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ASSESSMENT OF BUILDINGS FOR SEISMIC RESISTANCE

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Abstract: The recent earthquakes in India and different parts of the world have caused loss of human lives and damage to property due to the collapse of structures. Though an earthquake cannot be prevented, the loss of life and property can be minimized by taking necessary steps on the existing structures to reduce the damages. The seismic codes contain provisions for planning and designing earthquake resistant structures. It becomes essential to carry out a survey and identify existing structures that are deficient and carry out appropriate retrofit. This study first identifies the earthquake resistant features stipulated by the seismic codes for buildings. Then a survey assessment carried in the district of Kollam (Kerala, India) is reported. Kollam is in moderate seismic risk zone, in the seismic zone map prepared by the Bureau of Indian Standards. This city deserves attention owing to high concentrations of population. Each area differs from one another in terms of climate, culture, methods of construction and living standards. Materials used for construction also differ. The localized survey has found out the methods of construction, materials used for construction and general pattern of the structures in Kollam city. Structures that are prone to damage during a seismic event were identified. Recommendations are given based on the guidance available in seismic codes and other references for retrofitting such structures.

Keywords: *Earthquake, Types of Buildings, Resistance, Retrofit, Survey*

1. Introduction

Buildings have consistently exhibited poor performance in the past earthquakes around the world. Some of the deadliest earthquakes that occurred across the world after 2005 are Haiti M 7.0 (2010), Southern Sumatra, Indonesia M 7.5 (2009), Eastern Sichuan, China M7.9 (2008), and Java, Indonesia M 6.3 (2006). The observations of structural performance of buildings during earthquakes provide volumes of information about the merits and demerits of the design and construction practices in a region. Earthquake hazard can be minimised with proper understanding of behaviour of buildings during earthquake and careful planning, design and construction. This information has been incorporated into the seismic codes which contain provisions for planning and designing earthquake resistant structures. Examples of seismic codes are (1) IS 1893 Part 1: 2002, (2) BS EN 1998-1:2004, (3) NBCC, (4) ACI 530 -88, (5) UCBC and (6) ASCE/ SEI 31-03.

Kollam (Kerala, India) is in Zone III, a moderate risk zone, in the seismic zone map prepared by the Bureau of Indian Standards (BIS). This city deserves attention owing to its high concentration of population. While an earthquake cannot be prevented, the damage to life and property can be minimized if effective steps are taken. Each area differs from one another in terms of climate, culture, methods of construction and living standards. Materials used for construction also differ. In this context it becomes essential to carry out a survey and identify deficient structures and carry out appropriate retrofit. This study first identifies the earthquake resistant factors in buildings by a study of the seismic codes. Then an assessment carried in the district of Kollam (Kerala, India) is reported. A localized survey identifies construction methods, materials used, general pattern of the structures etc. This enables identification of structures that are prone to damage during a seismic event. Suitable retrofit measures can then be planned. Guidance for this is available in the seismic codes (BS EN 1998-3:2005, IS 13935:2006 Draft, IS -13828-1993 and IS 4326-1993) and other published reports.

Seismic vulnerability assessment of structures has been carried out by researchers in different parts of the world. Kamatchi et al (2011) reviewed the various methodologies available for seismic vulnerability assessment of buildings. Arya (2008) discussed the seismic assessment of masonry buildings. Srikanth et al (2010) carried out earthquake vulnerability assessment of existing buildings in Gandidham and Adipur Cities in Kachchh, Gujarat (India). Alam et al (2007) carried out earthquake vulnerability analysis of buildings in Sylhet (Bangladesh) using Rapid Visual Screening methodology and a structural scoring system. Sadat et al (2010) assessed the seismic vulnerability of reinforced cement concrete structures of selected area in Dhaka city in Bangladesh using Rapid Visual Screening method and Turkish method. Agrawal and Chourasia (2011) explained the process of seismic evaluation on representative buildings in 134 zones / wards of Delhi using questionnaire framed based on Indian Seismic codes. Both qualitative and quantitative methods were used.

Kerala (India) which has high torrential rains, sloped roof or concrete roofs with facilities for draining out storm water is used. The town of Kollam was selected due to its proximity to the second author. This study is also significant since Kerala was elevated from zone II to zone III on seismic zone map. Local tremors have been reported in various areas of Kerala in the near past (Bhattacharya and Dattatrayam, 2002). There exist no hard and fast rules regarding the magnitude of earthquake up to which a particular structure is safe. Only predictions and suggestions can be made about retrofitting structures to withstand seismic shocks if and when it happens. Kollam has got different soils varying from rocky, sandy to reclaimed soil. All these strata bear a considerable number of structures. Hence data collected will have a representation from all types of soil. No available records exist on tremors in Kollam. In this study the general pattern of structures is determined and the numbers of structures that can with stand moderate tremors are identified using provisions of the Indian Seismic codes. A qualitative approach was adopted for the study. The factors that cause additional damages and steps to improve the seismic resistivity of the buildings are answered through a field survey using a questionnaire generated on basis of some important parameters regarding seismic design.

2. Objectives

The objectives are to identify features considered to be earthquake resistant from a study of seismic codes (IS 1893 Part 1:2002, IS 4326-1996 and Eurocode 1998-1:2004), conduct a localized survey on the materials and methods of construction, geometry and general pattern of the structures in Kollam, Kerala India (no such survey has been reported in literature for that area), to identify the buildings that are vulnerable to earthquake and require retrofitting using qualitative methods and to compile suggestions for retrofit of these structures based on the codes (IS 13935: 2006 and Eurocode 1998-3:2005) and other literature (IIT Roorkee, 2006; Paul et al,2002; Brzev, 2004).

3. Methodology

Firstly, the seismic provisions required in new structures recommended by the codes of practice for masonry structures and RCC structures are reviewed. Second part involves a case study of the seismic evaluation of buildings using (1) Visual screening and (2) inspection of the building plans at Kollam, India. Kollam Corporation has 52 wards with estimated one lakh legal licensed structures. The city extends from the Arabian Sea to hilly areas of Western Ghats, and also has back waters. The coastal areas have sandy soil while the eastern zones have laterite soil. Some regions have marshy soil. Six soil categories were included. In slums, mud bricks were commonly used. Framed, reinforced masonry, ordinary masonry and mortar free construction were included. The number of floors, floor areas, height of walls etc was included. The use of the building was also considered as the number of causalities during an earthquake differs in various

types of structures. Special consideration was given to strategically important buildings like power station, telephone exchanges and water treatment plants.
To ascertain the general strength of masonry, the types of masonry, the mortar composition used for construction and the plastering was included. Most of the structures being masonry, wall shear failure will be high during a quake. Hence the longest wall length was considered. The size and positions of openings in bearing wall is the most important criteria proposed by IS codes. Similarly pier width between consecutive openings, and distance of the first opening from inside corner of outside wall were considered. Laterite, wire cut and country burnt bricks; hollow cement block, solid cement block, random rubble masonry, interlocking bricks, wooden planks etc were included in the materials used. The roof type covers RCC- flat, RCC-sloped, Tiled, AC sheet, Tin sheet and Thatched. Filler slab was also included but only a few houses were found in that category. In order to check the overall stability of the structures, especially at corners, the provision for lintel and plinth beam all around the building were noted. The symmetry of the structure and age of structure play an important role during an earth quake. Considering the sub structure, the points noted were the presence of plain cement concrete at the bottom of trench and type of foundation. The foundation types include Random Rubble, Isolated footing, Strip footing, Raft foundation, Brick foundation, Pile foundation etc.

The average number of occupants was also noted irrespective of the type and use of the structure. The new trend of providing cellar parking spaces, high weight RCC overhead tanks etc. was also noted. The presence of high rise towers adjacent to a selected structure was considered. Care was taken to select various types of structures from each ward so as to get a clear cross section of structure types in the locality. Interaction with the incumbents gave much detail about the selected structure. Lot of details was available from the City Corporation office. Those found correct in all respects were included. Numerous problems were faced during field survey. Important one being some owners was not sure whether plain cement concrete was placed at the bottom of trench for the substructure. Many were doubtful about the presence of plinth beam. The type of cement mortar used for construction of the super structure was vague. As many structures are plastered, there was no way to find the composition of mortar used for construction. Same problem was faced with plastered walls. Application of wall putty had made the walls hard and the mortar combination was not known and difficult to find. The type of roof covering also created some problems. Many multi storied structures had sloped roof at the top. The doubt was where to include the data, as flat slab or as sloped roof. Later it was decided to include in sloped roof segment. Many more questions and doubts arose about the details of data to be collected during the survey. The questionnaire, with 30 questions, focused on the many factors on which the seismic resistivity of structures depends on. IS 1893-1984, IS 113828-1993 and IS 4326-1993 were used as a guideline for preparing the questionnaire and also assessing the areas of a structure that is more prone to seismic damage. It helped in pinpointing the parts of a structure that has to be strengthened to attain seismic resistance. The third stage of the work consisted of recommending suitable retrofit measures for the deficiencies observed in structures during the assessment.

4. Seismic Resistance Features – Guidelines

This section summarises the seismic resistance guidelines under 2 sections: General guidelines and Guidelines for masonry structures.

General Guidelines: IS 1893 Part 1 contains general provisions applicable to all structures and also provisions specific to buildings. The code tries to ensure that structures are able to respond without structural damage to shocks of moderate intensities and without total collapse shocks of heavy intensities. In highly seismic areas construction types that may result in heavy debris and resulting loss of life and property should be avoided (particularly mud masonry, rubble masonry). The important guidelines are:

1. The intensity of vibrations depends also on the soil strata on which the structure stands.
2. The response of a structure to ground vibration is a function of the nature of foundation soil, materials, form, size and mode of construction of the structure and the duration and characteristics of ground motion.
3. An addition which is structurally independent from the existing structures shall comply with the seismic requirements of new structures. An addition that is not structurally independent shall be designed to ensure that the entire structure conforms to seismic requirements for new structures.
4. When a change in occupancy occurs, the structure shall be reclassified to a higher importance factor, and shall conform to the requirements of a new structure with higher importance factor.
5. The four main attributes for a building to perform well in an earthquake are simple and regular configuration, adequate lateral strength, stiffness and ductility. Buildings having simple regular geometry and uniformly distributed mass and stiffness in plan as well as elevation, suffer much less damage than buildings with irregular configurations. Buildings shall be considered as irregular under following conditions: (1) Re-entrant corners with corner dimensions greater than 15% of plan dimension in the direction (Figure 1). (2) When diaphragm is discontinuous or has variations in stiffness including those having cut-out or open areas greater than 50 percent of gross area (Figure 2). (3) When there are discontinuities in the lateral force resistance path as shown in Figure 3. (4) When the vertical elements resisting the lateral force are not parallel to or symmetric about the major orthogonal axes (Figure 4).

6. Structures with vertical irregularities are prone to damages during earthquakes. Examples are (1) Soft storey where the lateral stiffness is less than 70% of that in the storey above or less than 80% of the average lateral stiffness of the three storeys above (Figure 5). (2) Mass irregularity when the seismic weight of any storey is more than 200% of adjacent storeys (Figure 6). (3) Vertical geometric irregularity when the horizontal dimensions of the lateral force resisting system in any storey is more than 150% of that in the adjacent storey (Figure 7). (4) Weak storey when the storey lateral strength is less than 80% of that in the storey above (Figure 8).
7. Non-structural components have to be assessed for their capacity to withstand EQ forces. Their failure in buildings such as hospitals, telephone, exchanges etc may lead to disruption of function and sometimes loss of lives.
8. All parts of the building, except between the separation section, shall be tied together to act as integrated single unit.

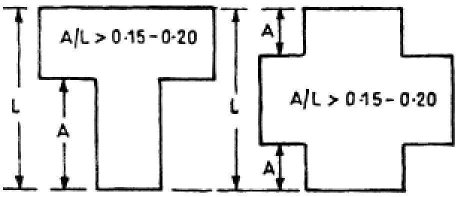

Figure 1: Example of Re-entrant corner (IS 1893 Part 1:2002)

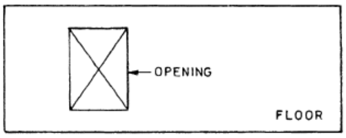

Figure 2 : Diaphragm discontinuity (IS 1893 Part 1:2002)

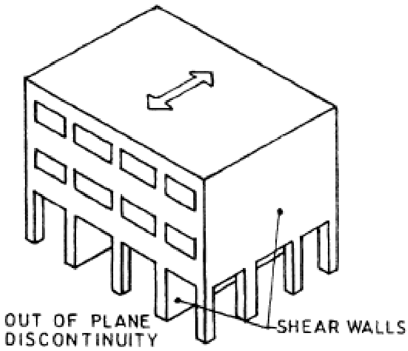

Figure 3: Out of plane offsets (IS 1893 Part 1:2002)

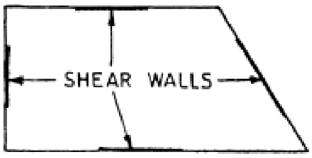

Figure 4: Non parallel systems (IS 1893 Part 1:2002)

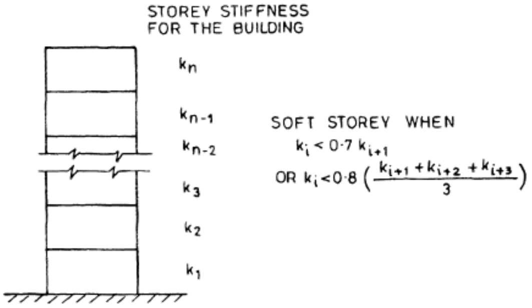

Figure 5: Stiffness irregularity (IS 1893 Part 1:2002)

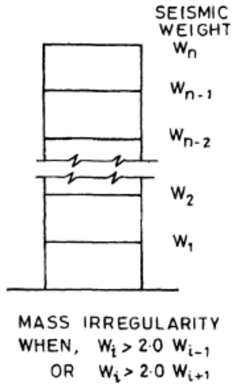

Figure 6 : Mass irregularity (IS 1893 Part 1:2002)

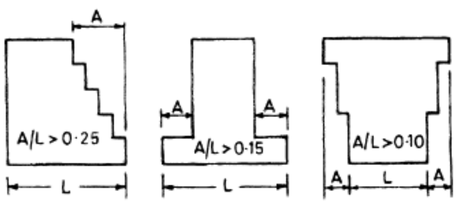

Figure 7: Vertical geometric irregularity (IS 1893 Part 1:2002)

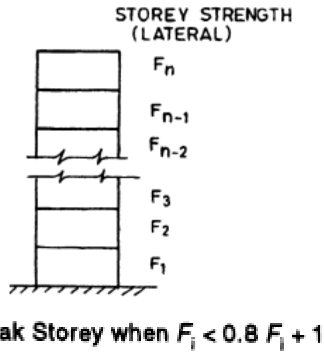

Figure 8: Weak storey (IS 1893 Part 1:2002)

Masonry buildings: The minimum distance from the inside corner of the outside wall to the opening is 23 cm. A minimum pier width of 45 cm was required between consecutive openings. The ratio of width of the opening to the length of the wall was limited to a range of 0.40 to 0.46. The minimum mortar proportion proposed by the codes is 1:6. The buildings should have all-round lintels. Symmetry plays an important role during earthquake as stability is directly related to symmetry. If the structure is symmetric, the additional shear and moment that occurs at the time of quake gets distributed uniformly over the structure. Otherwise it will create an unbalanced effect. Residential buildings constructed on marshy and reclaimed strata should be provided with plinth beams and plain cement concrete at base. Surface finishes like plastered walls makes good sense as during an earthquake, it holds the walls and transmits the forces. Stair cases rigidly attached to the structures are not good for seismic resistance; though they conform to minimum requirement of IS codes and building rules.The discussion has considered only architectural requirements and not detailed design requirements.

5. Survey and Analysis of Buildings – Case Study

A total of 6817 data were collected. Those without enough details or ambiguity were removed, resulting in 6800 data for analysis. In Kollam city, the percentage distribution of different building types is shown in Table 1.

Table 1 Percentage Distribution of building types

No.	Type of building	Percentage
1	Residential Buildings	64.2
2	Commercial Buildings	19.2
3	Government Buildings	3.5
4	Public Buildings	4.0
5	Educational Buildings	5.1
6	Hospitals	4.0
	Total	100.0

Kollam, once an industrial area has now only 1% industrial buildings. Educational standards and facilities are high and hence educational buildings contribute to 5.1%.

5.1 General Pattern of Structures in Kollam

It is seen that residential buildings are increasing in numbers, compared with commercial ones. Residential buildings are constructed largely by individuals, with their own likes and knowledge; seem to have no seismic provisions. The general method of making structure strong by adding “more cement, more steel” creates an over reinforced structure only. This is not a good practice since the structure will not give enough warning before collapse.

5.2 Detailed Analysis of Residential Structures

From the residential structures sampled, 17.63% does not satisfy the requirement of minimum distance of opening from the inside corner of the outside wall. The minimum pier width between consecutive openings was not satisfied by 5.88% of the total buildings. The ratio of width of the opening to the length of the wall was modified as no attics and mezzanine floors are seen in Kollam. The value was interpolated to 0.45. A total of 77.77% of buildings satisfies this requirement. Majority of the residential buildings satisfy the three important requirements proposed by IS codes. Even though these code provisions draw less attention of the builders, accidently or fortunately majority have satisfied the requirement. All the surveyed buildings which used masonry were constructed with cement mortar proportions not less than 1:5. The eagerness to attain more strength for their structures has made many house owners spend lavishly on cement and sand. Only 10.45% buildings do not have all-round lintels. This can be accepted to a certain level as this percentage contains buildings that are mortar free, thatched sheds etc. An important thing noticed was that some of the residential structures, that too multi-storeyed ones, did not have all-round lintels.

In some places lintels are as thin as a line with a very small percentage of reinforcement. It has been found that these structures were constructed by contractors, who often exploit the owner. 27.45% of the residential buildings were found to be non symmetric. Symmetry has not received sufficient importance in residential structures due to the reasons like aesthetics, better cross ventilation, space constraints, non availability of enough land; extension works etc. 86.92% of the residential buildings rest on soft soil strata of which 93.23% rests on sandy soil, 4.5% rests on clayey strata, 1.3% on marshy strata and 0.97% on reclaimed land. It is good to see that all the residential buildings constructed on marshy and reclaimed strata were provided with plinth beams and plain cement concrete base. 30.97% of the buildings in sandy soil have plinth beams. This is of concern because, at places where sandy soil was supported by some other weak soil strata, cracks were seen on structures. These areas require special attention since a mild quake can topple these structures. But another surprising fact is that 75.18% of buildings in sandy soil have got a PCC bed beneath the foundation. The genuiness of this is bit difficult to prove. Percentage wise distribution of various types of masonry structures showed that ordinary masonry structures constituted (90.32%), framed structures (5.66%), mortar free construction (0.84%) and reinforced masonry (3.18%). On surface finishes 92.81% had plastered walls. This makes good sense as during an earthquake, it holds the walls and transmits the forces. Of the unplastered buildings, 36.36% are non-masonry constructions and 44.33% are random rubble construction. 19.31% of masonry buildings are left unplastered. Walls are not plastered due to aesthetics or non availability of raw materials or labour. Many owners admit that it is due to the cost incurred for plastering, with plan to plaster it in the immediate future.

As it is a normal procedure, 95.42% of residential buildings have foundation and basement constructed using rubble. Out of the remaining minority, 60.32% have got laterite or brick foundation. This type of buildings has got mainly tile roofs. A small percentage has got isolated footings. The isolated footing-plinth beam construction is seen in many newly completed buildings. A new trend of using concrete for substructure is observed in Kollam city. The percentage wise break up of roof types in Kollam city is shown in the Table 2.

Table 2 Percentage distribution of roof types in residential buildings

No	Roof Type	Percentage
1	Reinforced cement concrete roof	84.31
2	Tiled roof	4.19
3	Tin sheet or AC sheet	2.61
4	Thatched roof	8.89
	Total	100.00

The latter two are found commonly in coastal areas where there is tendency for corrosion. This can keep losses to a minimum. No residential structures were found to be older than 70 years. Even structures aged about 50 to 60 years were altered and modified not due to aesthetics, but on fear about the strength of the structure. The residential structures were classified percentage wise based on age as shown in Table 3.

Table 3 Age wise percentage distribution of residential buildings

No	Age of residential building	Percentage
1	More than 50 years	1.32
2	21-50	13.72
3	11-20	7.84
4	0 -10 years	77.12
	Total	100.00

The data shows that among older buildings, buildings aged between 21 to 50 years are comparatively more. These structures on an average should have further minimum life of 15 more years. This needs the prime attention. Here retrofits are to be provided to increase the life span and seismic resistivity. This group contains both RCC buildings and tiled roof buildings. A total of 80.39% of residences has got water tanks. The percentage wise distribution of different types of tanks is shown in Table 4.

Table 4 Percentage wise distribution of water tank types

No	Type of water tank	Percentage
1	Fibre tanks	86.17
2	RCC tank	7.31
3	Masonry tanks	6.52
	Total	100.00

Even though RCC and masonry tanks are stronger and can be cast as per size and shape requirements, they pose a big danger as in most of the cases it is impossible to place these tanks in the central point of the structure. The eccentricity of the water tank may cause it to overturn during an earthquake. The water tank being a big structure, its break up may result in debris that affect the incumbents. Thus permanent water tanks cause secondary damages. Fibre tanks are more advisable than other types. For larger capacity more number of tanks can be used with interconnections and these tanks can be placed uniformly throughout the structure.

5.3 Detailed Analysis of Commercial Structures

Among the commercial structures surveyed the percentage distribution is shown in Table 5.

Table 5 Percentage wise distribution of Commercial structures

No	Type of commercial structure	Percentage
1	Framed structure	55.0
2	Reinforced masonry	7.5
3	Ordinary masonry	32.5
4	Mortar free construction	5
	Total	100.0

The mortar free buildings were small pan shops, tea shops and provision stores of temporary nature. Age wise distribution of commercial buildings is shown in Table 6.

Table 6 Age wise distribution of commercial buildings

No	Age	Percentage
1	>50	5
2	20-50	40
3	10-20	15
4	0-10	40
	Total	100

Commercial buildings more than 50 years of age include establishments for cashew and coir production where lot of people are employed. An important point noticed was the absence of big type commercial complexes. The highest was a five floor structure owned by government. Medium type commercial structures ranging up to three floors are common. All of them have stair cases rigidly attached to the structures which are not good for seismic resistivity, though they conform to minimum requirement of IS codes and building rules. 73.22% of the commercial buildings can be considered as rigid frames since they have structural support between walls and roof. Those that do not fall under this criteria poses risk, but many are single storied commercial structures with light weight roof or RCC. Only 50% of the structures satisfy the minimum requirement of width of opening to length of wall of 0.40. This is for maximum exposure of the shop for exhibiting the products to the public. Majority of first floor shops have this value greater than 0.40.

Almost the same is the case of width between adjacent piers. About 69% of the commercial buildings satisfy the minimum width of 50 cm. The recommended minimum distance requirement from inside of the outside wall to first opening is satisfied by 88% of buildings. For space saving and for obtaining maximum floor area, symmetry was achieved by majority of structures. 93% of commercial structures were found to be symmetric. Only 20% of the commercial building had over head water tank. Here also economy had played a vital role. Two-three storied commercial buildings were served by four or more number of tanks connected together. It constituted about 12% of the total commercial structures. The rest have RCC over head tank, most being at centre portion of the structure creating a balance. The percentage wise distribution of roofing types is shown in Table 7.

Table 7 Percentage wise distribution of roofing types in commercial structures

No	Roofing type	Percentage
1	RCC	71
2	Tiles roof	12
3	AC or tin roof	17
	Total	100

The tiled roofs account for most of the aged structures. The percentage wise distribution foundation types are shown in Table 8.

Table 8 Distribution of foundation types in commercial structures

No	Type of foundation	Percentage
1	Isolated footing	63
2	Random rubble masonry	35.3
3	Pile foundation	Just above 1%
4	Raft base	0.7

The presence of strong soil and absence of big business malls may be the reason for this low percentage of pile and raft foundations. The pile foundations were all cast-in-situ concrete piles. 71% of the commercial establishments had all-round lintels, also all of the cashew factories got intermittent concrete horizontal bands in addition to lintels. About 21% of the commercial buildings had cellar floors. Most of them are used as parking lots or storage spaces. The existence of cellars merely over columns is not advisable from seismic point of view. The case of Chile, where earthquake struck recently is remembered. Most of the commercial structures overturned because of cellar openings. However strong the basement, there are chances of structural failure in case of an earthquake. Space constraints for parking etc are making constructors to go for cellars.

5.4 Detailed Analysis of Hospitals, Government Buildings and Public Buildings

These structures play a vital role during an earthquake. 90% of hospital buildings rest on isolated footings with tie beams and plinth beams. All are well plastered and have the required width to length wall ratio. About 80% of hospitals have got separate overhead water tanks, which is good. 65% of hospitals exists in core areas of the city and have another hazard from adjacent towers, which repeat mobile communication signals. These towers can fall over hospitals thereby harming their smooth functioning as relief centres. The average occupant rates in the surveyed hospitals were 45. Thus the magnitude of danger posed by these towers is comparatively high and has to be avoided immediately. These towers may be kept away from hospital and city centre, or to make use of some new technique for mobile receptions. Due to expansion, 95% of hospitals have lost symmetry. Only a few seems to have planned growth pattern. However construction joints were provided on the expanded structures. The designers deserve credit for these measures which reduce the risk of total collapse. Majority of hospitals have RCC roof. And many have additional tin sheet covering, few have tiled roof. It can be accepted as there are no inpatient wings functioning in these hospitals.

The government buildings seem to conform to all the code regulations and buildings rules, but the quality of work is a matter of concern. Even a government building less than 10 years of age was found to have large cracks on main walls. In the planning stage engineers can avoid risk by keeping the structure symmetric. Only one building was found to be non-symmetric throughout this survey. Most government buildings had overhead water tank, but all are of fibre material. The credit is due to the PWD schedule of rates for incorporating fibre tanks in them. The age wise distribution of government buildings is shown in Table 9.

Table 9 Age wise percentage distribution of commercial structures

No	Age	Percentage
1	10-20 years	67
2	21-30	13
3	31-40	5

Just a few were greater than 40 years of age. But they were also face lifted and retrofitted in the near past. About 30% of the government buildings are tile roofed. Rest are RCC covered. A few government structures were with AC sheet roofing, but they were negligible in numbers and were eliminated from analysis. About 20% of the government buildings were adjacent to high structures in the form of over head water tanks or mobile towers, which is a source of hazard. The strategically important structures were very few in number. The KSEB (Kerala State Electricity Board) substations conform exactly to the code provisions. They are also symmetric, had plinth beam and lintels all-round and isolated footing as foundation. Same was the case with the communication department also. They extensively use random rubble masonry with concrete bands in between. But some structures were not symmetric. Anyway the strategically important structures can function well if an earthquake happens. Public buildings were largely in the form of clubs, libraries and reading rooms where the pattern of occupancy is more in the evening time. About 78% of the public buildings were less than 10 years in age. This is due to the fact that the local aid schemes for people's representatives are being used for these type of structures. They have plinth beam, lintels, isolated footings and RCC roof covering. Only less than 3% buildings were more than 30 years of age. Just 6% has got overhead water tanks that too fibre made. Symmetry was there in most of the structures. 35.7% of structures fall short of the criteria for ratio of the width of opening to length of the wall. This is due to the usage of mild steel grills extensively, especially in the case of reading rooms. Some other public buildings like fish market simply rests on columns with roof and tie beams posing a big question mark about seismic resistivity. In general, public buildings appear to be safe during an earthquake according to the general standards.

5.5 Detailed Analysis of Educational Buildings

About 5% of the total buildings fall under this category. Tradition plays a big role in this field. Educational institutions aged greater than 60 years were seen. The most salient features found from the analysis are - 98.7% of buildings are symmetric, 76.8% have RCC roofs, and 23.2% have tiled roofs. Some were found with AC sheets and thatched roofing, but authorities said they are not used for currently for education purpose. All the tiled roof buildings had intermediate bands of concrete in addition to all round lintels. A few of the tiled roof buildings were two storied with wooden floor, which performed well. The width of opening to length of wall ratio, pier to pier opening distance and minimum corner edge distance was found to be satisfied by all the structures with tiled roof, i.e. those having age between 30 to 50 years. Surprisingly the comparatively new buildings of RCC fall well short of this criteria. About 48.7% does not satisfy all three provisions regarding openings. 67% schools got separate over head water tanks. Structures which have overhead water tanks use fibre tanks. As most schools have play ground adjacent to buildings, the possible danger of high rise structure is avoided. Educational buildings has got random rubble foundation for 55%, isolated footing for the rest of 45%. The average number of occupants for each class was about 45. As the old buildings do not have rigid structural support between walls and roof; it seems dangerous. 52% of schools have multi-storey structure. But the maximum number of storeys was limited to three, that to a minimum number. No educational building was found to have raft or pile foundation.

6. Summary Of Analyses

6.1 Residential Structures

Structures in soft soil strata constitute 86.92% whereas structures in hard soil strata constitute 13.08% of the structures. The most important feature that affects the seismic resistivity of masonry structures is the structural support between walls and roof. On an average of 31.13% of buildings do not have that support. Hence they need the prime attention for retrofit. Also an average of 11.41% does not have all round lintels. Here retrofit in the form of wire-meshed concrete at corners is necessary. In general, an average of 21.27% structures requires essential retrofits.

6.2 Commercial Structures

Framed structures constitute 55% and non-framed structures constitute 45% of the structures. The important factors that affect the seismic resistivity of commercial buildings are the ratio of openings and the cellar parking provisions. 50% of the commercial structures have to be modified for necessary ratio of openings. 21% of the structures have to be altered to reduce the risk due to cellar parking. Hence a total of 35.5% commercial structures require essential retrofits.

6.3 Hospital Buildings

The secondary damages from the collapse of high rise structures may affect the proper functioning of hospitals after an earthquake. The functionality can be harmed by the collapse of water tanks also. Hence on an average 41.65 **%** of hospital structures are likely to be affected by earthquake.

6.4 Government Buildings

Majority of government buildings have satisfied the requirements by IS codes. But the quality of workmanship is a matter of concern. The structural support between walls and roofs are essential and 42% of government buildings require retrofit in that section. The high rise structures also pose danger. Hence an average of 31% of government buildings is to be retrofitted suitably to avoid the danger of earthquake. Most of the public buildings do not satisfy the criteria of minimum opening ratio. Hence 64.3% of public buildings are to be retrofitted. Absence of structural supports is seen in 42 %. Therefore an average of 53.15% has to be considered for retrofit to ensure their successful functioning. Educational buildings have an average of 45 incumbents per class. Hence the prime importance must be given to the structural support between walls and roof and the opening ratios. As per analysis, both the criteria are not fulfilled by majority. Hence an average of 38.15% of educational structures requires retrofit. Overall 36.78% of the existing building structures in Kollam Corporation require essential retrofitting for smooth and safe functioning.

7.0 Methods of Retrofit

7.1 Masonry buildings

They can be retrofitted effectively by strengthening the corners and ensuring box action, by providing external bandage. For this, the wall plastering of the corners is to be removed first. Then an iron mesh that having exactly the same width of the plaster removed is nailed in the gap (Figure 9). Concreting can be done over that additional reinforcement using a rich mortar mix of 1:1.5:3 or 1:2:4.The surface is then plastered and trowelled smooth. This process is comparatively cheap and requires less skilled labour. After retrofit the wall will look the same as before retrofit (Figure 10).

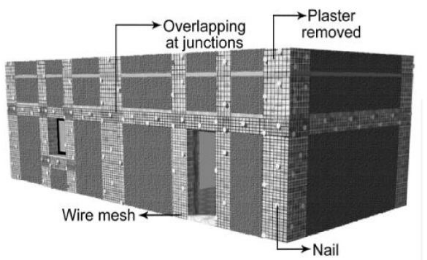

Figure 9: Nailing of wire mesh (IIT Roorkee, 2006)

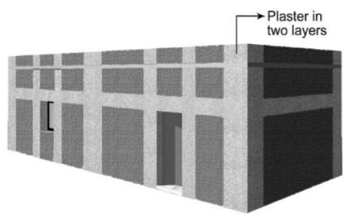

Figure 10 : Plastering of nailed wire mesh (IIT Roorkee, 2006)

The problem of lack of structural connection between roof and walls of ordinary masonry structures can be remedied by using specially made clamps and bolts. This method is comparatively cheap and can be adopted in a region like Kollam very easily. Large unsupported lengths and heights are remedied by providing cross walls or buttresses. When length of opening is excessive, some openings are closed completely or partially, ensuring proper bond between old and new masonry. Existing timber structures can be retrofitted using MS plates at joints of the members with the help of nut and bolts. The joints which are generally weak are held together using two plates placed on the both sides of the members. Bolts are inserted through holes drilled and the members are held in tight position with the help of nuts. This method has the advantage of easy maintenance and can be used for many years. Periodic checking and tightening, if necessary, can be done in this method. Existing commercial buildings can be retrofitted using mild steel beams and channels. Foundations are strengthened by increasing the bearing area by providing RC beams on both sides of the wall. Proper connection to the existing foundation is ensured by gaps created in the walls (Figure 11). The problem of tiles falling from roof is avoided by replacing with light weight corrugated Galvanised Iron sheets. The tendency of sloped roof to open up can be remedied by provision of proper bracing in different planes (Figure 12). The roofs have to be connected to the walls by anchor bolts.

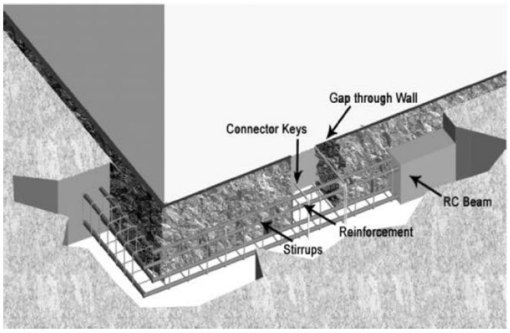

Figure 11: Strengthening of foundation (IIT Roorkee, 2006).

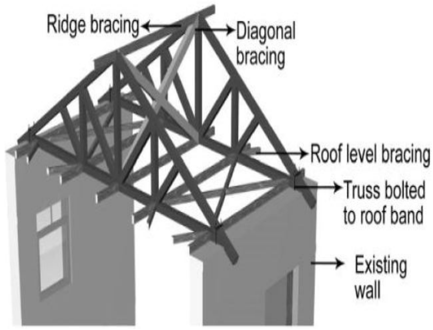

Figure 12: Bracing of sloped roof (IIT Roorkee, 2006)

7.2 Reinforced concrete buildings including high rise buildings

From the survey these "engineered structures" are seen to have serious deficiencies. (eg. Structures with floating columns have incomplete load paths. Such buildings have to be provided with new column (or shear wall panel) to complete the load path. For new multi storey constructions, cross bracings can be provided on columns to reduce the effect of quakes. The soft / weak storey is remedied by RC jacketing of columns and beams. Also shear walls can be provided between some of the columns at ground storey. Alternately steel braces are provided between some of the columns. Building asymmetry is remedied by providing slits at proper locations along with additional columns. Sometimes additional shear walls are provided to reduce torsion. To compensate for varying stiffness of columns of buildings on hilly slopes (which cause torsion); shear walls may be provided on the down hill side.

7. Conclusions

In general buildings in Kollam city seems to have sufficient resistance against moderate earth quakes as per Indian standard specifications and general criteria. Immediate and important attention is required for the residential structures. The growth rate of residential structures is very high and just a few have got seismic resistivity of its own. Government should impose new rules regarding seismic resistivity regulations and should educate the public about the possible damages due to earthquakes. The tendency of providing large openings and asymmetric designs are to be curbed. Economic retrofits in the form of wire meshed concrete on the corners of masonry walls in tiled roof structures and division of longer walls to shorter ones can be done for structures greater than 30 years of age. In commercial structures strict rules must be imposed to avoid huge capacity overhead water tanks. Also the provision of open cellar area for parking must be avoided. Tie beams at regular intervals should be provided for structures having floor height higher than 4m. Alternate technology must be developed to remove the mobile service towers from highly occupied areas. Schools should be of single storey as far as possible. The water tanks must be kept away from the buildings in the campus. The structural support between roof and walls of old tiled buildings should be improved by using cleat and angles connection. Long and big construction in a single stretch must be avoided. On the other hand smaller structure must be placed well apart.

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9. References

ACI 530 -88/ ASCE 5-88 1988 Building code requirements for masonry structures, ASCE, New York.

Agrawal S.K and A. Chourasia, Estimation of Seismic Vulnerability of Buildings in Delhi Municipal Area, Central Building Research Institute, Roorkee, India. From website on 03-10-2011: nidm.gov.in/idmc/.../A1-11-Shailesh%20Kr%20Agrawal.pdf

Alam M.J.B., M.A. Ansary, M.S. Rahman, Z. Uddin Ahmed, A.B.A. Imtiaz and M.M. Hossain (2007) Assessment of Vulnerability of Critical Infrastructures due to Earthquake in Sylhet City and Management, Proceedings of Pakistan Academy of Sciences, 44(3), 197-200.

Arya, A.S., 2008, Seismic Assessment of Masonry Buildings, Journal of South Asia Disaster Studies,1, 1, 23-43.

ASCE/SEI 31-03 ASCE Standard for Seismic Evaluation of Existing Buildings.

Bhattacharya, S.N., and Dattatrayam, R.S., 2002, EQ sequence in Kerala during Dec 2000 and Jan 2001", Current Science, 82,10, pp. 1275 – 1278. 25 May.

Bhupesh.S., Santhosh Unni.V, Hussain.M., Abhilash.B and Usha Kumari.T.S, Seismic Risk Assessment Of Existing Buildings In Kollam Corporation Limits, UG Project Report, Kerala University.

Brzev,S., 2004, Unreinforced brick masonry buildings with reinforced concrete roof slab, World Housing Encyclopedia report.

BS EN 1998-1:2004 Eurocode 8: Design of structures for earthquake resistance – Part 1: General rules, seismic actions and rules for buildings

BS EN 1998-1:2005, Eurocode 8 Design of structures for EQ resistance Part 1: General Rules, seismic actions and rules for buildings

BS EN 1998-3:2005, Eurocode 8 Design of structures for EQ resistance Part 3: Assessment and retrofitting of buildings

IIT Roorkee, 2006, Earthquake Risk Management, Lecture Notes, Department of Earthquake Egineering, India.

IMD (India Meteorological Department), Lodhi Road, New Delhi. http://www.imd.gov.in/section/seismo/static/welcome.htm

IS -13828-1993, Improving earth quake resistance of low strength masonry buildings.

IS 13935 Draft 2006, Guidelines for repair, restoration, condition assessment and seismic strengthening of masonry buildings.

IS -1893-Part 1 2002, Criteria for earth quake resistant design of structures- General Provisions and Buildings.

IS -4326-1993, Earth quake resistant design and construction and buildings-code of practice.

Kamatchi P., K. Balaji Rao, S.Arunachalam and N.R. Iyer (2011) Methodologies for Vulnerability Assessment of Built Environment subjected to Earthquakes, International Journal of Earth Sciences and Engineering, 4,6 SPL, pp. 183-188.

NBCC 1990, National Building Code of Canada, National Research Council of Canada, Ottawa, Ontario, Canada.

Paul, D.K.,Yogendra Singh, and Ruhela, M.K., 2002, Guidelines for Earthquake resistant buildings, Department of Earthquake Engineering, IIT Roorkee.

Rai,D.C., Review of Documents on Seismic Evaluation of Existing Buildings, Department of Civil Engineering, Indian Institute of Technology Kanpur India

Sadat, M.R., M.S. Huq and M.A. Ansary, 2010, Seismic Vulnerability Assessment of Buildings of Dhaka City, Journal of Civil Engineering, IEB, 38,2, 159-172.

Srikanth, T., R.P. Kumar, A.P. Singh, B.K. Rastogi and S.Kumar (2010) Earthquake Vulnerability Assessment of Existing Buildings in Gandhidham and Adipur Cities in Kachchh, Gujarat, India, European Journal of Scientific Research, 41,3,pp.336-353.

UCBC 1991 Uniform Code for Building Conservation, International Conference of Building Officials, Whittier, California.