ANALYSIS OF AN RCC FRAMED BUILDING STRUCTURE BY RAPID VISUAL SCREENING

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Abstract- India's seismic record includes several devastating earthquakes that have caused immense loss of life and property. Notable among them are the Bhuj Earthquake (2001), the Indo-Nepal Earthquake (2015), the Kashmir Earthquake (2005), and the Great Assam Earthquake (1897), with many others adding to the toll. The scale of destruction seen in these events makes risk assessment and mitigation essential. Seismic design practices have advanced considerably over time, but so have the challenges, especially those tied to design and execution on ground. Regardless of the maintenance efforts, structural deterioration over the long term remains unavoidable. At the same time, rapid population growth and increasing pressure on land for urban expansion have led to widespread lapses in construction quality control across the country.

In this article, there is a clear need for a method of structural performance evaluation that is fast, cost-effective, and dependable. One such practical approach is Rapid Visual Screening, commonly referred to as RVS.

Keywords- Rapid Visual Screening (RVS), RCC Framed Building, Seismic Assessment, Structural Vulnerability, Earthquake Risk Evaluation, Building Safety Inspection.

I. INTRODUCTION

Earthquakes cannot be stopped from happening. Over the years, India has been hit by several major earthquakes, each leaving behind heavy casualties and widespread destruction. In the last century alone, four great earthquakes struck different regions of the country: the 1897 Great Assam earthquake, the 1905 Kangra earthquake, the 1934 Bihar-Nepal earthquake, and the 1950 Assam earthquake. More recently, damaging events have continued to occur, including the 1988 Bihar-Nepal earthquake, 1991 Uttarkashi earthquake, 1993 Killari earthquake, 1997

Jabalpur earthquake, 1999 Chamoli earthquake, 2001 Bhuj earthquake, and the 2005 Jammu Kashmir earthquake. The repeated nature of these events points clearly to India's high seismic exposure and underscores how urgently a well-rounded disaster risk management framework is needed.

Urban centres across the country have seen a massive surge in population over the past few decades. A key reason has been the shrinking of livelihood options in rural belts, pushing people to migrate toward cities. This pace of urbanisation has given rise to sprawling slums and has stretched urban resources thin. Much of what gets built today in cities tends to be poorly planned and executed. Older stock, even where it once met the standards of its time, often falls short when measured against today's stricter codes. Before Bhuj, the country had largely been spared a major earthquake directly under an urban setting. That changed in 2001. The towns of Bhuj, Anjar, and Bhachau saw extreme damage across both old and newly built structures. Even in Ahmedabad, more than 200 kilometres from the epicentre, many recently built concrete buildings suffered severe cracking and failure—damage that should have remained minor had proper design and construction practices been followed.

The last decade has witnessed a swift rise in population across the globe, most visibly in developing nations. With this has come an explosion in demand for housing, commercial space, power networks, and transport infrastructure. Existing systems are being pushed harder than ever, and construction has had to speed up to keep pace with the growing needs.

With the arrival of fast-track construction methods, the importance of quality has only grown, particularly where seismic safety is concerned, and codes have become tighter in response. Yet, on the ground, a troubling gap persists. Shortcuts in construction, questionable practices, and deliberate neglect of code requirements remain all too common. When such lapses are combined with poor materials and increased loading, structures deteriorate faster, their vulnerability climbs, and the case for better assessment tools becomes stronger.

For a country like India, dealing with limited resources and vast building stocks, what is needed is a method that is quick, affordable, and trustworthy for evaluating seismic risk in structures. That is where Rapid Visual Assessment finds its place. The approach was built keeping exactly these constraints in mind and has already proven its worth across numerous projects worldwide.

“Rapid Visual Screening or Sidewalk Survey is a procedure of visual inspection of a particular building or a group or cluster of buildings of same type so as to identify the presence of basic structural anomalies and environmental damage which that building has faced during the years, recording these Observations and thus commenting on the seismic and overall safety of the building or group of buildings”

India’s national vulnerability assessment methodology as a component of earthquake disaster risk management framework should include the following procedures.

It is to be noted that RVS is only a method for visual assessment and no form of testing procedure can be involved in the process, also it must always be rapid and quick. Thus on the whole it is a process that uses visual inspection techniques and pertinent data for rapid assessment of structures. According to A Proposed Rapid Visual Screening Procedure for Seismic Evaluation of RC-Frame Buildings in India Sudhir K. Jain,a) M.EERI, Keya Mitra,b) Manish Kumar,c) M.EERI, and Mehul Shah Rapid visual screening (RVS) is a simple procedure for quick evaluation of a large building stock to prioritize the buildings for preliminary and detailed evaluations. It is usually based on walk down surveys requiring 15– 30 minutes on site for each building. RVS formats usually record the important components of seismic vulnerability and propose a scoring system that forms the basis for classifying buildings in different risk categories. Preliminary assessment techniques are employed to analyze the building performance when a more reliable assessment is required. This requires detailed information regarding the structural components, material properties and site conditions.

II. OBJECTIVES AND SCOPE

Objectives of the

The present study aims to evaluate the seismic vulnerability of RCC framed building structures using the Rapid Visual Screening (RVS) methodology and to develop an improved assessment framework suitable for Indian conditions. The study involves a detailed review of various RVS methodologies proposed by Indian researchers and integrates their significant features into a unified framework with appropriate modifications to FEMA-based scoring criteria. Special emphasis is given to identifying and incorporating structural and non-structural parameters that are more relevant to the Indian construction environment, thereby improving the reliability and accuracy of seismic assessments. In addition, a computer-based tool is developed to simplify and accelerate the screening process, making it more user-friendly and efficient. The proposed methodology is then applied to a number of RCC framed buildings, where field data are collected and corresponding vulnerability scores are generated. Finally, the results obtained from the assessment are analyzed to identify trends in structural vulnerability and to provide recommendations for future research and improvements in the proposed framework.

Scope of the Present Study

The scope of the present study is centered on the development and implementation of an enhanced Rapid Visual Screening methodology for the seismic assessment of RCC framed building structures. The study seeks to establish a practical and adaptable prototype that can serve as a foundation for a more comprehensive seismic vulnerability assessment model specifically tailored to Indian conditions. The proposed framework aims to offer a cost-effective, time-efficient, and reliable alternative to detailed structural evaluations while maintaining satisfactory accuracy. The study encompasses the modification of existing scoring procedures, collection of field data, and development of a computerized assessment tool capable of automating the evaluation process. Furthermore, the framework is designed with sufficient flexibility to accommodate future changes in seismic design codes, assessment parameters, and research findings. With continued validation through extensive field studies and data collection, the methodology has the potential to evolve into a standardized assessment tool for large-scale seismic vulnerability studies. In the future, the framework may also be extended to assess multiple hazards and contribute to the development of city-level databases for disaster risk reduction, emergency planning, and urban resilience management.

III. METHODOLOGY

1. Pulling together whatever information is available for the structure under review. This could mean building plans, details of materials used, what the building is used for, how old it is, and any past records of quake-related damage the structure may have suffered.

2. Putting together a small team of people who know what to look for, ideally architects, engineers, and building

inspectors who have worked on seismic evaluations before.

3. Doing a quick first pass through the gathered data to single out buildings that appear potentially risky or vulnerable and ought to be looked at on priority.

4. Walking through the building and looking things over by eye. The team moves through the structure, noting the condition of key structural parts, spotting possible weak points, and writing down any clear signs of damage or distress that are visible.

5. Building a list of the structures covered and ordering them by how vulnerable they appear. The ranking can be done with numbers or a colour scheme, with the higher ranks indicating greater cause for concern.

6. Carrying out the vulnerability screening itself using a set of pre-decided factors or a standard evaluation form. Things typically looked at include the kind of building, materials of construction, foundation type, any irregularities in shape or layout, and dangers posed by neighbouring structures or features.

7. Placing each building into a risk bucket based on the screening results, labels like "low," "moderate," "high," or "very high" risk being common. This step helps decide which structures need immediate attention and which can wait.

8. Offering broad suggestions tied to each risk level, meant to help owners and local authorities figure out what to do next. These could range from recommending a deeper engineering study, to retrofit measures, to full structural upgrades.

9. Shaping a model better suits local needs by reworking the weights and the factors taken into consideration during assessment.

10. Putting together a computer programme that can handle the basic inputs, churn out scores, and allow side-by-side comparison with the scoring formats used under FEMA and Indian Standard guidelines.

11. Taking the modified method out into the field, inspecting and rating a batch of real structures, and studying the results.

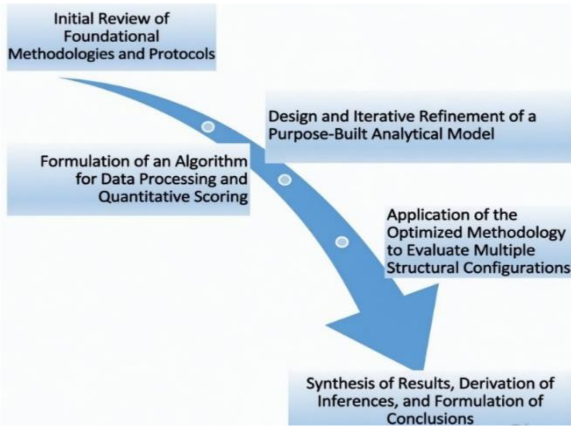

Figure 1. RVS Methodology

IV. RESEARCH & DEVELOPMENT

RVS has been in practice since time immemorial and is not a modern day tool. Since ancient times, those that were involved in the construction of structures were frequently called upon for their advice about the condition or construction of any new building. This, in essence, is the RVS methodology and those technical experts filled in the roles of the screeners.

The modern day variation of this method however is far more sophisticated than those in the

old days. It was initially developed by Federal Emergency Management Agency or FEMA in short. It is an agency functioning under the department of homeland security of

USA. It came into print in 1988 in the form of FEMA 154, Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook which was used to instruct both engineers and other trained personnel about the basic procedure and guidelines involved in the process.

Over the next decade there was a rapid rise in the use of RVS procedure among the private as well as government organizations to evaluate structures. The ease of use prompted many countries to develop methodologies of their own.

This was later on followed up by FEMA 154 2nd edition in 2002. The basic guidelines and the framework was same as that of the previous edition but there were improved score modifiers based on ground motion criteria as given by FEMA 310 Report, Handbook for Seismic Evaluation of Building.

After that "Rapid Visual Screening of Buildings for Potential Seismic Hazards"

Supporting Documentation FEMA 155, Edition 2 was released to further improve the FEMA RVS procedure. It explained how the scores for structure type and modifiers were decided based on Hazus vulnerability analysis.

The latest edition being FEMA 154 3rd editions published in 2014, this is also referred to as FEMA P-154. The major enhancements being:

1.An optional Level 2 Data Collection Form has been added.

2.The number of seismicity regions has been expanded from three to five to increase accuracy of screening in higher seismicity regions. The Third Edition seismicity regions are based on MCER ground motions (rather than the two-thirds of MCE ground motions that were used in the Second Edition).

3.Large multi-unit, multi-story wood frame residential and manufactured housing building types have been added.

This is supported by FEMA P-155, which includes the following enhancements:

1.Update of the Data Collection Form, and the addition of an optional more detailed page to the form.

2.Update of the Basic Scores and Score Modifiers.

3.Inclusion of additional building types that is prevalent.

4.Inclusion of additional considerations, such as non-structural hazards, existing retrofits, building additions, and adjacency.

Another major development following this was the IRVS, Integrated Rapid Visual

Screening process developed under BIPS, Buildings and Infrastructure Protection Series, September 2007 developed by the Department of Homeland Security, USA. This was used to improve the basic RVS method by integrating it with Google Earth with the help of a computer to assess building vulnerability to resist a wider variety of disasters like fires, terrorist attacks, cyclone etc. in addition to the seismic risk.

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RVS PROCEDURE BASIC WORKFLOW CHART

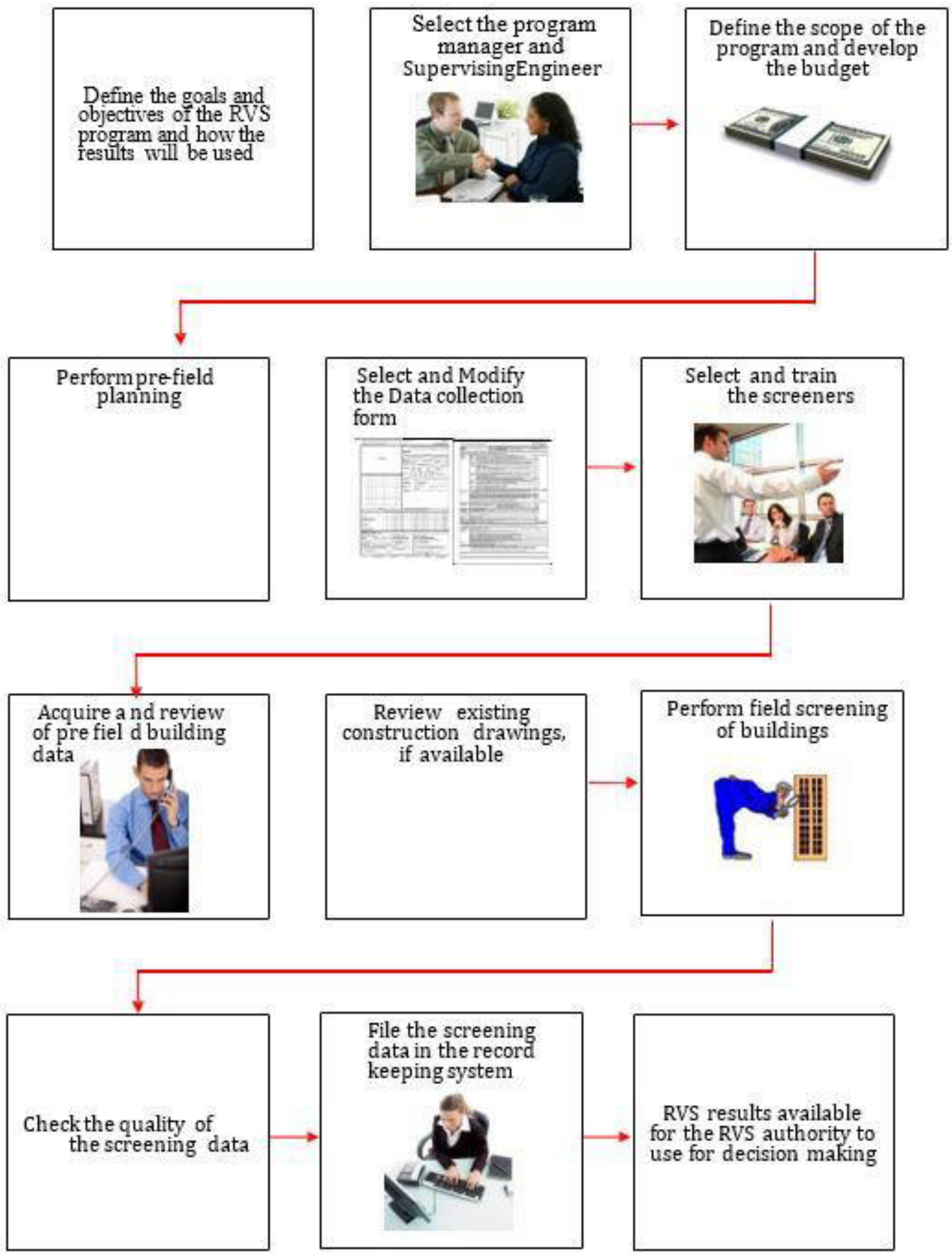

Figure 2: Basic Workflow Chart of RVS Procedure

The basic process as per this flowchart involves the following steps:

1. Defining the goals and objectives of the RVS program and how the results will be used.

2. Selecting the Program Manager and the Supervising Engineer.

3. Defining the scope of the program and develop the budget.

ISSN 2277 – 8322

4. Performing pre-field planning, to identify the area to be surveyed, dividing it into a grid pattern and assigning teams to each area, collection of suitable local data about soil types etc.
5. Selection and modification of the Data Collection Form, to suit the needs of the current survey.
6. Selection and training of the screeners, making them aware of the methods of collecting and reporting data and the proper protocol to be followed.
7. Acquisition and review of pre-field building data.
8. Reviewing existing construction drawings, if available from the local municipal corporation or the builder that performed the construction.
9. Performing field screening of buildings.
10. Filing the screening data in the record-keeping system.
11. Quality check of the collected data and reviewing it to draw suitable conclusions about the survey quality.

4 Basic Structural Forms and Their Scores

Following are the 17 FEMA Building Types considered in the FEMA P-154 RVS procedure.

1. Light wood frame single- or multiple-family dwellings of one or more stories in height (W1).
2. Light wood frame multi-unit, multi-story residential buildings with plan areas on each floor of greater than 3,000 square feet (W1A).
3. Wood frame commercial and industrial buildings with a floor area larger than 5,000 square feet (W2).
4. Steel moment-resisting frame buildings (S1).
5. Braced steel frame buildings (S2).
6. Light metal buildings (S3).
7. Steel frame buildings with cast-in-place concrete shear walls (S4).
8. Steel frame buildings with unreinforced masonry infill walls (S5).
9. Concrete moment-resisting frame buildings (C1).
10. Concrete shear-wall buildings (C2).
11. Concrete frame buildings with unreinforced masonry infill walls (C3).
12. Tilt-up buildings (PC1).
13. Precast concrete frame buildings (PC2).
14. Reinforced masonry buildings with flexible floor and roof diaphragms (RM1).
15. Reinforced masonry buildings with rigid floor and roof diaphragms (RM2).
16. Unreinforced masonry bearing-wall buildings (URM).
17. Manufactured housing (MH).

FEMA Building Type	Photograph	Basic Score	Characteristics and Performance
W1 Light wood frame single- or multiple-family dwellings of one or more stories in height		(VH) = 2.1 (H) = 3.6 (MH) = 4.1 (M) = 5.1 (L) = 6.2	• Wood stud walls are typically constructed of 2-inch by 4-inch (2-inch by 6-inch for multiple stories) vertical wood members set about 16 inches apart. • Most common exterior finish materials are wood siding, metal siding, or stucco. • Buildings of this type performed very well in past earthquakes due to inherent qualities of the structural system and because they are lightweight and low rise. • Earthquake-induced cracks in the plaster and stucco (if any) may appear, but are classified as non-structural damage. • The most common type of structural damage in older buildings results from a lack of connection between the superstructure and the foundation, and inadequate chimney support.
W1A Light wood frame multi-unit, multi-story residential buildings with plan areas on each floor of greater than 3,000 square feet		(VH) = 1.9 (H) = 3.2 (MH) = 3.7 (M) = 4.5 (L) = 5.9	• These are typically residential buildings, but some may have commercial space at the ground floor. • Large openings are common at the ground floor for parking. These are often termed tuckunder buildings. • W1A buildings with large openings at the ground floor for parking or commercial purposes have performed poorly in past earthquakes because the large openings create a soft story.

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W2 Wood frame commercial and industrial buildings with a floor area larger than 5,000 square feet		(VH) = 1.8 (H) = 2.9 (MH) = 3.2 (M) = 3.8 (L) = 5.7	• These are typically commercial buildings or industrial structures usually of one to three stories, and, rarely, as tall as six stories. • For commercial and industrial buildings with less than 5,000 square feet, the W2 type can be assigned as well.
S1 Steel moment-resisting frame		(VH) = 1.5 (H) = 2.1 (MH) = 2.3 (M) = 2.7 (L) = 3.8	• Typical steel moment-resisting frame structures have similar bay widths in both the transverse and longitudinal directions, around 20-30 feet. • The floor diaphragms are usually concrete, sometimes over steel decking. This structural type is used for commercial, institutional, and public buildings. • The 1994 Northridge and 1995 Kobe earthquakes showed that the welds in steel moment frame buildings were vulnerable to severe damage. The damage took the form of broken connections between the beams and columns. • The relatively low stiffness of the frame can lead to substantial nonstructural damage. • This building could also have a concrete seismic force-resisting system. See Appendix D for advice on how to identify FEMA Building Type.

Figure 3: FEMA structural types, scores and characteristics

ISSN 2277 – 8322

S2 Braced steel frame	  Close-up photo of building above	(VH) = 1.4 (H) = 0 2 (MH) = 2.2 (M) = 2.6 (L) = 3.9	• These buildings are braced with diagonal members, which usually cannot be detected from the building exterior. • Braced frames are sometimes used for long and narrow buildings because of their stiffness. • From the building exterior, it is difficult to tell the difference between steel moment frames, steel braced frames, and steel frames with interior concrete shear walls. • In recent earthquakes, braced frames were found to have damage to brace connections and, in some cases to the braces, especially at the lower levels.

S3 Light metal building		(VH) = 1.6 (H) = 2.6 (MH) = 2.9 (M) = 3.5 (L) = 4.4	• The structural system usually consists of moment frames in the transverse direction and braced frames in the longitudinal direction, with corrugated sheet-metal siding. In some regions, light metal buildings may have partial height masonry walls. • The interiors of most of these buildings do not have interior finishes and their structural skeleton can be seen easily. • Insufficient capacity of tension braces can lead to their elongation and consequent building damage during earthquakes. • Inadequate connection to a slab foundation can allow the building columns to slide on the slab. • Loss of the cladding can occur.

S4 Steel frames with cast-in-place concrete shear walls		(VH) = 1.4 (H) = 2.0 (MH) = 2.2 (M) = 2.5 (L) = 4.1	• Lateral loads are resisted by shear walls, which usually surround elevator cores and stairwells, and are covered by finish materials. • An interior investigation will permit a wall thickness check. A thickness in excess of six inches usually indicates a concrete shear wall. • Shear cracking and distress can occur around openings in concrete shear walls during earthquakes. • Wall construction joints can be weak planes, resulting in wall shear failure below expected capacity. • This building could also have a concrete frame. See Appendix D for advice on how to identify FEMA Building Type.
S5 Steel frames with unreinforced masonry infill walls		(VH) = 1.2 (H) = 1.7 (MH) = 2.0 (M) = 2.7 (L) = 4.5	• Steel columns are relatively thin and may be hidden in walls. • Usually masonry is exposed on exterior with narrow piers (less than 4 ft wide) between windows. • Portions of solid walls will align vertically. • Infill walls are usually two to three wythes thick. • Veneer masonry around columns or beams is usually poorly anchored and detaches easily. • This building could also have a concrete frame. See Appendix D for advice on how to identify FEMA Building Type.
C1 Concrete moment-resisting frames		(VH) = 1.0 (H) = 1.5 (MH) = 1.7 (M) = 2.1 (L) = 3.3	• All exposed concrete frames are reinforced concrete (not steel frames encased in concrete). • A fundamental factor governing the performance of concrete moment-resisting frames is the level of ductile detailing. • Large spacing of ties in columns can lead to a lack of concrete confinement and shear failure. • Lack of continuous beam reinforcement can result in hinge formation during load reversal. • The relatively low stiffness of the frame can lead to substantial nonstructural damage. • Column damage due to pounding with adjacent buildings can occur.

<table>
<tr>
<td>C2
Concrete shear wall buildings</td>
<td></td>
<td>(VH) = 1.2
(H) = 2.0
(MH) = 2.1
(M) = 2.5
(L) = 4.2</td>
<td>• Concrete shear wall buildings are usually cast-in-place, and show typical signs of cast-in-place concrete.
• Shear wall thickness often ranges from 6 to 18 inches.
• These buildings generally perform better than concrete frame buildings.
• They are heavier than steel-frame buildings but more rigid due to the shear walls.
• Damage commonly observed in taller buildings is caused by vertical discontinuities, pounding, and irregular configuration.</td>
</tr>
<tr>
<td>C3
Concrete frames with unreinforced masonry infill walls</td>
<td></td>
<td>(VH) = 0.9
(H) = 1.2
(MH) = 1.4
(M) = 2.0
(L) = 3.5</td>
<td>• Concrete columns and beams may be full wall thickness and may be exposed for viewing on the sides and rear of the building.
• Usually masonry is exposed on the exterior with narrow piers (less than four feet wide) between windows.
• Portions of solid walls will align vertically.
• This type of construction was generally built before 1940 in high seismicity regions but continues to be built in other regions.
• Infill walls tend to buckle and fall out-of-plane when subjected to strong lateral out-of-plane forces.
• Veneer masonry around columns or beams is usually poorly anchored and detaches easily.</td>
</tr>
</table>

PC1 Tilt-up buildings	  Partial roof collapse due to failed diaphragm-to-wall connection	(VH) = 1.1 (H) = 1.6 (MH) = 1.8 (M) = 2.1 (L) = 3.8	• Tilt-ups are typically one or two stories high and are basically rectangular in plan. • Exterior walls were traditionally formed and cast on the ground adjacent to their final position, and then tilted up and attached to the floor slab. • The roof can be a plywood diaphragm carried on wood purlins and glulam beams or a light steel deck and joist system, supported in the interior of the building on steel pipe columns. • Weak diaphragm-to-wall anchorage results in the wall panels falling and the collapse of the supported diaphragm (or roof).

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PC2 Precast	 Building under construction 	(VH)=1.0 (H)=1.4 (MH)=1.5	Precast concrete frames are in essence, post and beam construction in concrete. Structures often employ concrete or reinforced masonry (brick or block) shear walls. The performance varies widely and is sometimes poor. In addition to damage to shear walls similar to C2 buildings, PC2 buildings have additional issues as follows. Poorly designed connections between prefabricated elements can fail.

concrete frame buildings	Detail of the precast components  Building nearing completion	(M)=1.9 (L)=3.3	Loss of vertical support can occur due to inadequate bearing area and insufficient connection between floor elements and columns. Corrosion of metal connectors between prefabricated elements can occur.

			Walls are either brick or concrete block. Wall thickness is usually 8 inches to 12 inches. Interior inspection is required to determine if diaphragms are flexible or

RM1 Reinforced masonry buildings with flexible	 Truss-joints support plywood and light- weight concrete slab	(VH)=1.1 (H)=1.7 (MH)=1.8 (M)=2.1 (L)=3.7	rigid. The most common flexible floor and roof diaphragm systems are wood or light steel. These buildings can perform well in moderate earthquakes if they are adequately reinforced and grouted, with sufficient diaphragm anchorage. Poor construction practice can result in ungrouted and

diaphragms	 Detail showing reinforced masonry		unreinforced walls, which will fail easily.

RM2 Reinforced masonry buildings with rigid diaphragms		(VH) = 1.1 (H) = 1.7 (MH) = 1.8 (M) = 2.1 (L) = 3.7	• Walls are either brick or concrete block. • Wall thickness is usually 8 inches to 12 inches. • Interior inspection is required to determine if diaphragms are flexible or rigid. • The most common rigid floor and roof diaphragm systems are precast concrete or concrete over metal deck. • These buildings can perform well in moderate earthquakes if they are adequately reinforced and grouted, with sufficient diaphragm anchorage. • Poor construction practice can result in ungrouted and unreinforced walls, which will fail easily.
URM Unreinforced masonry buildings		(VH) = 0.9 (H) = 1.0 (MH) = 1.2 (M) = 1.7 (L) = 3.2	• These buildings often used weak lime mortar to bond the masonry units together. • Arches are often an architectural characteristic of older brick bearing wall buildings. • Other methods of spanning are also used, including steel and stone lintels. • Unreinforced masonry usually shows header bricks in the wall surface. • The performance of this type of construction is poor due to lack of anchorage of walls to floors and roof, soft mortar, and narrow piers between window openings.

MH Manufactured housing		(VH) = 1.4 (H) = 1.8 (MH) = 2.2 (M) = 2.9 (L) = 4.6	• These buildings can be mobile homes or modular buildings, such as those used for portable classrooms. • The buildings are mobile, raised up off the ground, not anchored to the ground, and may or may not have an earthquake resistant bracing system (ERBS). • Manufactured homes are typically one story and come in different sizes. A single-wide unit can be up to 18 feet in width. A double-wide unit is 20 feet or more in width. • Floors and roofs are usually constructed with plywood or oriented strand board, and the outside surfaces are covered with sheet metal. • The primary source of damage is due to the lack of a permanent foundation connection or an earthquake-resistant bracing system (ERBS). In moderate shaking, the building can fall off its supports, and jack stands can penetrate the floor. Connecting utility lines can be severed, and escaping gas can cause fires.

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