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Vulnerability Assessment of Buildings through Rapid Visual Survey

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***Abstract*- This paper presents a methodology to predict the qualitative seismic vulnerability of buildings based on a number of structural parameters determined on the basis of engineering knowledge and observations through rapid visual survey (RVS). It's better to evaluate earthquake damage in a probabilistic way due to the uncertainty in occurrence of earthquake and respective structural response. Again, detailed seismic vulnerability evaluation is a technically complex and expensive procedure and can be applied on a very few number of buildings. Therefore, Rapid Visual Survey (RVS) can be much more effective to rapidly evaluate the vulnerability profile of different types of buildings, so that more complex procedures can be applied to the most critical buildings. The formats to evaluate score of R.C.C. and masonry structure are discussed. Further analytical study can be carried out to prepare risk maps for better disaster mitigation strategy. As RVS is the first stage for Seismic vulnerability assessment of the building, after that preliminary and detailed survey can be carried out. Base on the method discussed in this paper vulnerability assessment was carried out for Gandhidham city.**

Index Terms: Seismic Vulnerability, Rapid Visual Survey, R.C.C., Masonry

I. INTRODUCTION

Urbanization has increased pressure on housing industry, especially in high seismic zones. Many buildings of these zones have been found seismically vulnerable as most of these constructions are without earthquake resistant measures. The damage to the structures during recent earthquake in India has demonstrated the need for seismic risk assessment through which the consequences of earthquakes can be predicted. The collapse of buildings during an earthquake is the main contributor to the loss of lives and injuries to the people.

Seismic vulnerability is a measure of the capacity of a structure to resist seismic forces and is the main component of seismic risk assessment. Assessment of seismic vulnerability of existing buildings in urban areas would help in disaster mitigation and management by planning mitigation measures before an earthquake strikes. It is also useful to evaluate seismic safety of these constructions and to take necessary steps for their retrofitting so as to protect them from future earthquakes. The seismic vulnerability estimation is normally carried out based on earthquake resistance of buildings, past earthquake damage history & repair thereof, construction practices being adopted, building typology, seismic zoning of the area, building samples, detailed survey of selected buildings, and creation of database and its quantitative and qualitative analysis.

The quantitative approach of vulnerability assessment consists of evaluation of demand-capacity ratio (DCR) under extreme loading conditions. Qualitative procedure consists of visual inspection of buildings and estimation of structural scores for buildings and is known as Rapid Visual Survey (RVS).

II. METHODS FOR ASSESSMENT OF VULNERABILITY

Existing buildings can become seismically deficient when seismic design code requirements are modified to consider advances in engineering knowledge. Buildings built over past two decades are seismically deficient because of lack of awareness regarding seismic resistance measures. Also seismic design is not normally practiced in most of the buildings being built. Therefore, seismic vulnerability estimation is pre-requisite for disaster mitigation & management.

Vulnerability estimation is a complex process, which has to take into account not only the design of building but also the deterioration of the material and damage caused to the building, if any. The difficulties faced in seismic vulnerability estimation of a building are manifold. There is no reliable information / database available for existing building stock, construction practices, in-situ strength of material and components of the building. For earthquake load definition, ground motion parameters available in present code (IS: 1893- 2002) can be taken, if site dependent accentuations are not available for the area. The effect of local soil conditions are known to greatly modify the earthquake ground motion. Therefore, seismic vulnerability estimation mainly relies on set of general evaluation statements. There are two approaches for seismic vulnerability assessment: Quantitative approach and qualitative approach.

A. Quantitative Approach (Demand-Capacity Approach):

Quantitative approach for vulnerability assessment consists of a comparison between some measures of demand that the earthquake places on a structure to a measure of capacity of building to resist. The Demand/capacity ratio (DCR), thus evaluated is measure of earthquake resistance of a building. The DCR less than unity indicate the building is safe for respective stresses under consideration. However, any DCR exceeding one indicates that building is vulnerable to earthquake loads as defined in IS: 1893-2002.

B. Qualitative Approach (Rapid Visual Survey - RVS):

The Rapid Visual Survey (RVS) is aimed for identifying potentially hazardous buildings in the study area, without going into detailed analysis. RVS utilizes a methodology based on visual inspection of a building and noting the structural configuration. The methodology begins with identifying the primary structural lateral load resisting system and materials of the building. The method generates a Structural Score 'S', which consists of a series of 'scores' and modifiers based on building attributes that can be seen during building survey. The Structural Score 'S' is related to probability of the building sustaining life-threatening damage during a severe earthquake in the region. A low 'S' score suggests that the building is vulnerable and needs detailed analysis, whereas a high 'S' score indicates that the building is probably safe for defined earthquake loads.

III. RAPID VISUAL SURVEY

There are several steps involved in planning and performing a RVS of potentially seismically hazardous building.

1. If it is to be a public or community project, the local governing body and local building officials should formally approve of the general procedure.
2. The public or the members of the community should be informed about the purpose of the visual survey process and how it will be carried out. And also other decisions to be made, such as use of the survey results, responsibilities of the building owners and actions to be taken.

The general sequence of implementing the RVS is:

- Pre-planned survey and identify the area to be surveyed.
- Inspect the building from the exterior on all available sides; sketch the plan and elevation.
- If you have access to the interior, verify construction type, plan irregularities, size of the columns and others details.
- Photograph the building with instant or digital camera.
- Check for quality and file the field data in the record keeping system.

A. Field Survey of Buildings

The RVS uses a methodology based on a "sidewalk survey" of a building and a Data Collection Form, is filled up for each building based on visual observation of the building from the exterior, and if possible, the interior. RVS of buildings in the field should be carried out by teams consisting of two or three individuals. Teams of two are recommended to provide an opportunity to discuss issues requiring judgment and to facilitate the data collection process. If a building receives a high score (i.e., above a specified cut-off score), the building is considered to have adequate seismic resistance. If a building receives a low score on the basis of this RVS procedure, it should be evaluated by a professional engineer having experience or training in seismic design. On the basis of this detailed inspection, engineering analyses, and other detailed procedures are carried out. Finally determination of the seismic adequacy and need for retrofitting can be evaluated. The steps to be followed in RVS are shown in following Fig.1.

In the present study qualitative approach – Rapid Visual Survey (RVS) is followed with reference of Gandhidham city. The Kutch region in Gujarat state comes in the Zone V and Earthquake of intensity IX or more can be experienced in this zone. The 2001 Bhuj earthquake showed the high seismic vulnerability of Bhuj, Anjar and Gandhidham cities. In order to carry out a seismic vulnerability assessment of building in those cities, RVS can be carried out. As RVS is the first stage for Seismic vulnerability assessment of the building, subsequently preliminary and detailed survey can be carried out. RVS of Gandhidham city was carried out by Institute of Seismological Research and Institute of Technology, Nirma University. Database of RVS was prepared by International Institute of Information Technology, Hyderabad.

The study area of Gandhidham was divided into 12 wards. Formats of RVS form prepared by IIT Kanpur were used. The formats for R.C.C. building and Masonry building are shown in Fig. 2 and 3 respectively. For each building, performance score was calculated. Using data collected through the RVS, building database was generated using GIS for different area of Gandhidham city.

IV. BUILDING CHARACTERISTICS AND ASPECTS

There are two types of building: RCC & Masonry Buildings. Performance of building is evaluated through scores. Base score, Vulnerability score (VS) and Vulnerability score modifier (VSM) depends on type of buildings and their features.

A. Various features of R.C.C. Framed Building

- Building height and Natural period of Building
- Soft Storey
- Vertical Irregularities & Plan Irregularities
- Heavy Overhangs
- Water tank at Roof level
- Falling Hazards
- Soil Condition
- Pounding
- Short Column
- Frame Action
- Apparent Quality

The above features of RCC framed buildings are illustrated as under.

1) Building height and Natural period of Building

Building height is related to the vulnerability of the building. Low rise buildings are seismically less vulnerable. Natural period of the building depends upon mass of the building and stiffness. It can also be calculated approximately from height and dimension of building. When building's natural frequency matches with frequency of ground during earthquake maximum damage may takes place.

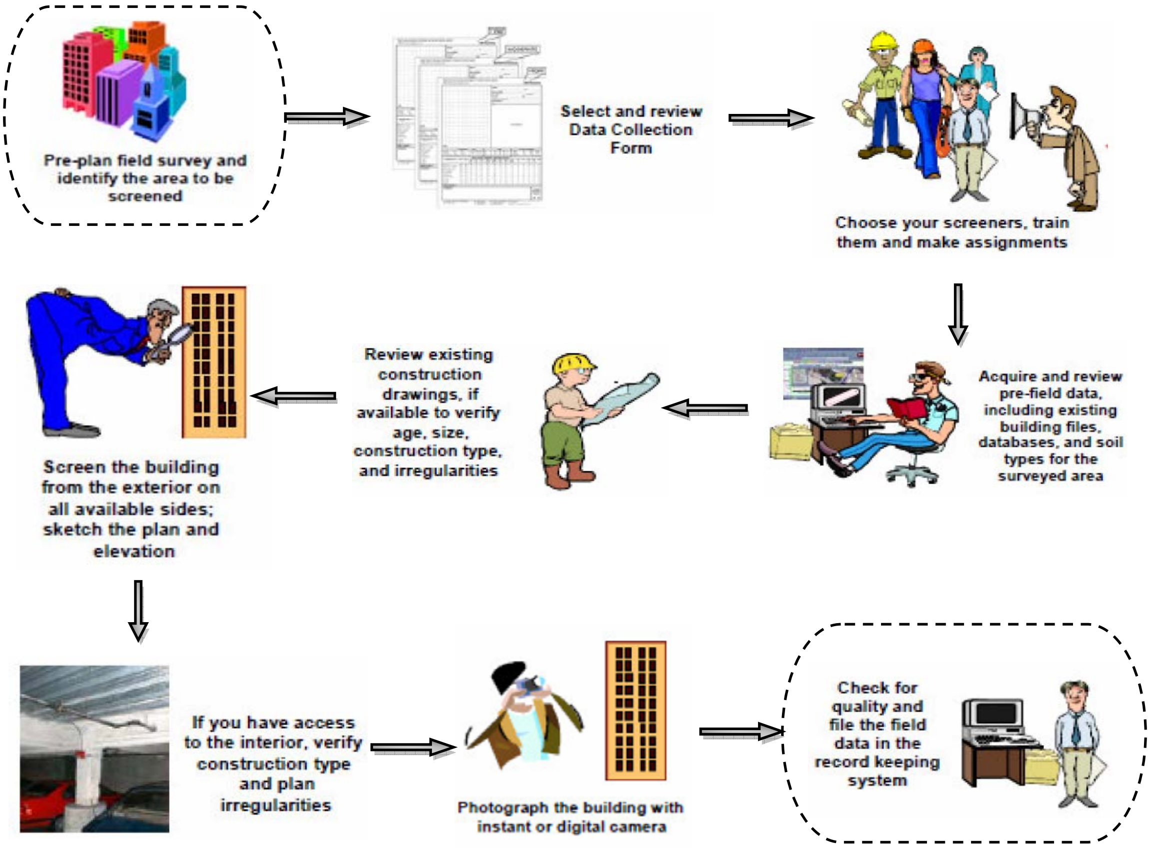

Fig. 1 Steps to be followed in Rapid Visual Survey (FEMA 154)

RAPID VISUAL SURVEY OF RC FRAME BUILDINGS FOR EARTHQUAKE SAFETY						**SEISMIC ZONE V**	
Address/Location/Street					CITY: Gandhidham		FULL ACCESS
Year of construction					STATE: Gujarat		PARTIAL ACCESS
Type of Construction	RC Frame		Number of Floors				NO ACCESS
Use	Residential	Commercial/ Office	Mixed	Other	Please specify		

CHECKLIST OF OBSERVABLES	**COMMENTS**
Soft Storey Open parking at ground level Absence of partition walls in ground or any intermediate storey for shops or other commercial use Taller heights in ground or any other intermediate storey	
Vertical irregularities Presence of setbacks Building on slopy ground	
Plan irregularities Irregular plan configuration Reentrant corners	
Heavy Overhangs Moderate horizontal projections Substantial horizontal projections	
Apparent Quality Apparent quality of materials and construction Maintenance	
Short Column	
Size of Columns at GF	
Pounding	
Soil Condition	
Frame Action	
Falling Hazards Non-structural elements such as elaborate parapets, AC unit grilles, elevation features	
Water tank at roof Capacity Location – Symmetrically placed or not	
Basement - Full or Partial	
PICTURES/SKETCHES	

RAPID VISUAL SURVEY OF BUILDINGS FOR EARTHQUAKE SAFETY			CALCULATION SHEET RC FRAME	
Falling Hazard Identifier 'F'			Seismic Zone	Base Score
Marquees/Hoardings/Roof Signs		Stories	V	
AC Units/Grillework		1 or 2	100	
Elaborate parapets		3	90	
Heavy elevation features		4	75	
Heavy Canopies		5	65	
Substantial Balconies		> 5	60	
Heavy Cladding				
Structural Glazing				

Number of storeys	1 or 2	3	4	5	> 5	Vulnerability Score Modifiers	
Vulnerability Scores (VS)						(VSM)	(VS X VSM)
Soft Story	0	-15	-20	-25	-30	Doesn't exist=0 Exists=1	
Vertical irregularities Setbacks Buildings on Slopes	-10	-10	-10	-10	-10	Doesn't exist=0 Exists=1	
Plan irregularities	-5	-5	-5	-5	-5	None=0 Moderate=1 Extreme=2	
Heavy Overhangs	-5	-10	-10	-15	-15	Doesn't exist=0 Exists=1	
Apparent quality	-5	-10	-10	-15	-15	Good=0 Moderate=1 Poor=2	
Short columns	-5	-5	-5	-5	-5	Doesn't exist=0 Exists=1	
Pounding	0	-2	-3	-3	-3	Doesn't exist=0 Unaligned floors=2 Poor apparent quality of adjacent building=2	
Soil Condition	10	10	10	10	10	Medium=0 Hard=1 Soft=-1	
Frame Action	10	10	10	10	10	Doesn't exist=-1 Exists=+1 Not sure=0	
Water tank at roof Capacity	0	-3	-4	-5	-5	Doesn't exist=0 Capacity < 5000 lit =0.5 Capacity > 5000 lit =1	
Location of Water tank	0	-3	-4	-5	-5	Symmetric = 0 Unsymmetrical = 1	
Basement - Full or Partial	0	3	4	5	5	Doesn't exist=0 Exists=1	
						∑ [(VSM) x (VS)]	

Performance Score= (BS) + ∑ [(VSM) x (VS)] where VSM represents the vulnerability score modifiers and VS represents the Vulnerability Score that is multiplied with VSM to obtain the actual modifier to be applied to the Basic Score (BS).		**Performance Score**	
Field Survey by:	Reviewed by:	Approved by:	
Date:	Date:	Date:	

Fig. 2 RVS Form for R. C. C. structure

RAPID VISUAL SURVEY OF MASONRY BUILDINGS FOR EARTHQUAKE SAFETY				SEISMIC ZONE V		
Address/Location/Street				CITY : Gandhidham		FULL ACCESS
Year of construction				STATE : Gujarat		PARTIAL ACCESS
Type of Construction	Brick Masonry	Stone Masonry	Composite	Number of Floors		NO ACCESS
Use	Residential	Commercial /Office	Mixed	Other	Please specify	

CHECKLIST OF OBSERVABLES IN MASONRY BUILDINGS	Tick	COMMENTS
Structural Irregularities Lack of adequate walls in both orthogonal directions Heavy overhangs Reentrant Corners Corner buildings	☐ ☐ ☐ ☐	
Apparent Quality Apparent quality of materials and construction Maintenance	☐ ☐	
Soil Conditions	☐	
Pounding Contiguous buildings Poor apparent quality of adjacent buildings	☐ ☐	
Openings Large openings in walls Irregularly placed openings Openings at corners of bearing wall intersections	☐ ☐ ☐	
Diaphragm Action Evidence of absence of diaphragms Evidence of large cut outs in diaphragms	☐ ☐	
Other features Horizontal bands at plinth level Horizontal bands at lintel level Horizontal bands at sill level Horizontal band at roof level Arches present/absent Jack Arch roofs Stone/masonry chimneys	☐ ☐ ☐ ☐ ☐ ☐ ☐	
Random rubble stone masonry walls Presence of thick walls 600mm and above Use of rounded stones Heavy roofs on URRM walls	☐ ☐ ☐	
Falling Hazards Non-structural elements such as elaborate parapets, AC unit grilles, elevation features, advertisement hoardings, roof signs, marquees, etc.	☐	
Wall Thickness at Ground Floor External Internal		
Water tank at roof Capacity Location – Symmetrically placed or not		
Basement - Full or Partial		
ANY OTHER SPECIAL FEATURES		

RAPID VISUAL SURVEY OF MASONRY BUILDINGS FOR EARTHQUAKE SAFETY			CALCULATION SHEET MASONRY	
FALLING HAZARDS IDENTIFIER 'F'			Seismic Zone	Base Score
Marquees/Hoardings/Roof Signs		Stories	V	
AC Units/Grillework		1 or 2	100	
Elaborate parapets		3	85	
Heavy elevation features		4	70	
Heavy Canopies		5	50	
Substantial Balconies				
Heavy Cladding				
Structural Glazing				

Number of storeys	1 or 2	3	4	5	Vulnerability Score Modifiers	
Vulnerability Scores (VS)					(VSM)	(VS X VSM)
Structural Irregularity	-10	-10	-10	-10	Doesn't exist/unsure=0 Exists=1	
Apparent Quality	-10	-10	-10	-10	Good=0 Moderate=1 Poor=2	
Soil Conditions	10	10	10	10	Medium=0 Hard=1 Soft=-1	
Pounding	0	-3	-5	-5	Doesn't exist=0 Normal apparent condition of adjacent building=1 Poor apparent condition of adjacent building=2	
Openings						
Wall openings	-5	-5	-5	-5	Small (less than 1/3) = 0 Moderate (Between 1/3 and 2/3) = 1 Large (Above 2/3) = 2	
Orientation of openings	-2	-5	-5	-5	Regular = 0 Irregular = 1	
Diaphragm Action	-10	-15	-15	-15	Present/Unsure=0 Lack of diaphragm action=1	
Other Features						
Horizontal Bands	20	20	20	20	Exist =+1 Don't exist=0	
Arches	-10	-10	-10	-10	Exist=1 Doesn't exist/unsure=0	
Stone Masonry						
Random Rubble Stone Masonry Walls	-15	-15	-15	-15	Remedial measures exist= 0 Don't exist = 1	
Water tank at roof Capacity	0	-3	-4	-5	Doesn't exist=0 Capacity < 5000 lit =0.5 Capacity > 5000 lit =1	
Location of Water tank	0	-3	-4	-5	Symmetric = 0 Unsymmetrical = 1	
Basement - Full or Partial	0	3	4	5	Doesn't exist=0 Exists=1	
					∑ [(VSM) x (VS)]	
Performance Score= (BS) + ∑ [(VSM) x (VS)] where VSM represents the vulnerability score modifiers and VS represents the Vulnerability Score that is multiplied with VSM to obtain the actual modifier to be applied to the Basic Score (BS).					**Performance Score**	
Field Survey by:		Reviewed by:			Approved by:	

Fig. 3 RVS Form for masonry structure

2) Soft Storey

Many buildings have higher storey heights at ground level (as shown in Fig. 4) or at any intermediate level i.e. different height at one or more levels, .Generally this is adopted at ground floor level which reduces stiffness of supporting columns compared to upper storey. Different cases of soft storey at different levels have been found. During an Earthquake this becomes a major cause of building failure.

Fig. 4 Picture showing soft storey

3) Vertical Irregularities

Vertical irregularities present in the building can be judged from the structural system at various floor levels. Setbacks in elevation cause vertical irregularity. The vertical irregular buildings are shown in Fig. 5.

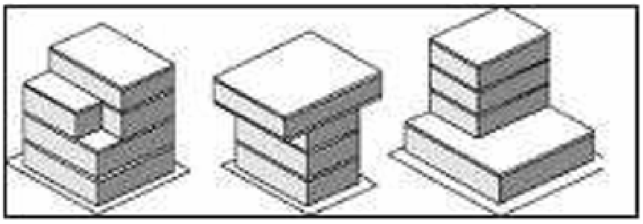

Fig. 5 Presence of Setbacks

4) Plan Irregularities

It is the irregularity in the plan caused due to various shapes as shown in Fig. 6. It causes torsion during earthquake and is responsible for major damage.

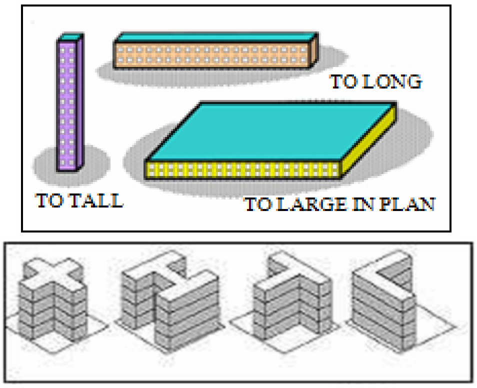

Fig. 6 Irregular Plan Configuration

When separation joints are provided complex plans are converted into simple plans.

Symmetry: The building as a whole should be symmetrical about both axes to avoid torsion damage during earthquake. If the building is divided into parts by movement / expansion joints each part will be symmetrical in itself. Symmetry is also desirable in the placing and sizing of door and window openings.

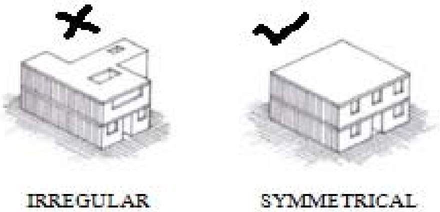

Fig. 7 Various Building Plan

Reentrant Corners: As per Fig. 8 where both the projection of structure are greater than 15 percent of its plan dimensions in the given direction, it is known as re-entrant corner. i.e. $A_1 > 0.15L_1$ & $A_2 > 0.15L_2$

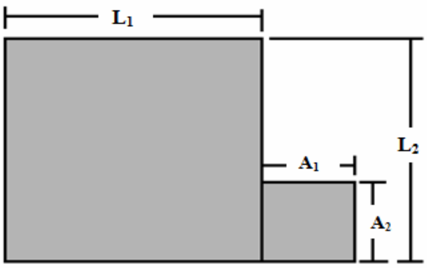

Fig.8: Reentrant Corners

5) *Heavy Overhangs*

Heavy overhangs refer to extra projections of a building that are suspended in air and have no vertical support (Fig. 9). They can be dangerous because they are subjected to greater seismic forces during an earthquake.

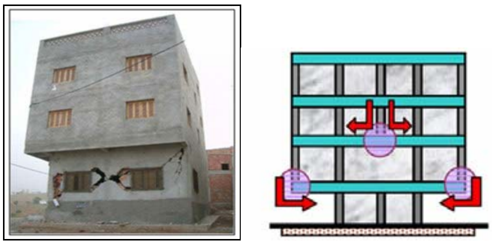

Fig. 9 Building with Heavy Overhang /Floating columns

6) *Water Tank at Roof*

Water tank at roof is dangerous because it has lot of dead load and if they are placed near the center of plan they may cause large amount of torsion.

Fig. 10 Water Tank at roof causing structural damage

7) *Falling Hazards*

Falling Hazards have contributed more to the causalities than any feature of a building. Fig.11 Shows the Chimney and large hoardings that is likely to fall during earthquake.

Fig. 11: Falling Hazard

8) *Soil Condition*

Soil condition is one of the Important Features to be considered. Soil is classified as hard, expansive and soft. These soil conditions are shown in Fig. 12. The hard soil is considered to be better than any other type of soil. SPT test can be carried out to know the soil condition.

Soft Soil Hard Soil Expansive Soil

Fig. 12: Various soil Conditions

9) *Pounding Action*

Pounding is the result of irregular response of adjacent building of different heights and different dynamic characteristics. When two buildings are too close to each other, they may pound on each other during strong shaking. As shown in the Fig. 13 the roof of the shorter building may pound at mid height of the column of the taller one; this can be very dangerous.

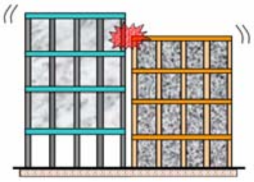

Fig.13: Pounding action

10) *Short Column*

Partial height walls adjoining to columns, give rise to short column effect in RC building (Fig. 14). Effect is implicit here because infill walls are often treated as non-structural elements. During past earthquakes, reinforced concrete (RC) frame buildings that had columns of different heights within one storey were damaged more in the shorter columns, as compared to taller columns in the same storey.

Consider a wall of partial height built to fit a window over the remaining height. The adjacent columns behave as short columns due to presence of these walls. If short and tall columns exist within the same storey level, then the short columns attract several times larger earthquake force and get damaged more compared to taller ones.

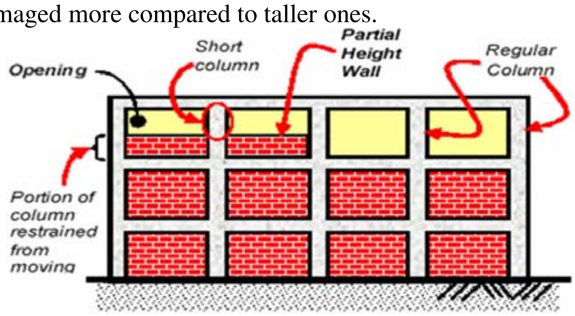

Fig. 14 Short column effect in RC buildings

Damage in these short columns is often in the form of X-shaped cracking due to shear failure. When a building is rested on sloped ground, during earthquake shaking all columns move horizontally by the same amount along with the floor slab at a particular level (this is called rigid floor diaphragm action) as shown in Fig. 15.

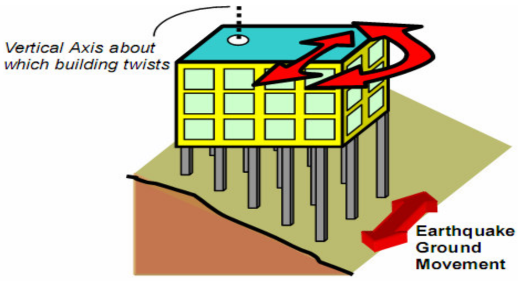

Fig. 15: Short Column Effect of Building on Sloppy Ground

11) *Frame Action*

Frame Action is to be present in the RCC buildings to transfer the load uniformly to the ground (Fig. 16).

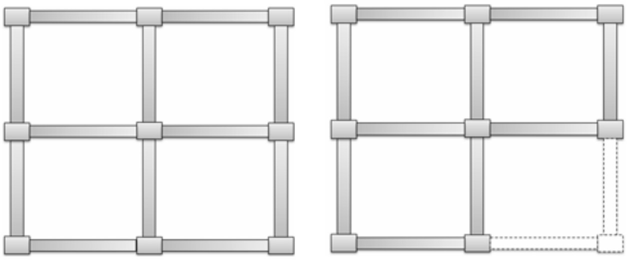

Fig. 16 Complete & Incomplete Frame action

12) *Apparent Quality*

Visible Quality of the material used in the construction works is also known as apparent quality. It also depends upon workmanship and materials used during construction.

Fig. 17: Poor Quality of Materials

B. *Various features of Masonry Structures*

Many features of masonry buildings are same as framed structures as evident from table 1.

The features that are different from RCC Building are as:

- Random Rubble Stone Masonry Walls
- Diaphragm Action
- Openings
- Other Features

1) *Random Rubble Stone Masonry Walls*

Most of the houses in the rural area are made of Random Rubble Stone Masonry Walls (as shown in Fig. 18). Hence the importance of structural integrity of these structures is required.

Fig. 18 Stone Masonry walls

2) *Diaphragm Action*

Diaphragm in form of rigid slab plays an important role in the transfer of lateral (horizontal) load on supporting structural elements. (as shown in Fig. 19).

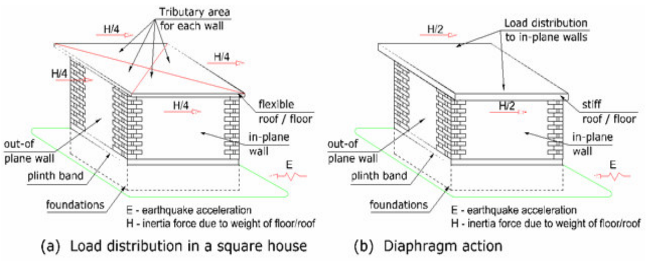

Fig. 19 Diaphragm Action

Stiff roof/ floor would allow distribution of inertia load in proportion to the wall stiffness. Fig. 20 illustrates the importance of diaphragm action. Simple model of square bearing-wall without opening in the slab behaves in better way. Large openings in slab and inclined roof cannot develop rigid diaphragm action.

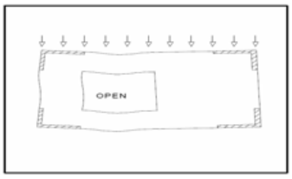

Fig. 20 Diaphragm Action in roof

3) Openings

General recommendations regarding the configuration of openings to be followed are as:

- Openings should be vertically aligned. The top ends of openings in the storey should be horizontally aligned.
- Openings should be located symmetrically in the plan of the building so that the uniform distribution of strength and stiffness in two orthogonal directions can be achieved.

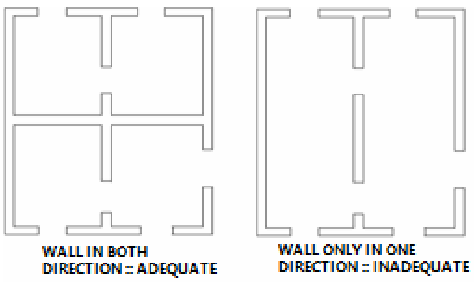

Fig. 21 Wall Openings

4) Other Features

It includes various Horizontal bands

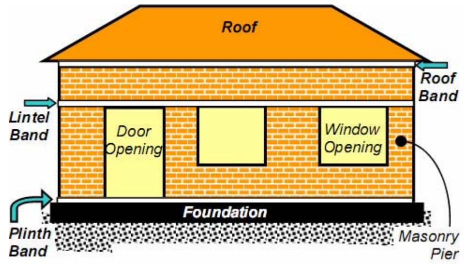

Fig. 22 Other Features of Building

5) Other Guidelines

Masonry walls should be constructed following simple instructions for quality workmanship:

- In dry and hot climate, masonry units should be soaked in water before the construction in order to prevent quick drying and shrinkage of cement based mortars.
- Lintels should also be provided at sill level (as shown in Fig. 23) and Masonry units should be assembled together in overlapped fashion with the reinforcement (as shown in Fig. 24) for making it Earthquake resistant.

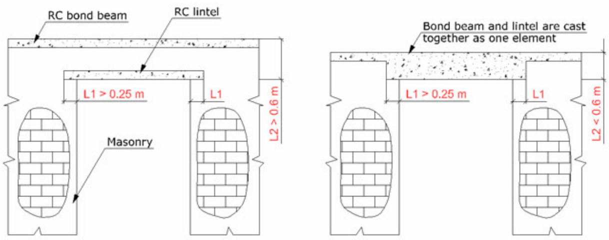

Fig. 23 Requirements for lintels in seismic zones

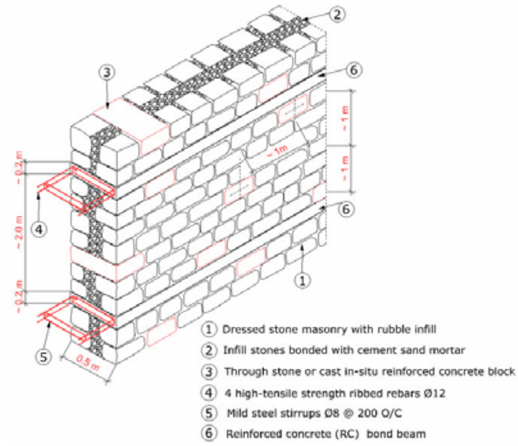

Fig. 24: Construction of Earthquake resistant masonry walls

V. SUMMARY

In present paper procedure for qualitative seismic vulnerability assessment of RC framed structures and masonry structures through rapid visual survey (RVS) is discussed. The formats to evaluate score of RC and masonry structure are discussed with appropriate illustration. RVS was carried out in Gandhidham city. Subsequent to RVS database of buildings having various features and having different range of score can be prepared. Further analytical study can be carried out to prepare risk maps for better disaster mitigation strategy.

VI. ACKNOWLEDGEMENT

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