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ECONOMIC FEASIBILITY ASSESSMENT OF SESIMIC RETROFITTING OF HEALTH FACILITIES – CASE STUDY FROM UTTARAKHAND, INDIA

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Abstract

As per Indian codes and guidelines, retrofitting is recommended when total cost of retrofitting is within 50% of reconstruction. This paper discusses the factors needed for seismic retrofitting, the procedure adopted to quantify factors and finally apply Benefit-Cost Analysis (BCA) adopting Net present Value method for the economic feasibility of the seismic mitigation options. This checks the feasibility for seismic retrofitting investment. To validate the proposed methodology, health facilities in various districts of Uttarakhand, India are considered.

Quantity is estimated from the designed retrofitting options. Outcome showed the retrofitting versus reconstruction ratios varies between 0.31 to 1.64. However, for most facilities ratios are falling between 0.50 to 0.65. This paper discusses the reasons and factors for this variation in masonry structures. Hence, there is a need to conduct BCA to arrive at a judicious decision to opt for retrofitting or reconstruct option. The economic feasibility depends on the estimation of tangible and non-tangible losses. The loss estimation, however depends on wide range of factors and parameters. This paper discusses and compares the methodologies for estimating the tangible and intangible losses in context with the masonry health structures. This is being analyzed through the comparison of two similar buildings: with and without retrofitting measures, for the life of the building. Further, the comparison is made to project the benefit to cost involved in the retrofitting. The paper will detail the results of economic feasibility and present same with facts and figures. The challenges and opportunities are further reflected with conclusion.

Keywords: Uttarakhand State; Benefit-Cost Analysis; Masonry Structures; Net Present Value

1. Project Background

State of Uttarakhand is located in high to very high seismicity areas corresponding to seismic zones IV and V [1]. To address the mitigation of their lifeline buildings, the Government of Uttarakhand conducted an extensive exercise of Rapid Visual Screening (RVS). 11,239 lifeline government buildings comprising of 18,835 units spread across all thirteen districts in the state were surveyed [2]. From the surveyed buildings, they identified 90 hospital buildings comprising of 150 units for conducting a simplified vulnerability assessment (SVA) followed by detailed vulnerability assessment (DVA) to design the seismic retrofitting scheme.

The 90 hospital buildings comprised of 16 RC frame structures and 134 masonry structures. This study concentrates on the 134 masonry buildings. Seismic retrofitting scheme was designed using Splint and Bandage strengthening technique as per [3] and Jacketing with stainless steel wire mesh and mortar. The cost of retrofitting was worked out for all buildings. It was found that ratio of cost of retrofitting to new construction cost varied between 0.31 to 1.64. However, for most buildings this ratio was found to lie within 0.5 to 0.65. The guideline [4] mentions that for critical & lifeline buildings, the cost of retrofitting should preferably be less than 0.5. Hence, a need for carrying out economic feasibility arose.

Implementation of any retrofitting project will depend upon its economic feasibility. Accordingly, a Benefit-Cost Analysis (BCA) is required. All tangible and intangible losses associated directly or indirectly with the execution of seismic retrofitting activities is worked out. The benefits include savings from damage reduction and losses saved due to the seismic retrofitting. The investment corresponds to the cost of retrofitting. Thereafter using any of the three established methods: (i) Net Present Value (NPV); (ii) Internal Rate of Return (IRR); or (iii) Benefit Cost Analysis (BCA), the economic feasibility can be worked out.

Under current study, economic feasibility study for 10 sample buildings located across nine districts has been carried out. The samples were selected randomly so that they represent varying features and material of construction. Net Present Value (NPV) as given by FEMA 227/228 was used to determine the economic feasibility of seismic retrofitting.

2. Methodology

The approach steps in brief includes, data collection, building model simulation, vulnerability assessment, retrofitting scheme design, estimate corresponding cost of retrofitting, new construction cost for similar size and material of construction, damage and loss assessment. Finally, the benefits using the Benefit Cost Analysis method was followed to arrive at the economic feasibility for the buildings. Net Present Value (NPV) method given in FEMA 227/228 is modified as per local conditions to arrive at the economic feasibility of the retrofitting project. Figure 1 shows the flowchart of detailed methodology.

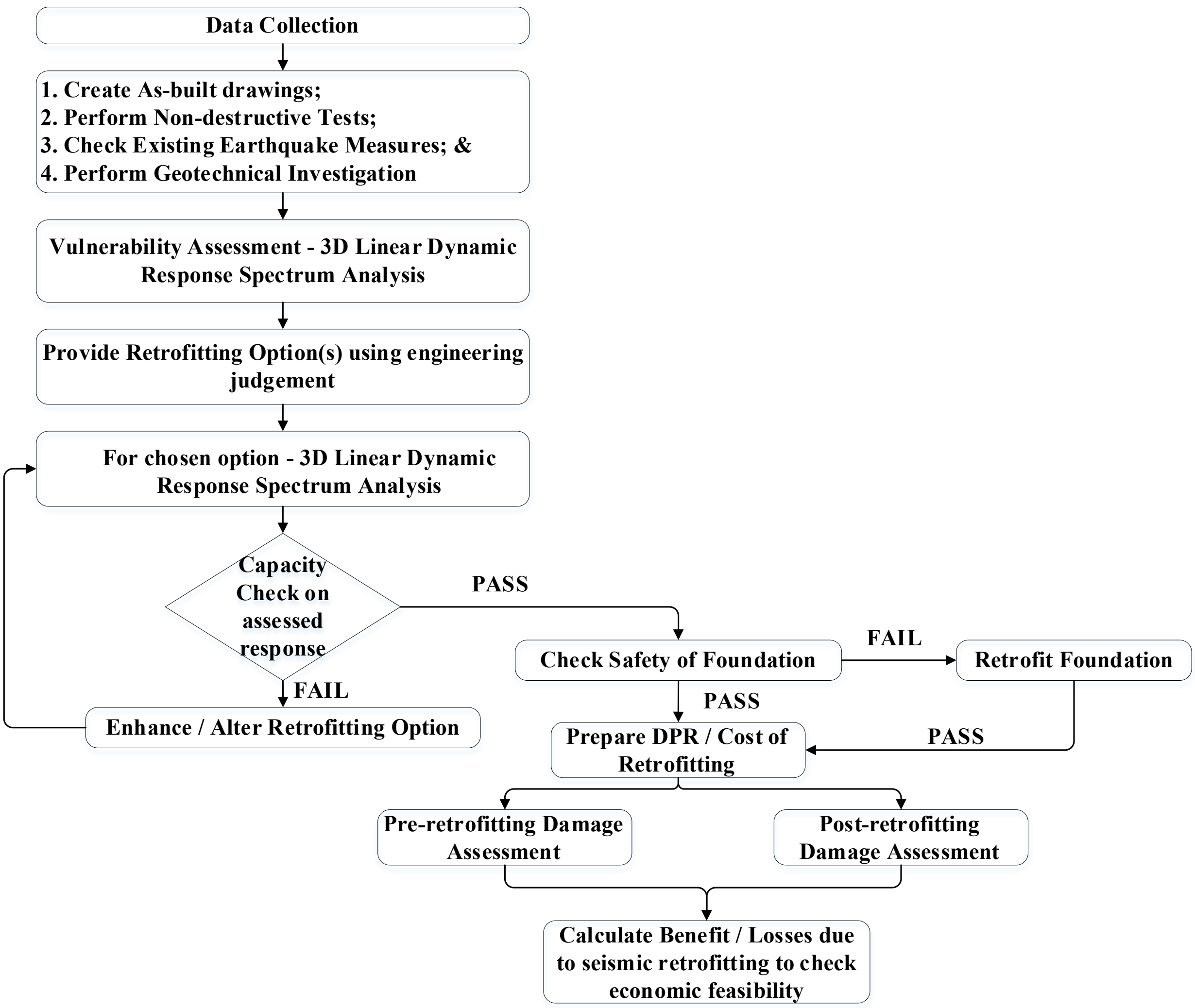


Fig. 1 – Methodology Flowchart

Data pertaining to as-built condition, existing material properties and founding soil properties were collected from site survey and testing. Building model was simulated using the above properties and vulnerability assessment carried out. A suitable seismic retrofitting scheme using splint & bandage strengthening technique [3] and jacketing was designed and incorporated in the model. Response Spectrum Analysis of the retrofitted model was carried out to check the building to be within permissible limits. Thereafter, the foundation was checked and if found deficient, retrofitting by increasing the width of the footing up to maximum allowable limits was designed. Estimation of cost of retrofitting and new construction, was computed using the Central Public Works Department (CPWD)-Schedule of Rates [8] and Plinth area rates [9], respectively. Appropriate cost index was applied over them as per the directive of the State Government Engineering Department. Due to limitation of data, the pre-retrofitting damage cost ratios was obtained from a similar study [5] wherein similar typology buildings were studied. The post retrofitting damages was worked out on basis of sound engineering judgement and calculations. The degree of damage post-retrofitting was based on judgmental rationale whereas the cost of repairs on unit area basis was worked out using rate analysis method. Casualty was estimated as per formulation and percentages estimated in a similar study [6]. However, the gratuitous relief (monetary compensation) figures were referred from document of Fourteenth Finance Commission (FFC), Government of India. It is obvious that due to damages facilities will be non-operational. This will require the operation to relocate and rent the safer building. The rental payment will be considered as financial losses. Rental losses were calculated on unit area basis rates obtained from State Engineering Department while the period of loss of function was obtained from well established Hazus model [7]. Furthre the Asset losses will arised due to strutcural and non-structural damages. The asset loss are calcauted by using Hazus model with modified parameters [7].

The Benefit Cost Analysis was carried out by estimating the benefits accrued from savings in damage in pre and post conditions, casualty losses, rental losses, relocation losses and Asset losses. Net Presnet Value model has been used to asses sthe economic feasibility. Accordingly, the NPV was obtained by subtracting the costs from the total benefits. Postive NPV indicates that the project is feasible whereas negative NPV relates to non-feasibility. The benefits accrued were then accounted for over a discount rate equal to 2.5% for 3, 5 and 10 years. NPV was calculated using same discount rate using above formula i.e. (total accrued benefits – investment) to check the economic feasiblity over longer periods of time. The detailed procedure and result are explained below.

3. Data Collection

For simulating the building model, it was a pre-requisite to obtain the existing building dimensions and material properties. Hence, data collection involved creation of as-built drawings after physically measuring the dimensions of the structure on site. Non-destructive tests such as rebound hammer test and ultrasonic pulse velocity test were carried out to characterize the building parameters. Simultaneously, semi-destructive tests to identify the presence of earthquake strengthening measures such as bands, etc. were carried out. Masonry units and mortar samples were collected and tested in reputed laboratories. Geotechnical investigation to get the founding soil properties were carried out. The results of these tests were used in conjunction with IS 1905:1987 [10] and IS 1893(Part 1):2016 [1] to calculate the existing material properties.

For carrying out the economic feasibility study, the relevant central and state documents and data were procured. For items not covered in the schedule of rates, rate analysis in prescribed State Government format using market rates was done. Hence, minimum three quotations from different vendors were obtained to establish the new item rates. The rental on unit area basis was obtained from the State government engineering department Officials.

Fig. 2 – Hospital Buildings in Lalkuan, Nainital and Kota Muradnagar, Haridwar

4. Vulnerability Assessment

Data collected was compiled. It was found that most of the masonry buildings were single or double storied. Roofs of most buildings located at higher altitudes had flexible diaphragm whereas rigid diaphragm was found for buildings located in the plains. The geometric and material properties was used to simulate the models on commercial software platform ETABs. Response Spectrum Analysis as per IS 1893(Part 1):2016 was carried out for the earthquake forces corresponding to Design Basis Earthquake. Target performance level was kept as Life Safety. Failing members were identified. For walls with openings less than 50%, splint and bandage strengthening technique as mentioned above was used whereas for load bearing walls where the total opening size was more than 50% of the wall area, jacketing was provided. Stainless steel wire mesh covered in cement mortar was used in both the techniques. Fig. 3 below shows the splint and bandage strengthening technique. The modified retrofitted model was again subjected to 3D analysis. If any failure was observed, the splint and bandage width was increased. This process was repeated until entire superstructure was found to be within permissible limits. Thereafter, the footing was checked for safety for the corresponding soil properties obtained from the geotechnical investigation and laboratory test of the soil samples. If the footing was found to be failing, retrofitting of the footing was carried out by increasing the width of the footing within maximum allowable limits.

Non-structural appendages and elements were checked for their respective forces and indigenous design prepared for their stability against overturning and sliding in case of any seismic event. Finally, the retrofitting drawings were prepared and estimate of the structural and non-structural appendages and elements cost of retrofitting computed.

During site inspection, it was observed that almost all buildings were affected by damping, corrosion of reinforcement, growing vegetation, etc. Accordingly, cost for repair and rehabilitation was also computed as a percentage of cost of construction and included in the cost of retrofitting to arrive at a final figure.

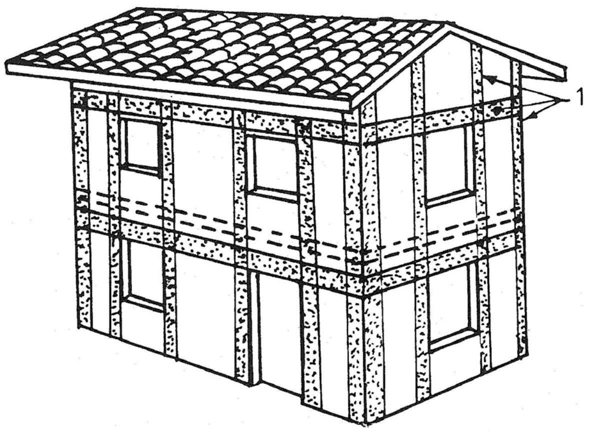


Fig. 3 – Splint & Bandage Strengthening Technique [3]

5. Benefit Cost Analysis

To check whether the retrofitting scheme was viable as per the guideline limiting the cost of retrofitting to be within 50% of cost of new construction, the new construction cost was estimated. The ratio was computed and found to be mostly above 50% limit specified. Hence, FEMA 227/228 [11,12] was referred to for computing the parameters required to compute the benefits and the losses for checking the economic feasibility. The pre and post-retrofitting damage cost was computed followed by Casualty loss estimation. Thereafter, the rental and relocation losses which are considered to be the same in this study were estimated. Finally, asset loss was calculated. Lastly, salvage value of 20% of new construction cost was assumed based on prevailing practices and computed. The ensuing subsections share the details for calculating each parameter.

5.1 New Construction Cost Estimation

Cost of new construction was computed using the CPWD Plinth area rate [9] basis multiplied with suitable cost index applicable to the local area. Care was taken to include all similar parameters as found in the existing building.

5.2 Pre and Post Retrofitting Damage Assessment

The building typoogy is classified based on AKDN Typology[5]. Similar typology masonry buildings were studied in detail[5]. For each building classified, a damage ratio due to its vulnerability under PGA equal to 0.25g was worked out and expressed as a percentage. The buildings under the current study were found comparable to SM-3, BM-3 and BM-4 category buildings. The corresponding damage ratio percentages for these category buildings was calculated as 84, 71 and 35.5 respectively. Hence, using these values the damage of the sample 10 buildings was computed. This corresponded to damage loss for pre-retrofitting condition.

For estimating the damage cost in post-retrofitting period, it was considered that the buildings would undergo different grades of damages as intensity increases. For intensity VI, slight damage closer to 5% of total wall area were consided; for intensity VII, moderate damage covering 15% of the total wall area; for intensity VIII, extensive damage would occur that would affect 25% of the total wall area and for intensity IX, extensive damage was assumed to affect 50% of the total wall area. The total wall length and height were calculated to obtain the wall area and corresponding to the intensities, the damage cost for post-retrofitting period was computed.

On obtaining both pre-retrofit and post-retrofit damage costs, the effectivness of the retrofitting was computed using the formulation in Eq. 1.

$$\text{Effectiveness of Retrofitting}=((\text{Damage Cost}_{\text{Pre-retrofit}} - \text{Damage Cost}_{\text{Post-Retrofit}}) / \text{Damage Cost}_{\text{Pre-retrofit}}) \text{x} 100 \quad (1)$$

5.3 Casualty Estimation

Eq. 2 and corresponding percentages for brick buildings following fatality ratio [6,13] is used for estimating the causalty losses. The parameters have been modified for current study. It is based on four parameters which are building population, occupancy at time of earthquake, the total trapped population during earthquake and the injury grade of the trapped occupants. The gratuitous charges are used from the the government circular. The monetary compensation figures [14] corresponding to each grade of injury is given in Table 1 below.

$$M = (M1 \text{ x } M2 \text{ x } M3 \text{ x } M4) \quad (2)$$

Where

M1	Building population
M2	Occupancy at time of earthquake
Occupancy during Day	40%
Occupancy during night	95%
M3	Trapped occupants
VI	Nil
VII	5%
VIII	30%
IX	60%
M4	Injury Category
Death	20%
Life threatening / Loss of limb	30%
Injury requiring hospitalization more than a week	30%
Injury requiring hospitalization less than a week	20%

Table 1 – Injury grade versus Monetary Compensation

Injury Grade	Gratuitous Charge
Death	INR 4,00,000
Loss of Limb	INR 59,100
Injury requiring hospitalization more than a week	INR 12,700
Injury requiring hospitalization less than a week	INR 4,300

5.4 Rental Loss

Rental loss is a function of the rental rates and non-functional period of the building. Accordingly, to compute the rental loss, an estimate of the days for which the building will be non-functional immediately after an earthquake until it starts functioning from another premises is required. Due to limitation of data, the loss of function is obtained from a document of FEMA for multi-hazard loss estimation Methdology [7]. For Hospital Buildings, the figures are shown below in Table 2. The rental rates were obtained from the state government. The total rental loss was obtained by multiplying the rental rate with area of subject building and the period non-functionality of the building as mentioned in Table 2. Eq. 3 below gives the formulation to compute the rental loss for a building.

$$RT_{Loss} = \text{Unit Area Rental Rate x Area of subject Building x LOF} \quad (3)$$

Table 2 – Loss of Function corresponding to damage level

Damage Level	Loss of Function (Days)
Slight Damage	10
Moderate Damage	45
Extensive Damage	180
Complete Damage	360

5.5 Relocation Loss

Relocation loss corresponds to the rental paid for renting of another premises till the building is fit for rehabilitation. For small buildings, as is in this case, the difference in loss of function period and repair period is negligible and hence can be considered same. Accordingly, the relocation loss is considered to be same as the rental loss.

5.6 Asset Loss

Asset loss corresponds to the loss of property due to collapse of buildings or portion of buildings during an earthquake. It is expressed as a percentage of the new cost of construction. It is based on an estimation based on asset loss observed in past earthquakes. The asset loss benefit in brick masonry buildings for varying intensities is obtained from [6] and shown in Table 3. Eq. 4 gives the formulation to compute the asset loss for a building.

Table 3 – Reduced Asset loss corresponding to the Earthquake intensity

Earthquake Intensity	Reduced Asset Loss (%)
VI	5%
VII	10%
VIII	15%
IX	20%

$$\text{Asset Loss} = \text{New Construction Cost x Reduced Asset Loss (Percentage)} \quad (4)$$

6. Benefit & Loss Computation

The total benefit accrued in a year is the sum of the difference between pre and post retrofitting damage cost, reduced casualty losses due to retrofitting, saving of rental and relocation losses and reduced asset loss plus a salvage value of the building at end of the period considered for building to be used in future. Eq. 5 shows the formulation to compute the Annual Benefits that accrue.

$$B_t = \sum_{M=VI}^{VIII} EAE^m \left[\sum_{t=1}^{N} \sum_{N=1}^{n} BD_{sf}^m + RT_{sf}^m + REL_{st}^m + PP \right] \quad (5)$$

Where:
EAE^m is expected number of earthquakes annually by Modified Mercalli Intensity ranging from VI-IX
BD_{st}^m is building damages avoided by social function and facility classes and MMI
RT_{st}^m is rental losses avoided by social function and facility classes and MMI
REL_{st}^m is relocation expenses avoided by social function and facility classes and MMI
PP is personal asset losses avoided by social function and facility classes and MMI
VDA_t is the annual value of expected deaths avoided by rehabilitating buildings to life-safety standards.

However, since investment is being made in present, hence, the benefits that would accrue each year till the end of the planned life of the building needs to be discounted to obtain all benefit accrued at present value. The same is obtained by formulation shown in Eq. 6. The annual benefits accrued is then used in Eq. 6 to compute the NPV which helps in deciding the economic feasibility of the building.

$$NPV = -INV + \frac{B_1}{1+i} + \frac{B_2}{(1+i)2} + ... + \frac{B_T}{(1+i)T} + \frac{V_T}{(1+i)T} + VDA_t\left[\frac{1-(1+i)^{-T}}{i}\right] \tag{6}$$

Where
i = Discount rate, for current study, it has been considered at 2.5%
t = planned use period in years. Planned use period has been considered for 1, 3, 5 and 10 years in this study.
B = Yearly Benefits as explained above. It is assumed to be constant for planned use period.
INV = investment i.e. cost of retrofitting

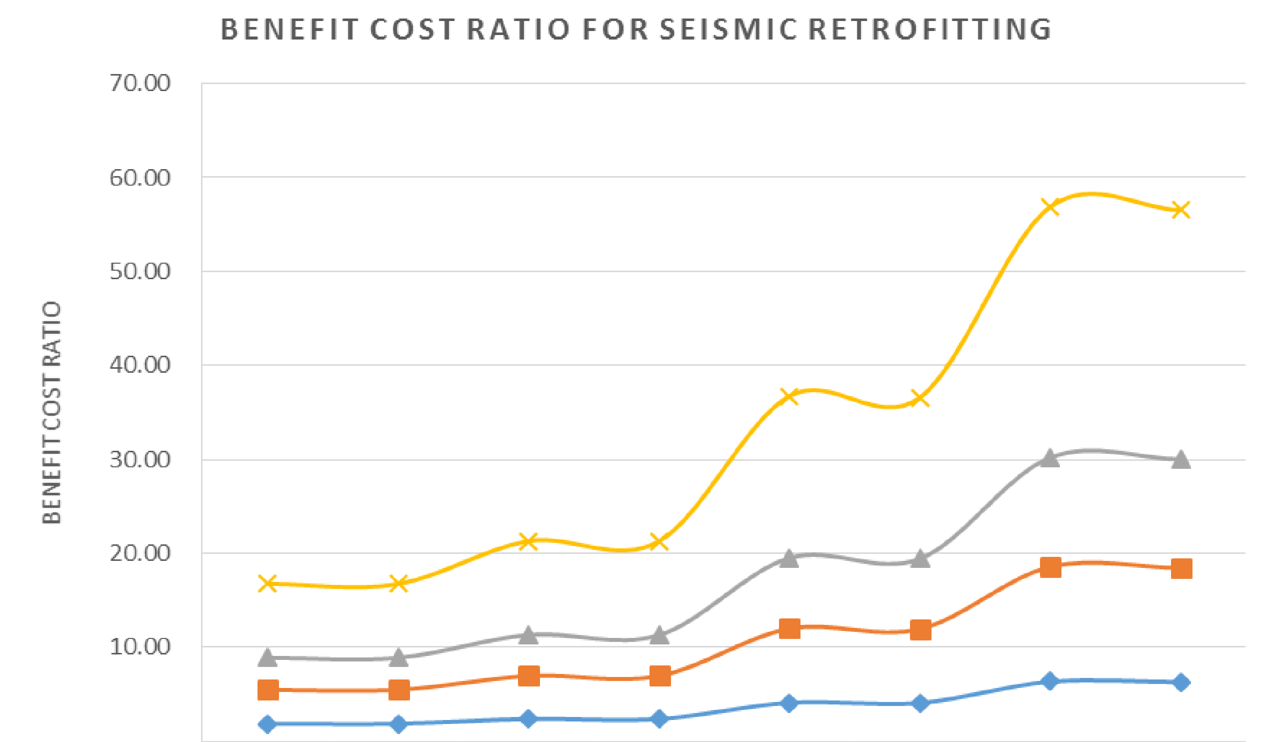
7. Analysis of Results

All buildings studied were found to be vulnerable and required seismic retrofitting. Without seismic retrofitting, these buildings can get distressed, develop cracks and even collapse. This could lead to trapping and killing many lives in the event of moderate to high earthquakes. Hence, the seismic retrofitting for buildings with varying differences in altitudes, construction features that are spread over a large área requires huge resources and time. Hence, Cost Benefit Analysis (CBA) which is a widely practiced tool in many countries can be used to assess the effectiveness of earthquake mitigation projects. This plays an important role in identifying the buildings with larger economic feasibility and aids in easy and cost effective decisión making.

Keeping the discount rate constant i.e. 2.5%, the number of years of planned use for the building was increased for 1, 3, 5 and 10 years. Table 4 shows the benefit cost ratio for one sample building that was studied. Figure 4 shows the tabular values in graphical representation.

Table 4 – Benefit Cost Ratio for fixed discount rate of 2.5% over varying use period of building

	1 yrs.	**3 yrs.**	**5 yrs.**	**10 yrs.**
BCR_{VID}	1.87	5.47	8.89	16.75
BCR_{VIN}	1.87	5.47	8.89	16.75
BCR_{VIID}	2.38	6.96	11.32	21.32
BCR_{VIIN}	2.37	6.95	11.30	21.29
BCR_{VIIID}	4.10	11.99	19.51	36.74
BCR_{VIIIN}	4.08	11.94	19.42	36.58
BCR_{IXD}	6.34	18.56	30.19	56.87
BCR_{VIXN}	6.30	18.45	30.01	56.53



	BCRVID	BCRVIN	BCRVIID	BCRVIIN	BCRVIIID	BCRVIIIN	BCRIXD	BCRIXN
1 yrs.	1.87	1.87	2.38	2.37	4.10	4.08	6.34	6.30
3 yrs.	5.47	5.47	6.96	6.95	11.99	11.94	18.56	18.45
5 yrs.	8.89	8.89	11.32	11.30	19.51	19.42	30.19	30.01
10 yrs.	16.75	16.75	21.32	21.29	36.74	36.58	56.87	56.53

Fig. 4 – Graph showing the Benefit Cost Ratio increment for longer use period of Building at constant discoutn rate of 2.5%

From Table 4 and figure 4, the following inferences were observed:

- From above graph, it is observed that the ratio of benefit to the investment i.e. the Benefit Cost Ratio (BCR) is above 1.0. This indicates that benefits outgrow investment from the first year. Hence, it can be concluded that the seismic retrofitting of the building would yield positive results and is an economically feasible project.
- For an earthquake intensity, as planning period is increased, the Benefit Cost Ratio increases exponentially. Similar increase pattern is observed for all earthquake intensities. From this we can conclude that with increase in planning period, the accrued benefits would increase exponentially with respect to the investment. Hence, longer planning period will yield better results of seismic retrofitting.
- For same earthquake intensity barring earthquake intensity VI, the BCR is slightly higher for day as compared to the night. This can be attributed to the higher number of building occupants due to higher OPD patients as compared to the fewer in-house patients during night.
- For similar planning period and increasing earthquake intensities, the BCR increases. This increase in BCR becomes larger as the planning period is increased. Such a behaviour suggests that if a building has been retrofitted, the benefits accrued when building is subjected to a higher intensity earthquake would yield better dividends as compared to benefits accrued from smaller intensity earthquakes.

8. Challenges Faced and Opportunities

8.1 Challenges

This work is a limited study. The multiple challenges faced during the course of this study is listed below:

- Precision of cost estimates is dependent on many judgemental factors and hence there is scope for increasing the precisión by decreasing the judgemental factors.
- Damage estimation is based on percentages of past similar studies that may vary for individual cases.
- Damage loss computation differs for each structure. In this study, it is based on data of previous earthquakes and hence leaving scope for further improvement.
- The cost and rate variation of materials, etc. is different for different áreas whereas, average values have been considered.
- Modelling of the building footing is done on limited data collection. Material properties are averaged and considered leading to slight variation in results.

8.2 Oppurtunities

Inspite of the challenges in this study, there was positive outcome too, which are mentioned as below:

- Fairly high values of BCR’s gives ample support in Policy Decisión making.
- However, for projects with BCR closer to 1.0 may need to be computed accurately rather than judgementally.
- This is a new área of work and further study in this área will give better, accurate and dependable results.

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