A Methodology for documenting Housing Typologies in the Moderate-Severe Seismic Zones

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SUMMARY
The paper presents first-cut of the salient findings and inferences of a pilot study of housing sub-typologies practiced in seven locations in moderate to severe seismic zones in India. Field trips were conducted to understand housing approaches, methods and constraints employed in 7 locations of the moderate-to-severe seismic zones of India. Based on these field trips, the following deliverables are offered: (1) A methodology for technical documentation of housing typologies in moderate-to-severe seismic zones, through documentation of all safety-related information of an individual house; and (2) A base-level Technical Evaluation Method of earthquake safety of a house for the prevalent earthquake hazard at the location of the house. This method provides both Seismic Safety Index and Performance Rating Method for benchmarking an individual house with respect to an ideal house of the same typology built to resist earthquake shaking in the same seismic environment.

Keywords: Life Threat; Economic Loss; Delphi-Method; Safety Assessment; Ideal House

1. INTRODUCTION

Housing is a major contributor to losses, both life and property, during earthquakes. The challenge is grave in many countries with moderate-to-severe seismic hazard along the Alpine-Himalayan belt. This is compounded by low perception of risk and therefore there is no or very low levels of preparedness. Many communities in earthquake regions of the country barely recognize the problem that safe housing is critical to their sustainable development. These communities need to be supported in reducing earthquake risk to their housing. Substantial amount of technical information on earthquake safe constructions is available within the world technical community and also in public domain. But, this knowledge currently is yet to reach communities that are (a) desirous of implementing housing projects, and (b) required to implement safer housing to reduce earthquake risk in future. The available literature may not always be applicable to specific local housing typologies. Many countries along the seismic belts of the world are far from reaching this target.

1.1 Seismic Risk of Indian Housing Stock

The existence of seismic faults in peninsular India and the consequent seismic threat has been articulated in the Indian seismic code IS:1893 since the early 1960s. The 1.2 billion population of India lives in over 25,000,000 houses built on soil cover that varies across the country. About 60% of land area (with ~78% population) is under the threat of moderate to severe seismic shaking as per the Seismic Zone Map of India. The seismic hazard and prevalence of large housing stock in seismic areas makes a significant part of housing in India at risk to earthquake damage and loss (Figure 1.1). Of the determinants of risk of the Indian population to seismic shaking across the country, *vulnerability* of Indian house construction strategies is the focus of this study.

A pointer that gives deep insights into *vulnerability* of housing in India is the choice of material used in the construction of houses across the country. Table 1.2 shows summary statistics of the material for wall construction in rural areas, urban areas and entire country (Census of India, 2001). The dominant materials of choice are: 9.9% of grass, thatch, bamboo, wood, etc; 29.6% of mud & un-burnt brick; 44.9% of burnt brick; and 10.2% of stone. These choices together total to 94.6% of houses in the country. This is in great contrast with the emphasis of the civil engineering and architectural education imparted across India. On the one hand, the dominant housing construction materials (stone, brick and adobe) listed above are reflected in only 3% of the courses taught to the undergraduate students. In particular, the course on masonry is almost extinct in the curriculum across the engineering colleges in the country. On the other hand, 97% of the curriculum in the country is addressing the small minority of 2.6% of RC buildings.

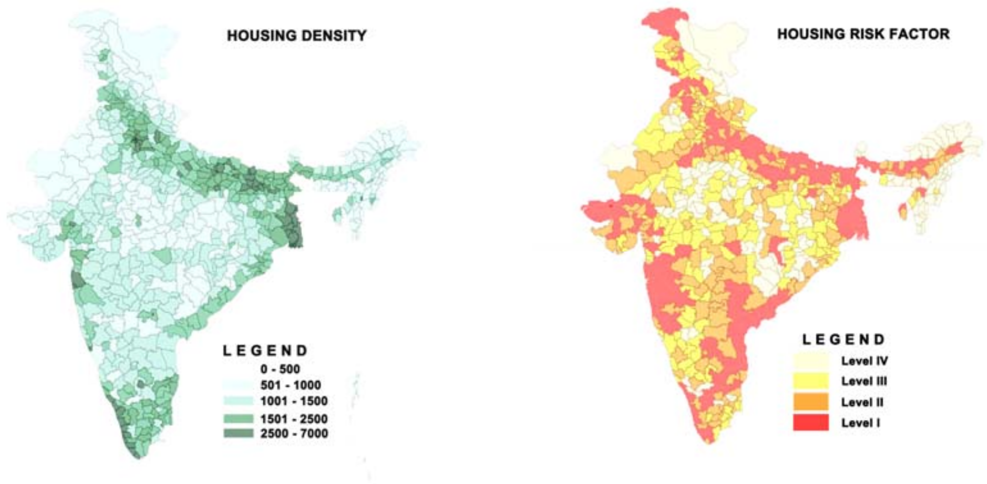

Figure 1.1 District-wise (a) housing density (Number of houses/km^2), and (b) Housing risk factor (Seismic Zone Factor multiplied by number of houses/km^2) (Data Sources: IS:1893(1)-2004 and BMTPC, 2007)

Table 1.2 India summary of choice of wall material in construction in houses (Source: Census of India, 2001)

S.No.	*Material*	*Number of houses*					
		India	*%*	*Rural*	*%*	*Urban*	*%*
1.	Grass, Thatch, Bamboo, Wood, …	247,737,121	**9.9**	22,162,932	12.5	2,574,189	3.6
2.	Plastic, Polythene	721,776	0.3	477,498	0.3	244,278	0.3
3.	Mud, Unburnt Brick	73,799,162	**29.6**	65,807,212	37.1	7,991,950	11.2
4.	Wood	3,196,992	1.3	2,363,200	1.3	833,792	1.2
5.	GI, Metal, Asbestos sheets	1,998,678	0.8	876,677	0.5	1,22,001	1.6
6.	Burnt Brick	111,891,629	**44.9**	62,715,919	35.5	49,175,710	68.7
7.	Stone	25,481,817	**10.2**	20,347,899	11.5	5,133,918	7.2
8.	Concrete	6,540,338	**2.6**	2,253,979	1.3	4,286,359	6.0
9.	Other	728,356	0.3	532,197	0.3	196,159	0.3
	Grand Total	**249,095,869**	**100.0**	**177,537,513**	**71.3**	**71,558,356**	**28.7**

Recognising the above skewed situation, we need to develop clear understanding of this vulnerability of the building stock in the country, towards (1) identifying measures that can retrofit the existing building stock to earthquake-resistant standard, (2) ensuring that new houses constructed are not vulnerable, and (3) making systemic changes (as part of capacity building and preparedness initiatives of disaster management) towards mitigating impending earthquake disasters. Hence, a systematic methodology is required for

(a) Documenting Housing Typologies in the Moderate-Severe Seismic Zones of India, with a view to (i) understanding the extent of loss that is expected in each existing housing type, and (ii) developing guidelines for all new constructions; and
(b) Retrofitting the vulnerable housing stock in the Moderate-Severe Seismic Zones of India.

1.2 Housing Safety Assessment

Four types of documents are available related to earthquake safety assessment of houses, namely

(a) *Rapid Assessment before an earthquake*: for understanding earthquake risk that a community/town/city is faced with regard to earthquake performance of houses. This assessment is useful for creation of an earthquake scenario and extrapolating the estimated damage and loss in a seismic event of a particular intensity;
(b) *Rapid Assessment after an earthquake*: for deciding whether a building in the earthquake affected area can be occupied or not;
(c) *Safety Assessment before an earthquake*: for assessing its earthquake resistance and compliance code, and determine the need for earthquake strengthening; and
(d) *Detailed Assessment after an earthquake*: for estimating the level of damage and loss and possible seismic retrofit methodologies for individual buildings.

Many documents are available that address these four levels of assessment. This study comes under the type (c) above. Detailed assessment of houses before earthquake largely is performed keeping in mind the relevant national standards. Explicit documents in this subject are published under the title of retrofitting. A number of documents are available worldwide for specific structure types. However, no explicit documents is available that is universally acceptable, owing to the need to be compliant with the national standards.

Rapid Visual Screening (RVS) procedures are useful in developing a broad based classification of the building stock; these are not applicable for ascertaining seismic vulnerability of individual buildings. They project trends of expected performance of housing in a given region during damaging earthquakes, because these methods are based on statistical correlations of few characteristics of a building with actual performance of buildings with these chosen characteristics during past earthquakes. But, characteristics considered in RVS methods do not cover all aspects of safety. For example, how well the roof and the walls are connected is not addressed in those RVS methods. Hence, the prevalent methods are able to give only a broad projection of the earthquake behaviour of buildings, but do not provide individual house owners with clear actionable items on how and where they need to improve their dwelling. Therefore, a formal method is required to comprehensively assess earthquake resistance of individual houses of a certain typology from many factors, like architectural aspects, structural system features, construction issues, utilities, and contents of the house.

The current study has the following three objectives related to housing sub-typologies in moderate to severe seismic areas in India:

(a) Arrive at a methodology for cataloging housing typologies in moderate-to-severe seismic zones of India, for technically documenting all safety-related information of an individual house,
(b) Propose a method for *Base Level Technical Evaluation* of earthquake safety of a house under prevalent earthquake hazard at the location of the house, that provides both *Seismic Safety Index* and *Performance Rating Method* for benchmarking an individual house with respect to an *IDEAL HOUSE* of the same typology built to resist earthquakes in the same seismic environment; and
(c) Suggest a plan for future initiatives aimed towards reducing earthquake risk to housing in India.

The subsequent sections of this paper dwell in brief on the first two objectives.

2. SAFETY INDEX-CUM-PERFORMANCE RATING METHOD FOR SEISMIC EVALUATION OF AN INDIVIDUAL HOUSE

A method is proposed to undertake a base level technical evaluation of a house before an earthquake to understand the possible performance of a house of a certain typology during strong earthquake shaking. This telescopic scheme has two evaluations, namely the (a) *Safety Index*, and (b) *Seismic Performance Rating*. The former assesses *overall safety* of the house (life safety) in an earthquake based on global parameters, and the latter helps *estimate the economic loss* in an earthquake based on *structure* and *contents* of the house. Only when building typology passes the first evaluation, it is subjected to the second; this implies that, if a building does not have *basic seismic safety* assured through the global parameters, assessing *economic losses* may not be meaningful. This assessment method may be undertaken for a number of reasons, including for first evaluation before undertaking detailed retrofitting of a house. Step-wise procedure is described in the sub-section below to evaluate the seismic safety of a house from the above two standpoints.

2.1. Step-wise Procedure for Safety Assessment

Step1: Describe the IDEAL form of the HOUSING SUB-TYPOLOGY
A detailed description should be prepared of the IDEAL way of constructing the specific housing sub-typology in focus, based on the following inputs: (a) post-earthquake field investigations, (b) experimental studies under dynamic ground shaking or equivalent static actions reflecting the ground shaking, (c) analytical understanding of the earthquake behaviour, and (d) field visits to learn practical, implementable ways of its construction. The description must have provision for expanding on the definition/description of the IDEAL way of constructing the housing sub-typology.

Step 2: List all Factors that affect earthquake safety of the house
List all factors that are likely to influence the seismic safety of the housing type under two broad categories, namely aspects related to:

(a) Structural System and Structural Elements: The house *structure* construction related factors (S), refer to the planning and making of the physical structure of the house, can be re-grouped under sub-categories of (i) Soil-Foundation, (ii) Architectural configuration and systems, (iii) Materials used and construction methods adopted, (iv) Structural systems, components and maintenance, and (v) Construction methods; and

(b) Utilities and Non-Structural Elements: The house *contents* and utilities related factors (C), refer to the utilities and non-structural components of the house, can be re-grouped under sub-categories of (i) Falling and Pulling Hazards, and (ii) Earthquake-induced Secondary Hazards.

This comprehensive list of factors within each of these sub-categories will be different for each housing typology, and different for different housing sub-typologies within each housing typology. And, such a list for any particular building sub-typology is expected to evolve through field surveys, which study the possible regional variations and their implications on earthquake safety of the house.

Step 3: Identify Critical Factors
Classify these factors into one of two basic streams, namely

(a) *Life-Threatening Factors*: An unsafe condition related to this factor reflects that the house is in jeopardy from safety stand-point. These are of two types, namely (i) those related to the house structure, and (ii) those related to the contents and utilities of the house; hereinafter, these two sets of factors will be referred to as *Life Threatening House Structure Factors L(S)* and *Life Threatening House Contents Factors L(C);* and

(b) *Economic Loss-Inducing Factors*: A departure from the ideal condition related to this factor may not cause the house to collapse or cause life-threatening conditions in the house, but will attract huge economic losses when retrofitting the house to be earthquake-resistant. Hereinafter, these factors will be referred to as *Economic Loss-Inducing House Structure Factors E(S)* and *Economic Loss-Inducing House Contents Factors E(C)*. These factors include items drawn from clauses of the relevant Indian Standards to be adopted in the construction of a house belonging to the said housing typology.

Step 4: Assign Safety Indices to L Factors

Assign Safety Index values, 0 or 1, for each of the *Life-Threatening Factors*, depending on whether that factor is likely to be life threatening or not, respectively. If any one of the L Factors is assigned a Safety Index of 0, STOP the *Safety Evaluation* of the Housing Typology; the house is UNSAFE. If all of the L Factors are assigned a Safety Index of 1, then undertake the *Performance Rating* of the E factors of the Housing Typology as per Step 5. That exercise in Step 5 should be done for both the E(S) factors and E(C) factors.

Step 5: Undertake Seismic Performance Rating of E Factors

The IDEAL HOUSE will have a cumulative Performance Rating of 100%. To any building being rated, assign a total rating of 100% to begin with, *i.e.*, as if it is an ideal house with excellent earthquake-resistant characteristics. And, for each departure (including absence) from the declared set of ideal characteristics, apply a penalty by subtracting a *Non-performance Performance Rating Value (NPRV)* for each E factor; an upper-bound *Maximum Non-performance Performance Rating Value (MNPRV)* is prescribed for each E factor. Each of these NPRVs or MNPRVs is expressed in percentage. Therefore, the net performance rating or *Expected Performance Rating (EPR)* of the building is 100% minus the cumulative of the NPRVs assigned to all E-factors. This exercise should be done for both the E(S) factors and E(C) factors. Quantitative guidance is sought from relevant Indian Standards to be adopted in the construction of the house of the housing typology in focus.

2.2 Customisation for Different Housing Typologies

The above step-wise procedure is employed for each of the housing typologies. *Life Safety Assessment* is performed *first*, and if a house passes that, *only then* it is ready for the *Economic Loss Assessment*. Under the broad categories of housing construction factors (site conditions, soil conditions, architectural conditions, material conditions, and structural conditions), and non-structural elements (toppling and falling hazards, and earthquake induced secondary hazard), the individual parameters are different for different housing typologies. Hence, the assessments forms will be different for the different housing typologies, both life safety as well as economic loss. There will be similarities in the forms for various housing sub-typologies within a housing typology, but not across the housing typologies.

The approach taken above is to perform the safety assessment through the Life Safety Indices L(C) and L(S). If a house is rendered unsafe based on these two sets of indices, then the owner of the house should fix these items first. Then, even these houses are ready for Economic Loss Assessment. Currently, in the Economic Loss Assessment forms presented, the E(C) and E(S) parameters are generic for all seismic zones, namely Seismic Zones III, IV and V. Once the overall methodology is agreed upon, zone-specific Economic Loss Assessment forms can be created.

3. TYPICAL FIELD REPORT - STONE MASONRY HOUSE IN TEHRI, INDIA

Typical stone masonry houses in Tehri region of North India are two storeys tall (Figure 5.1). Often, the house is built along hill slopes, and is accessed only from the valley side. Sometimes, the house is built touching the hills slope; in such cases, the access is from the road for the upper storey. The report of the pilot project [Murty et al, 2012] has detailed description of the site, architectural aspects, structural aspects, constructional aspects, and overall appreciation of the seismic safety of the housing typology. These details are not presented in the paper for want of space; the same may be seen in the detailed report of the pilot study. The report has large number of photographs to support claim of possible variations as recorded during the field visit; again these are not provided in this paper.

Figure 5.1 Functional layout of a typical two-storey house in the Tehri-Garhwal region of Uttarakhand state in India provides for front open verandah in the upper storey for performing many domestic chores in sunlight

3.1 Safety Index Assessment

Life-threatening factors related to the house construction are classified under *site conditions*, *soil conditions*, *architectural conditions*, *material conditions* and *structural conditions*. Unacceptable variations in these factors are listed in Table 3.1 under each of these five categories. Associated Life Safety Indices L(C) also are listed therein for each of these unacceptable variations. Similarly, life-threatening factors related to non-structural elements of the house are classified as factors related to *Toppling/Falling Hazards*, and *Earthquake-induced Secondary Hazard*. Unacceptable variations in life-threatening factors are listed in Table 3.2 under each of these three categories. Associated Life Safety Indices L(S) also are listed therein for each of these unacceptable variations.

Table 3.1 Life-threatening factors related to the house construction, and the associated Safety Indices L(C) for unacceptable variations in them

S.No.	*Life Threatening Factors*	*Life Safety Index*	
		0, if	*1, if*
1	**Site Conditions**	(a) House is built on hill slopes that can slide, OR (b) House is built on river terraces that can slide/creep, OR (c) House is built on hill slopes /adjacent to hill slopes (even though on flat ground), but vulnerable to falling debris from the hill top	None of the conditions mentioned to the left are satisfied
2	**Soil Conditions**	(a) Soil underneath the house is liquefiable, OR (b) Soil in the area adjoining the site is liquefiable and can flow laterally to move the soil from underneath the house	
3	**Architectural Conditions**	(a) Outer dimensions of the house at plinth level are less than those at the top in either of the two horizontal plan directions, OR (b) House has large unanchored projections and overhangs, OR (c) Door and window openings in walls are at the corners, OR (d) House is touching or located too close to adjacent seemingly unsafe house.	
4	**Material Conditions**	(a) Walls of the house are made with mud mortar and are exposed to vagaries of weather (especially rain water beating)	
5	**Structural Conditions**	(a) Roof is is not integral within itself (i.e., it does not act as a single unit and breaks open during earthquake shaking) and is not anchored into walls, OR (b) Walls are thick and made in two wythes, OR (c) Walls are not integrated into each other at the corners, OR (d) Staircases are not anchored into the walls of the house	

Table 3.2 Life-threatening factors related to the contents and utilities of the house, and the associated Safety Indices L(S) for unacceptable variations in them

<table>
<tr><th rowspan="2">S.No.</th><th rowspan="2">Life Threatening Factors</th><th colspan="2">Life Safety Index, L(NS)</th></tr>
<tr><th>0, if</th><th>1, if</th></tr>
<tr><td>1</td><td>Toppling or Falling Hazards</td><td>(a) A large object on the roof is unanchored, OR
(b) Shelves inside the house are unanchored, OR
(c) Lofts inside the house are unanchored, OR
(d) Objects on/in the lofts/shelves inside the house are unanchored</td><td rowspan="2">None of the conditions mentioned to the left are satisfied</td></tr>
<tr><td>2.</td><td>Earthquake-induced Fire Hazard</td><td>(a) House has exposed wood used in construction (either as wall panels, roofs, lofts, or floors), thatch, husk, or exposed cloth in finishing of the house, at points close to locations of potential stove fire, electric sparks or gas leakage fire that can result in a fire in the house during an earthquake, OR
(b) House has electric wires held rigidly between house and street pole with no slack, that can result in short circuiting and fire during an earthquake, OR
(c) Gas cylinders are not strapped to wall, that can toppling, which in turn can lead to gas leakage and thereby fire during an earthquake, OR
(d) Electric wires are held rigidly between house and street pole with no slack, that can result in short circuiting and electrocution during an earthquake, OR
(e) Gas cylinders are not strapped to wall, that can toppling, which in turn can lead to gas leakage and thereby asphyxiation of persons during an earthquake</td></tr>
</table>

3.2 Seismic Performance Rating

Economic Loss-Inducing factors related to *house construction* are classified under *site conditions*, *soil conditions, architectural conditions, material conditions* and *structural conditions*. The ideal conditions for these factors and possible variations in Economic Loss-Inducing factors are listed in Table 3.3 under each of these five categories. Associated Seismic Performance Rating E(C) also are listed therein for each of these variations. Maximum penalties that can be levied under each of these categories are:

1. Site Conditions -5%
2. Soil and Foundation Conditions -5%
3. Architectural Conditions -35%
4. Material Conditions -20%
5. Structural Conditions -35%

If sub-total of penalties under each category (*i.e.*, sum of Seismic Performance Rating E(C) values for variations listed under the category) exceeds these stated maximum, sub-total is taken as these maximum values only.

Similarly, Economic Loss-Inducing factors related to *non-structural elements* of the house are classified as factors related to *toppling/falling hazards, lifelines,* and *earthquake-induced fire hazard.* The ideal conditions for these factors and possible variations in Economic Loss-Inducing factors are listed in Table 3.4 under each of these three categories. Associated Seismic Performance Rating E(S) also are listed therein for each of these variations. Maximum penalties that can be levied under each of these categories are:

1. Toppling/Falling Hazard -70%
2. Lifelines -30%

If sub-total of penalties under each category (*i.e.*, sum of Seismic Performance Rating E(S) values for variations listed under the category) exceeds these stated maximum, sub-total is taken as these maximum values only.

Table A3: Economic Loss-Inducing Factors related to the house construction, and the associated Seismic Performance Rating E(C) for variations in them

S.No.	*Economic Loss Inducing Factor*	*Ideal Condition*	*Variations*	*Rating (%), E(C)*
1. Site Conditions				
1.1	Siting	1. Entire house is on flat ground, at a single level. 2. House does not have connection with hillside, but is separated from slope by a clear gap.	1. House is on sloped ground with access to house at 2 or 3 levels	-5
			2. House is connected to sloped ground; there is no gap between house and natural slope of site	-5
			MNPRV (Maximum Sub-total)	**-5**
2. Soil and Foundation Systems				
2.1	Suitability of soil type	1. Hard/broken rock 2. Strong soil with no moisture 3. Stiff soil with no swelling characteristics	1. Soft soil	-2
			2. Weak soil	-2
			3. High water table	-1
			4. Soil with moisture	-2
2.2	Foundation	1. Strip foundation made of stone masonry with through stones at close-regular intervals along length and height, resting on a uniform hard base underneath 2. Continuous RC foundation beam system below the entire length of the wall, with hard base underneath	1. Strip foundation on non-uniform base	-2
			2. Strip foundation with no through stones	-2
			3. Strip foundation on soft soil	-1
			4. Discontinuous RC foundation beam system	-4
			5. Continuous RC foundation beam system on soft soil	-2
			MNPRV (Maximum Sub-total)	**-5**
3. Architectural conditions				
3.1	Plan shape	1. Small room sizes (i.e., maximum wall length <10 times wall thickness) 2. Symmetrical plan of rooms (i.e., walls form a regular grid in 2 orthogonal directions in plan) 3. Rectangular overall plan	1. Large room sizes	-5
			2. Irregular orientation of rooms	-3
			3. Complex overall shape including those with re-entrant corners	-5
3.2	Elevation profile	1. Balanced structure with low center of gravity - Wider base dimension & narrower top dimension 2. No unduly large and heavy projections and overhangs 3. No split roof 4. Small storey heights 5. Uniform storey heights 6. Symmetrically placed staircase	1. Wider top and narrower bottom	-5
			2. Heavier top	-5
			3. Large projections or overhangs	-3
			4. Split roof	-5
			5. Large storey heights	-5
			6. Differences in storey heights	-5
			7. Unsymmetrical staircase location with respect to plan	-5
3.3	Door and window openings in walls	1. All openings far away from wall corners 2. Small area of door and window openings (i.e., opening is less than a third of wall length) 3. Large structural plan density	1. Rare single window close to corners	-1
			2. About half of openings close to corners	-2
			3. Almost all openings close to corners	-4
			4. Large window openings	-4
			5. Large door openings	-6
			6.	
3.4	Distance from adjacent building	1. Away from the adjoining house by a large distance	1. Houses touch each other	-3
			2. Houses have small gap between them	-3
3.5	Parapets, objects on roof or projections	1. Secured to wall system 2. No large and heavy projections and overhangs	1. Not secured to the structural system	-4
			2. Large and heavy projections and overhangs	-10
3.6	Staircases	No staircase, but if present 1. Wide dimension 2. Well supported on both sides against lateral sway	1. Narrow	-1
			2. Too few in number	-1
			3. Too far to reach	-1
			4. Poorly constructed	-1
3.7	Water Tanks on flat roof	1. Small in size 2. Located over interior walls, or well inside the plan of the house 3. Anchored to the roof	1. Large in size	-1
			2. Provided in the middle of the rooms	-1
			3. Not anchored to the roof	-1
3.8	Number of storeys	1. One or two storeys	1. 3 storeys	-2
			2. 4 storey or more	-5
			MNPRV (Maximum Sub-total)	**-35**

4. Material and construction conditions				
4.1	Quality	Used good quality ingredients 1. Dressed granite stones 2. Use of through stones 3. Treated timber/bamboo 4. Uniformly sized stones 5. Good crushing strength of stones 6. Treated timber/bamboo 7. Uniform strength slates for roof 8. Uniform sized slates for roof	1. Random rubble stones	-15
			2. No use of through stones	-5
			3. Low quality untreated timber	-1
4.2	Workmanship	1. Straight geometries and plumb walls 2. Adopted formal procedures for the construction 3. Compaction by vibrator 4. Using mortar and concrete mixes in time from the time of mixing	1. Poor geometries of masonry and roof	-3
			2. Adhoc procedures of construction	-10
			MNPRV (Maximum Sub-total)	**-20**
5. Structural Conditions				
5.1	Walls	1. Walls symmetrically distributed throughout the plan of the house 2. Large wall area without openings in each plan direction 3. Adequate number of walls in both orthogonal plan directions	1. Indirect or limited load paths	-4
			2. Large openings in walls	-4
			3. Walls unsymmetrical in one direction	-3
			4. Walls unsymmetric in both directions	-4
5.2	Roof design	1. Small weight 2. Complete truss in vertical direction 3. Complete connections in roof frame and bracing in plan, along both of the two sloped surfaces of the roof	1. Heavy roof	-4
			2. Pitched roof	-4
			3. Split roof	-4
			4. Weak diaphragm action tiled roof or separate planks	-4
			5. Large openings in roof	-4
5.3	Foundation - wall connection	1. Vertical reinforcement provided 2. Formal anchorage of vertical reinforcement from walls to foundation	1. No anchorage of reinforcement from walls to foundation	-5
5.4	Wall-wall connection	1. Bands used at all levels (i.e., roof, lintel, sill and plinth) 2. Bands are continuous at the wall junctions and corners 3. No arches or vaults present or if present, these have proper tie rods	1. No roof band with pitched roof	-4
			2. No roof band with flat roof	0
			3. No lintel band	-5
			4. No sill band	-2
			5. No plinth band	0
			6. Arches/vaults without tie rods	-5
5.5	Wall to roof/floor connection	1. Anchorage of vertical reinforcement from walls to roof/floor	1. No/insufficient anchorage of vertical reinforcement from walls to roof/floor	-3
			2.	
5.6	Staircase	No staircase, but, if provided, 1. Staircase symmetrically located and integrally built in the house 2. Staircase separated by a large gap from house, avoiding diagonal forces on floor/roof	1. Unsymmetrical location	-5
			2. Both top and bottom integrally built into the building frame	-5
5.7	Large water tanks flat on roof	1. Formally anchored to roof slab	1. Unsymmetrically located and integrally built staircase	-3
			2. Staircase not adequately separated from the house	-3
			MNPRV (Maximum Sub-total)	**-40**
			GRAND TOTAL	**-100**

Table A4: Economic Loss-Inducing Factors related to the contents and utilities of the house, and the associated Seismic Performance Rating E(S) for variations in them

S.No.	*Economic Loss Inducing Factor*	*Ideal Condition*	*Variations*	*Rating (%), E(S)*
1. Toppling/Falling Hazard				
1.1	Shelves	1. Anchored to structural systems	1. Not anchored to structural system	-20
		2. Contents strapped	2. Contents not strapped	-10
1.2	Items on lofts	Secured	Unsecured	-20
1.3	Hangings from roof/floor and from walls	Light weight and diagonally strapped to structural elements	Heavy weight and unstrapped	-5
1.4	Gas cylinders and geysers	Secured to the wall	Unsecured to the wall	-5
1.5	Items on adjacent building	Secured to the adjacent building	Unsecured to the adjacent building	-20
			MNPRV (Maximum Sub-total)	**-70**
2. Earthquake-Induced Secondary Hazards				
2.1	Electric supply	Cable has slack between house and pole	Cable is taught between house and pole	-20
2.2	Water supply	Pipeline has flexible joint at the house	Pipeline is rigidly held between house and main line	-20
2.3	Sewage	Sewage main has flexible joint at the house	Sewage line is rigidly held between house and main line	-10
			MNPRV (Maximum Sub-total)	**-30**
			GRAND TOTAL	**-100**

4. CLOSING COMMENTS

This pilot study presents a methodology for documenting Housing Typologies in the Moderate-Severe Seismic Zones of India. The method alienates factors that impact the safety of the house into two sets, namely (a) life-threatening factors, and (b) economic loss-inducing factors. This way, the path is defined for the house owner to know the critical factors that really determine life safety of the occupants of the house in earthquake areas. Further, the house owner learns to prioritise these factors over the other factors that cause economic setback. This is the strong point of this method. Minute details of the process of documenting housing typologies need to be worked out, some through research and the rest through consultations with housing subject specialists.

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