COST BENEFIT ANALYSIS OF EARTHQUAKE PROTECTION PROGRAMME THROUGH RETROFITTING OF NON-ENGINEERED BUILDINGS

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SUMMARY

Perhaps, this is rightly said that the "earthquake don't kill people; but the buildings do". In this context, particularly, the earthquake resistant technology, which is now being adapted all over the world, is particularly more relevant to the modern age disaster management for the building constructions. It is noteworthy, that there are still a good number of the living structures, which may not resist the earthquake shocks. No wonder many researchers are working in this field of seismic strength assessment: and methodologies have been developed for different types of building constructions. Their retrofitting against the seismic forces can further strengthen these building structures. It is noted that over 60 % of the people killed in the earthquake due to collapse of the masonry buildings. These buildings can be upgraded by various retrofitting techniques depending upon the materials and the characteristics of the buildings.

To reduce the seismic hazard in any area under the disaster protection plans there is a need for the fund allocation for the retrofitting programmes. However, to decide the priority and the amount to be allocated for retrofitting out of the total budget allocation of disaster mitigation programmes, there is the need for the assessment of the necessity and advantages of these programs. This could be achieved through the proper Cost Benefit Analysis of the retrofitting planning.

The Cost Benefit Analysis depends on the estimation of the tangible and non-tangible losses. The loss estimation, however depends on wide range of various factors and many other parameters. The objective of the paper is to present and compare the methodologies for estimating the tangible and intangible losses in context with the non engineered buildings. This is being achieved through the comparison of two similar buildings: one which is retrofitted ; and the other which is not retrofitted. The tangible and non-tangible losses for both the buildings are being estimated for the life of the building. Further, The comparison is made to project the benefit to cost involved in the retrofitted.

The outcomes of the work will bring out the indicators to be considered for the loss estimation and Cost Benefit Analysis in the developing countries. The effects of these indicators on the loss estimation and Cost Benefit Analysis will be projected with the help of a model by way of the studies of the above. The benefits will accrue in terms of the loss savings. The loss estimation model will become the data source for the Cost Benefit Analysis model. The result and the conclusion of the work will be focused in the final paper with the help of facts and figures.

INTRODUCTION

Social projects like Retrofitting of Existing Building need assessment because the government invests heavy amount for benefits of the people. There are various methods available to assess the viability of such projects. Those are Cost Benefit Analysis, Cost Effective Criteria and Acceptable Risk. The most commonly used method

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is Cost Benefit Analysis. Here the paper gives emphasis on assessment the benefits of retrofitting technique of typical Brick Masonry Buildings built with mud mortar.

The methodology includes the estimation of losses, which is catagorised in to tangible and intangible ones. The Tangible losses include direct structural and non-structural losses. The deaths, injuries to people caused by the earthquake come in intangible losses. Estimation of structural losses is one of the most important issue in earthquake damage assessment. The simplifies method i.e. Damage Probability Matrix (DPM) (Whitman.V. Robert, J.W. Reed, Hong, S.T, 1973) is applied for the calculation of damage to the structure as well as non-structural elements. As it is well known that, primary focus of the most earthquake protection programme is to save life. For loss estimation studies to be useful for earthquake protection; there is a need to include an assessment of the probable levels of human casualties both deaths and injuries which would be caused by the earthquake. It is notoriously difficult to estimate the same, but lots of attempts have been put in this area. The Lethality Ratio (A.W.Coburn, R.J.S.Spence & A. Pomonis, 1992) has been developed which can be effectively used to estimate the same. The lethality ratio has been applied to assess the injury, death of affected people. The loss estimation technique is applied to the mass of buildings, which are not retrofitted. Various parameters are analysed and then the same mass of building is applied retrofitting technique. The application of retrofitting certainly reduces the damage. The reduction of damage due to retrofitting is termed as benefits to the people. The concept is applied on a village as a case study.

CASE STUDY

The selected site lies on Indo-Nepal Border, Bhopatpur, a village in East Champaran, which is of high seismic importance. The whole area is lying on alluvial soil, which is vulnerable to liquefaction, followed by an earthquake. The questionnaire is prepared and details of mass housing are worked out. After complete survey, the building inventories and other information are given final shape by developing a database. The database includes building inventories and other parameters of geological and topological importance.

The surveyed village consists of various types of houses. Mainly the buildings are categorized as shown in table-1. For the paper typical residential Non-reinforced Burnt Brick Masonry with mud mortar with sloping tiled roof is selected.

ESTIMATION OF STRUCTURAL DAMAGE

The estimation of losses resulting from an earthquake is required that for each building class; the relationship between the intensity of ground shaking and damage degree should be known or developed. Various methods of estimating damage due to earthquake have been developed. Generally all these methods fall into one of these groups: Empirical, Theoretical and Experimental. Empirical methods are entirely based on statistical observations of building damage from past earthquake. The theoretical approach for building damage assessment are typically based on detailed analysis of structural models incorporating beams and column element, diaphragms and shear walls that are used to idealize building mathematically. The experimental method includes the laboratory testing based result and damage is estimated accordingly.

The adopted method for estimation is based on the combination of empirical and theoretical method, which includes the parameters and factors experienced from the past earthquake and accordingly the analysis is done to find the damage states. The damage levels are divided into 6 states as shown in Table-2. To describe and catagorise the damage that a building might experience, a set of damage states has been developed. Various damage states are identified. Table-2 shows the followings:

A subjective description of physical damage

An objective ratio of repair cost to replacement cost

The Damage Probability Matrix is a set of probability mass function for damage at the given intensity. Since it is difficult to evaluate with confidence each number in a column of a damage probability matrix, it is necessary to use Mean Damage Ratio.

In general , the most revealing expressions are the ratios of monetary loss and buildings damage(Damage Ratio). Almost any type of earthquake loss, For any facility or component, can be rationally deduced from these expressions. For this study these ratios are defined as follows:

Damage Factor(DF) = Monetary Loss/ Replacement Value

Damage Ratio (DR) = Number of buildings damaged / Total number of buildings

The mean damage factor for a group of similar buildings exposed to the same ground shaking intensity is defined as Mean damage factor (MDF) = $1/n \, \Sigma^{n}_{i=1}$ (Monetary Loss)$_i$ / (Replacement Cost)

n = Number of structures in selection

The mean damage factor reflects the damageability of building types, which is subjected to different ground motion.

A typical set of buildings hypothetically applied ground motion of different intensities. For each intensity of ground motion, the building loss is calculated in terms of money. The damage to the building is calculated as money spent for repair the damage. The ratio of Damage Cost to the Replacement Cost gives the particular building lying in prescribed state of damage. The damage ratio of each building is calculated following the theoretical analysis. The table-3 shows the number of building lying in each category of damage.

ESTIMATION OF HUMAN CASUALTIES

Apart from physical or structural damage estimation, there is an essential need of estimating the intangible losses. The casualties depend upon various factors (Coburn, A.W, R.J.S. Spence and A. Pomonis, 1992). The casualty model can be stated as a series of five factors, which are applied to frame and masonry buildings.

Lethality ratio is composed of various parameters, which varies from place to place. Here the described parameters are derived from place under study, and experience from the past earthquake of near by region. The relationship between the number of people killed and the number of buildings, which collapse, the Lethality Ratio, is the important parameters to determine. If this ratio is known, then human casualties can be estimated from estimates of the number of building collapsed.

The casualty model can be stated as a series of these factors, which are applied to classes of buildings. Number of people killed in buildings of type B1B cab is expressed as:

$Ks_{B1B} = D5_{B1B}$ x $(M1_{B1B}$ x $M2_{B1B}$ x $M3_{B1B}$ $(M4_{B1B} + M5_{B1B})$ - --------- (1)

Where $D5_{B1B}$ is the total number of building

M1 = Population per building

M2 = Occupancy at the time of earthquake

M3 = Occupant trapped by collapse

M4 = Injury distribution at collapse

M5 = Mortality per collapse

(i) Population per building M1

Population per building varies considerably from place to place can change significantly in a town or region in just few years. The factor can be estimated by a ratio of population to the number of buildings in a region. The ratio is found to be 6 persons for selected village.

(ii) Occupancy at the Time of Earthquake M2:

The time of day that earthquake occurs has been known to affect the number of people killed. An earthquake occurring when a lot of the population is an indoor kills more people in the buildings that collapse. The graph has been plotted by surveying the area and it has been found that 97 % of people being inside house from 22 hrs to 4 hrs in morning. To estimate the maximum effects of severity, midnight is considered and factor is found to be 0.97.

(iii) Occupant trapped by collapse M3:

There is a little details available to quantify it empirically, it is clear that not all the occupants that are inside a building when an earthquake occurs are trapped if it collapse. People escape before collapse, or the collapse of the structure is not total, or they are able to free them selves relatively easily by their own efforts. The factor is found to be 0.38 from the past experience.

(iv) Injury distribution at collapse M4:

People caught in buildings suffer a range of types of injuries. It has been broadly catagorised in terms of Deaths, Severe injuries, Moderate Injuries and Light Injuries. The ratio of injury distribution at collapse has been derived from past experience shown in Table-4.

(v) Mortality Post Collapse M5:

Those trapped in the rubble will die if they are not rescued and given medical treatment. Those who have serious injuries will die quickly. In developing counties the settlements are in horizontal direction. The size of the dwellings is very small. If it collapses, the relatives and other neighbors try to take out the people trapped as early as possible. Such data is not available for the selected site. So it is considered to be zero in this case study.

Results obtained from the model are shown in Table-5, which shows the injuries and casualties before and after retrofitting. It also shows the reduction of casualties due to retrofitting.

RETROFITTING TECHNIQUE:

Buildings of various types such as those of clay, stone or brick in general and of reinforced concrete to a lesser extent receive distress to various degrees in earthquake intensities VI and more on MMI or MSK scale. The level of distress may vary from minor crack to partial to total destruction. A very large stock of such damageable buildings exists in seismic zones III, IV and V of India. For this survival during future probable maximum earthquake appropriate seismic retrofitting methods need to be involved and implemented in the field. The method of strengthening naturally depends very largely on the structural scheme and materials used for the construction of buildings in the first instance and the technology that is feasible and economical.

The term seismic retrofitting means upgrading the structural strength of a structure to make incapable of resisting future probable earthquake shocks without serious damage. Here for retrofitting of existing masonry building, the installation of horizontal and vertical reinforcement i.e. splints and bandage is applied in case study. The splint and bandage method is preferable as it is cheap and no much skilled manpower is required. It can be performed without affecting the function of building. This is the most applicable technique for seismic strengthening of existing unreinforced buildings whether damaged or undamaged, to meet the requirement of design seismic intensity VII or higher. Since it will not be feasible to insert the band inside the walls, they will have to be added on the surface of masonry walls and bonded to them. In this technique the bandage is for horizontal bands and splint for vertical steel. Here welded mesh type steel, equivalent to the required steel area has to be provided at the critical section properly nailed to the masonry after removing the plaster and raking the joints and covering the steel with micro-concrete to band it with the walls. Such bands and splints should theoretically be provided on both faces of external as well as internal walls. As a minimum provision, however these must be provided on all external or internal wall along with cross tie bars going across the building in both directions, and embedded in the external wall bands. The crossbars are absolutely necessary in both directions to ensure integral action of the bearing walls like a crate without separating at vertical corners.

Structural and casualties are estimated following the methodologies mentioned above. These methodologies are applied before applying retrofitting to the mass of buildings. The additional cost for retrofitting incurred for each house is calculated. The damage of buildings at various intensities after applying retrofitting is worked out. The Figure-1 shows the number of buildings lying in particular state of damage before retrofitting technique is applied. Damage Probability Matrix is once again developed for buildings after retrofitting. Figure-2 shows the number of buildings lying in particular state of damage after retrofitting. The Figure-3 shows the mean damage factor, which has been reduced to greater extent.

Similarly, the probable casualties are calculated for building without retrofitting. The figure-4 shows scenario of various grades of injury and casualties before application of retrofitting. After application of retrofitting expected casualties are evaluated are evaluated and found to be reduced many folds (Figure-5).

Cost benefit analysis:

The most widely used method for choosing between alternative investment designed to achieve some socially desirable outcome is Cost Benefit Analysis. At its simplest, the idea is that all the benefits of the project are computed in financial terms, the cost are then deducted and the difference is the value of the project. All projects with a positive value are worthwhile but in a situation with a number of possible alternative projects and with limited reasons available for investment, The project with the higher value are chosen. Where earthquake protection strategies involving for example building design are to be considered, the cost of the project is the additional cost of providing earthquake resistance over the cost of construction in which no special provision for earthquake resistance is made. while the benefits are the reductions in future losses. Future losses may usefully be divided between tangible losses and intangible losses. Few assumptions have been made prior to calculation of Cost Benefit Analysis.

The discount rate is assumed following the norms of Planning Commission of India.

The cost of construction and other costs are taken to be present cost.

Frequency of an earthquake is taken as 3 years.

The cost of damage is taken for structural and non-structural elements.

The cost of indirect damage is calculated for injury and death of human beings.

The value of human life and compensation for injuries are assumed suitably.

The benefit from the earthquake protection programme is shown in terms of reduction of losses. Table-6 shows the reduction of structural damage after applying retrofitting in monetary terms. Similarly for casualties, following the government norms the valuation of person has been done. Each individual's death, the compensation of Rs. 1,00,000 is provided to the families, Rs. 50,000 for severely injured person, Rs. 25,000 for moderately injured person and Rs. 10,000 for light injured persons. Based on these facts the reduction in casualties is worked out in terms of money. The Table-6 shows the benefits of retrofitting for intangibles.

The Cost Benefit Analysis(CBA) is the ratio of benefits to the present cost of investment. Following the concept. CBA is calculated for each intensity for intangibles and tangible. The Figure-6 and Table-7 shows the cost benefit ratio for various intensities.

RESULT

The result shows (Figure-7) the retrofitting technique is feasible to reduce the vulnerability of damage caused by earthquake. This technique of retrofitting is most suited for the intensity VII and above, but it is very much suited for the intensity IX, as the cost benefit ratio is maximum at this intensity.

CONCLUSION

A methodology has been described for formulating the viability and feasibility of Splint and bandage type of retrofitting technique to reduce earthquake losses. The techniques have been suggested for assessment of losses for tangible and intangible ones. The parameters have been developed and derived for the developing countries for the assessment of losses and evaluation of disaster mitigation through retrofitting.

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CATEGORISATION OF BUILDINGS

Table-1

Category	A			B	C			X	
Sub-Category	A1	A2	A3	B1	C1	C2	C3	X1	X2
	Mud	Unburnt Brick	Stone	Burnt Brick	Concrete	Wooden	Ekra	GI & other Metal sheet	Bamboo & Thatch
Sloping Roof	✓	✓	✓	✓	✓	✓	✓	✓	✓
Flat Roof	X	✓	✓	✓	✓	✓	✓	✓	✓

DAMAGE STATES AND THEIR DESCRIPTION

Table-2

Grade	Damage State	Central Damage Factor Range	Description
1	Slight	0 - 1	Non-structural damage need not be repaired
2	Light	1 – 10	Fine cracks in plaster, Fall of small piece of plaster
3	Moderate	10 – 30	Small cracks in wall, fall of fairly large piece, pan tiles slip off; cracks in chimney, parts of chimney fall down
4	Heavy	30 – 60	Large and deep cracks in walls, fall of chimney
5	Major	60 – 100	Gaps in walls, parts of building may collapse, separate parts of building lose their cohesion, inner wall collapse
6	Destroyed	100	Total collapse of buildings

DAMAGE PROBABILITY MATRIX BEFOTE APPLICATION OF RETROFITTING

Table-3

Damage Grade	**Range**	**Central Damage Factor**	**INTENSITY**			
			VI	**VII**	**VIII**	**IX**
			Number of Buildings	**Number of Buildings**	**Number of Buildings**	**Number of Buildings**
1	**0 - 1**	**0.5**		********	********	********
2	**1- 10**	**5**	**35**	**11**	**6**	********
3	**10 - 30**	**20**	**13**	**7**	**2**	**14**
4	**30 – 60**	**45**	**9**	**16**	**5**	**43**
5	**60 – 100**	**80**	********	**23**	**44**	********
6	**100**	**100**	********	********	********	********

INJURY CATEGORY AND DISTRIBUTION AT COLLAPSE

Table-4

Injury	Grade	Description	% of affected people
Death	1	Death caused by collapse	**20 %**
Sever injury	2	Immediate medical attention	**30 %**
Moderate injury	3	Hospitalisation for long duration	**30 %**
Light Injury	4	Not necessitating Hospitalisation	**20 %**

AFFECT OF COLLAPSE ON HUMAN BEINGS

Table-5

Injury Level	Grade	VI			VII			VIII			IX		
		Before Retrofitting	After Retrofitting	% reduction	Before Retrofitting	After Retrofitting	% reduction	Before Retrofitting	After Retrofitting	% reduction	Before Retrofitting	After Retrofitting	% reduction
Dead or Unsavable	1	6	0	100	24	3	88	32	12	63	47	12	75
Severe Damage	2	11	2	82	36	5	87	48	18	63	71	18	75
Moderate Injury	3	11	2	82	36	5	87	48	17	65	71	18	75
Light Injury	4	7	1	86	24	2	92	32	10	69	46	17	63

BENEFITS FROM RETROFITTINGS

Table-6

Intensity	Tangible Damage cost		Intangible Damage Cost		Total Damage Cost	
	Before retrofitting	After retrofitting	Before retrofitting	After retrofitting	Before retrofitting	After retrofitting
VI	358938	176690	1495000	160000	1853938	336690
VII	2122630	537117	5340000	695000	7462630	1232117
VIII	3194906	1208625	7120000	2625000	10314906	3833625
IX	4809458	2915360	10485000	2720000	15294458	5635360

COST BENEFIT RATIO

Table-7

Benfits from retrofitting	Investments for retrofitting	Cost benefit Ratio
1517248	548335	2.767
6230513	548335	11.36
6481281	548335	11.82
9659098	548335	17.615

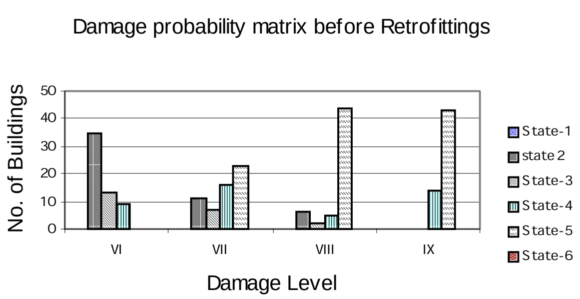


Figure-1

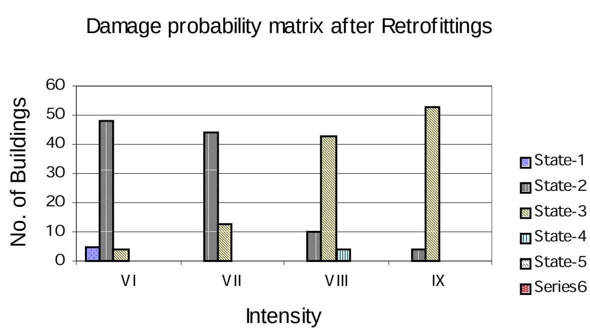


Figure-2

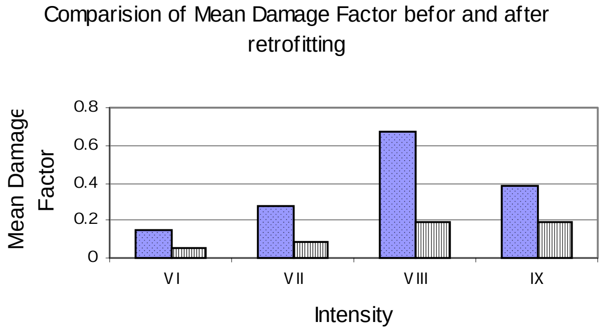
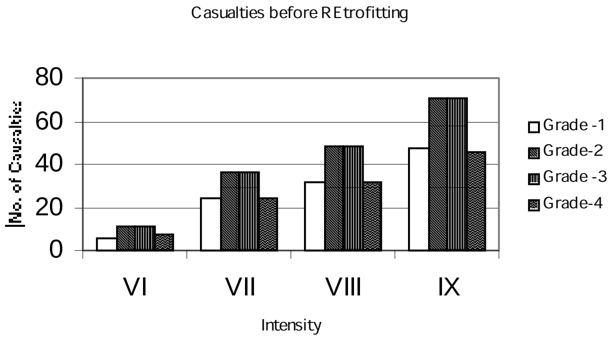


Figure-3



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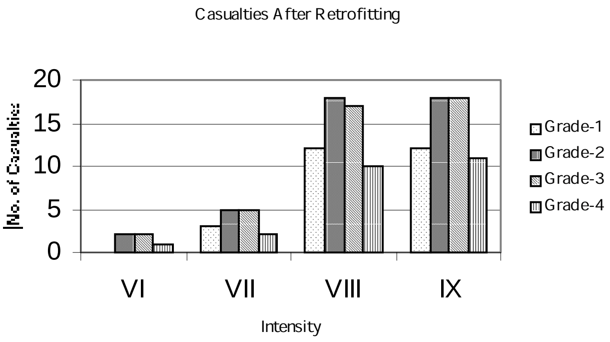

Figure-5

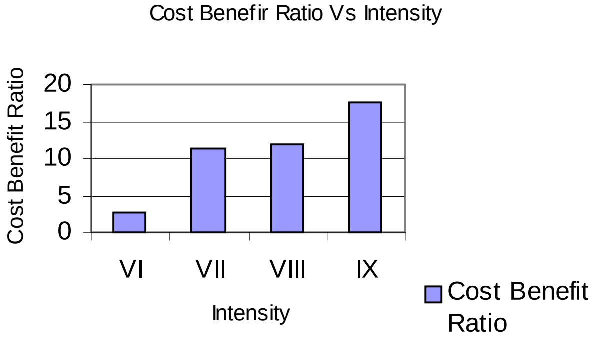

Figure 6

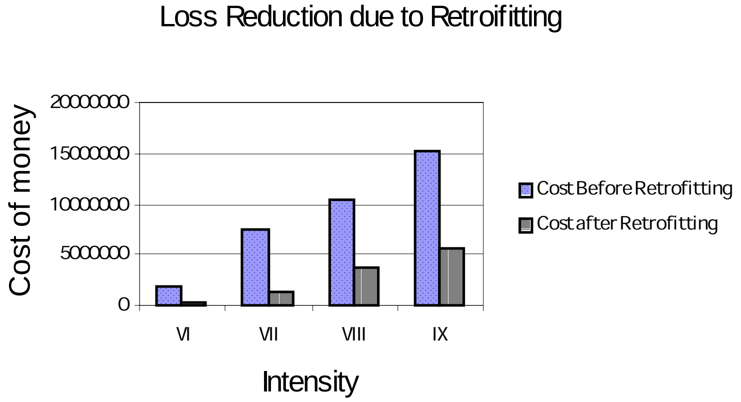

Figure-7