 11**)

Determination of spacing of lateral ties:

As per Clause 7.3.3 IS 13920:1993

- The spacing of hoops shall not exceed ½ the least lateral dimension of the column.
- Least lateral dimension = 440mm
So, the spacing shall not exceed 220mm.

As per IS 15988:2013

$$\text{Spacing of ties(s)} = \frac{f_{ck}}{\sqrt{f_y}} * \frac{d_h^2}{t_j} \quad [5]$$

where,

f_y = yield strength of steel,

f_{ck} = cube strength of concrete,

d_h = diameter of ties, and

t_j = thickness of jacket.

t_j = 100mm

Therefore, s = 90 mm

For columns where extra longitudinal reinforcement is not required, a minimum of 12φ bars in the four corners and ties of 8φ @ 100 c/c were provided with 135° bends and 10φ leg lengths (**Fig.11**).

Table 6 shows results for column size 240* 240. The cross-section of the column after retrofitting is shown in **Fig. 12**. The size, area of steel (A_s) and PMM ratio of the column before and after retrofitting were compared on the basis of analysis performed in SAP2000.

Before carrying out jacketing the surface preparation of the existing columns was done by treating, roughening and cleaning. Bonding between old and new material and transfer of forces to new reinforcement was ensured by proper connector arrangement (**Fig. 13**). For increased flexural strength the rods for jacketing were connected in the beams by welding and drilled at least 6 inches into the foundation (**Fig. 14**).

During visual assessment cracks were seen in masonry infill walls. Therefore, wall repairing was carried out along with column jacketing. The walls with diagonal shear cracks were demolished as they were liable to collapse from the confining frame under the action of vertical load. Cement-sand grouting was done in parts where cracks do not span a long distance. In parts where cracks of greater depth and larger distance were detected grouting was carried out along with net plastering (**Fig. 17**).



Fig. 8. Concrete spalling and exposure of reinforcement in column..



Fig. 9. Cracks in column and adjoining masonry infill wall.

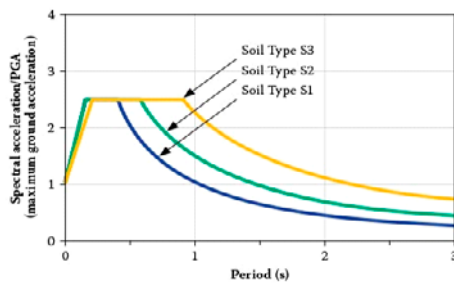


Fig. 10. Response Spectra for Rock and Soil Sites for 5 % Damping.

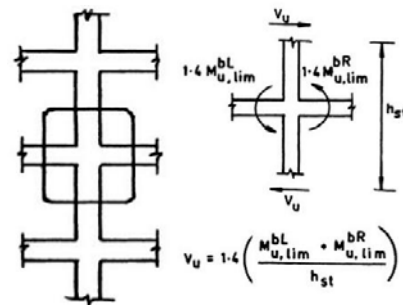


Fig. 11. Calculation of design shear force for column (Durgesh et al., 2005).

[As per IS 15988: 2013 Clause 8.5.1.2]

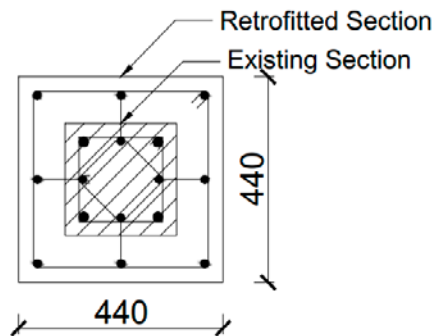


Fig. 12. Cross-section of retrofitted column.

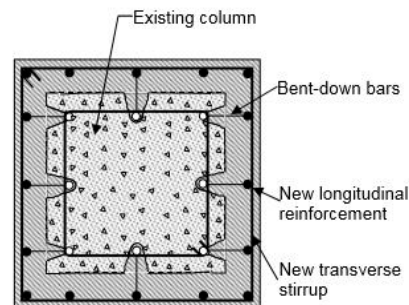


Fig. 13. Reinforcement bars and connector arrangement (IS 15988:2013).

Figure 18 shows plan of first floor of Kathmandu University Central Library. All the columns were observed failed after the model analysis done in SAP2000 v.14. These columns underwent flexural failure. Therefore, reinforced concrete jacketing was proposed as a viable solution for strengthening these columns. There were four types of columns (**Fig.19**):

- i. 240*240
- ii. 240*360
- iii. 360*360 (central column)
- iv. Hexagonal column

Before Retrofitting:

Since, the analysis showed the cause of failure was due to insufficient dimension of columns, the dimension

of all columns were increased by 100mm as per the code (IS 15988:2013).

After Retrofitting:

The required reinforcement was calculated as explained earlier and the arrangement of reinforcement is shown in **Fig. 20**.

6. Concluding remarks

This building housed in KU served an important function as central library of the university before Gorkha Earthquake of April 25, 2015. The foremost priority of the university was to strengthen this building as it was severely

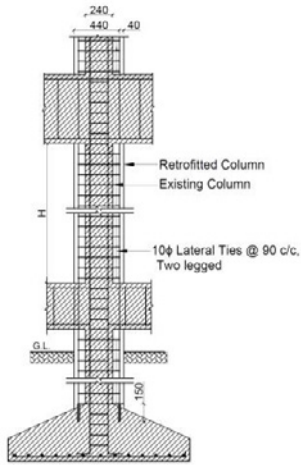


Fig. 14. Longitudinal section of Retrofitted column.



Fig. 15. Concrete jacking of Column, Kathmandu University Central Library, Dhulikhel.



Fig. 16. Concrete jacking at Beam-Column joint, Kathmandu University Central, Dhulikhel.



Fig. 17. Retrofitting of wall by net plastering and grouting.

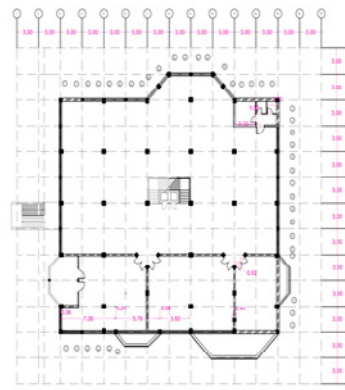


Fig. 18. First Floor Plan of Central Library.

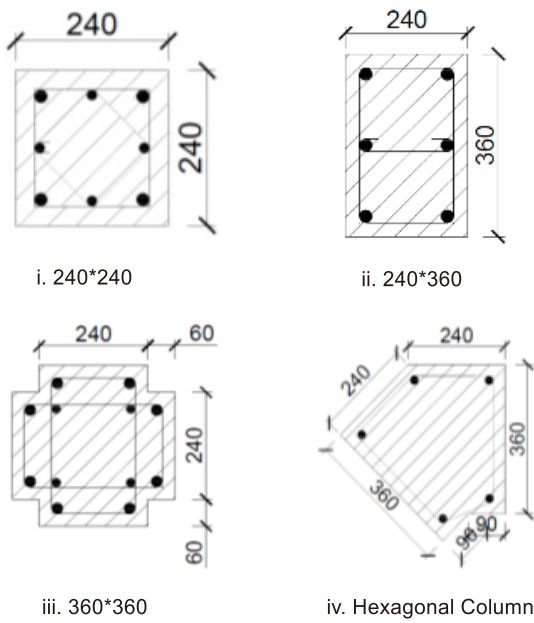


Fig. 19. Columns before Retrofitting.

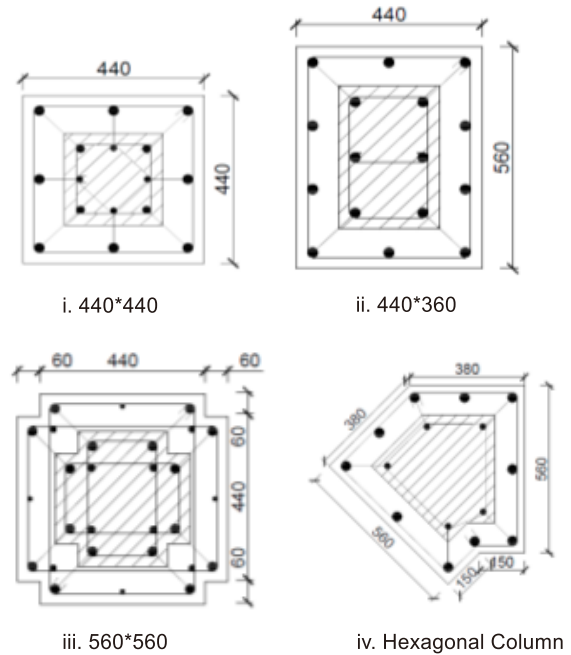


Fig. 20. Columns after Retrofitting.

damaged during the earthquake. The necessity to make the building functional again led to the preliminary surveys, discussion, and consultation; eventually producing the final data required for the retrofitting of this building.

The building underwent structural and functional failures in the event of earthquake because it was constructed without prior consideration of lateral forces and encompassed several deficiencies from structural view point. Therefore vulnerability of any structure to earthquake risk can be reduced by consideration of lateral forces during design. Proper load path should be defined and irregularities should be avoided. Retrofitting approach can also be effectively employed to strengthen the structures which were originally designed with old codes, structures deficient in design and construction and structures which are rendered weak during past earthquakes.

Retrofitting was proposed after the occurrence of earthquake as part of damage mitigation to make the KU Central Library building fit for its intended use. Rapid visual assessment followed by detailed analysis using SAP2000 led to the identification of failed members in the building and established the need for retrofitting.

All the columns of ground floor were found deficient in flexure during analysis, so all columns were retrofitted by reinforced concrete jacketing so that it was able to carry out its intended function (**Figs. 15** and **16**). For this purpose, guidelines for seismic evaluation and strengthening of existing reinforced concrete structures provided by Indian Standard Code IS 15988:2013 were followed. Similarly, the cracks in the wall were repaired by net plastering and grouting. Structural members like beams and slabs, if found failed, could also be retrofitted by considering viable retrofitting options.

Acknowledgement

The authors of this paper want to express their gratitude to the Centre for Educational Design (CED) for providing access to necessary documents.

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RVA	Rapid Visual Assessment
MSK Scale	Medvedev-Sponheuer-Karnik Scale
DCR	Demand Capacity Ratio
SAP2000 v.16	Structural Analysis Program 2000 version16
MCE	Maximum Considered Earthquake
MPa	Mega Pascal
DL	Dead Load
LL	Live Load
EQ _x	Earthquake Force in X-direction
EQ _y	Earthquake Force in Y-direction
FEM	Finite Element Model

Abbreviations

KU	Kathmandu University
OMRF	Ordinary Moment Resisting Frame
IS	Indian Standard
M _w	Moment Magnitude
RC	Reinforced Concrete