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A Study of Planning, Design and Construction of Buildings in Hilly Regions of India

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Abstract The architecture on hills always seems to be beautiful, attractive and soothing to eyes of the people, but there is a challenge for architects and structural engineers for planning, design and construction of these buildings. The planning and design of buildings in a hill settlement is a tedious and challenging task due to difficult terrain, steep gradient, adverse climatic conditions, rich flora and proneness to natural hazards. Numerous multi-storied buildings with contemporary materials and techniques are being constructed in different hill settlements without respecting the context, which affect health and wellbeing of residents and cause severe damage to sensitive fragile environment in and around hill settlements. The building regulations, which are enforced in hill settlements to regulate development and minimize its ill impacts on environment, are contextually not appropriate and lead to contextually inappropriate development and environmental degradation in environmentally sensitive hill settlements. Since vernacular practices are proven to be sustainable, therefore it is essential to take lessons from sustainable vernacular practices for new development and formulation of building regulations for achieving contextually appropriate and sustainable development in hill settlements. This paper analyses the planning, design and construction considerations of buildings in hilly regions in India. In this paper qualitative research method has been used. The systematic literature review of the construction systems of the hilly regions have been explored through internet and secondary data from relevant published academic literature from journals articles and research papers.

Keywords: *planning, design, construction hilly region, India*

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1. Introduction

According to topographic features, 10.7% of land area in India is mountains, 18.6% are hills, 27.7% are plateaus, 43% are plains. Hill areas are all the weathered high lands. It is the extended landform above surrounding terrain. Hills have unique ecosystem which has visual resources and is rich in biodiversity. When we talk about the architecture on hills some factors come through such as slope, vegetation, flora and fauna, heterogeneity of climate, and land use pattern. In some years the architecture and the growth of urbanization is expanding rapidly in the hilly areas. Any area above 600meters in height from the sea level is considered as hilly. According to this Jammu & Kashmir, Himachal Pradesh, Sikkim, Manipur, Meghalaya, Nagaland, Tripura, Arunachal Pradesh etc. are considered as the hill states of India [1].

Building construction in hilly regions requires comprehensive planning, site selection and design for slopes and sustainable concrete construction practices. In response to these harsh development conditions, numerous vernacular practices and styles have evolved with local materials and indigenous techniques to fulfill the needs of people, which cause minimal damage to environment and are sustainable. But, in spite of numerous benefits of these vernacular practices, these are often not used for new development due to increased demand for more built spaces due to rapid growth, availability of new construction materials and techniques and reluctance of residents to adopt vernacular practices. The economic growth and rapid urbanization in hilly regions have further encumbered the real estate development with an onus of developing multi-story buildings. Hilly regions, though tempting to construct a structure at, have wide variations in geology, geomorphology, climate, altitude and materials resources. The unpredictable geological situations and on-going development activities, precarious climatic variation, hydro geological conditions result in different types of hazards like landslides and mud flows in these areas which make planning and design of buildings in a hill settlement a herculean task [2].

2. Approach to the Building Structure

Buildings in hilly regions are the major challenge for architects. The building and the construction has to be

structurally strong enough to resist the topography and frequent seismic tremors and also bare the load of the building and as well as the building should be aesthetically attractive for tourists. According to the topography and requirement of the building, design and planning plays a major role. Some of the design approaches to be taken care of our settlement patterns, materials used in various spaces, open interactive spaces, sloping roofs, interior designs (rooms), retaining wall, etc. No doubt that the concrete has many advantages like strength, durability, weather resistant parameter and has been accepted as better construction material and has completely outdated the vernacular techniques and materials. But due to lack of proper guidelines about the use of material and techniques, it may lead to enormous loss of life and property in the wake of earthquake. Therefore the constraints of any material in the region shall be seen before being put to use and simple standards and guidelines shall be made available in bye-laws so that proper safety measures may be taken [3].

3. Challenges Faced in Design and Construction in Hilly Regions

- Frequent and Seismic Tremors.
- Problems of soil erosion and landslides.
- Suitable orientation on the hill slopes.
- Existence of tall shoddy trees and dense forest area, which obstruct the winter sun required for the buildings.
- Limitations on the height of the building due to earthquake risk.
- High cost involved in the site development due to the cutting and the filling process.
- Non-availability and transportation problems of construction materials.

4. Building Construction in Hilly Regions

There are four major points that should be considered while planning to construct a building in any hilly region [4]. They are summarized as follows:-

4.1. Site Selection and Construction Feasibility

- Check for Landslide-Vulnerable areas
- Check for Slope and sequence of rock structures
- Check for existing subsurface water
- Check for existing streams

The presence of subsurface water in an area may lead to the formation of cavities therefore inviting landslides. During landslide the materials like soil, rock, vegetation, and existing construction may move very rapidly within a second where as some may take longer time to develop. The result is livelihood security lost, socio-economic condition of people destroys and a huge amount of revenue spent with untold suffer of victims after landslide occurrences. Thus it is very important to identify the aforementioned areas before beginning any kind of construction on a hilly area.

4.2. Comprehensive Planning

4.2.1. Topographical Data

It involves detailed study of geological maps so that the engineers are aware and understand the geological formation of the site of the proposed development (Figure 1). Topographic map and aerial photographs of the site and abutting areas should be examined to know the geomorphological features, previous and present land use, current development, construction activities, problem areas like previous slope failure, etc. The knowhow of the site-histories particularly previous landslides and underground services is very important for the planning of the layouts and designs (Figure 2).

4.2.2. Site Reconnaissance

It helps confirm the information acquired from the topographical data and also to obtain additional information from the site. For hill-site development, it is also very important to locate and study the protuberances to identify previous landslides or collapse that can act as an indicator of the stability of the existing slopes.

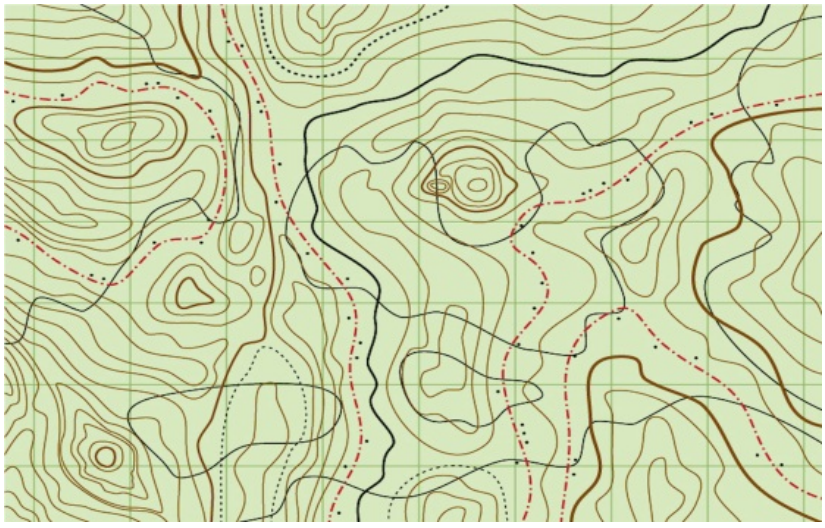

Figure 1. Topographical map of a hill region showing contour lines

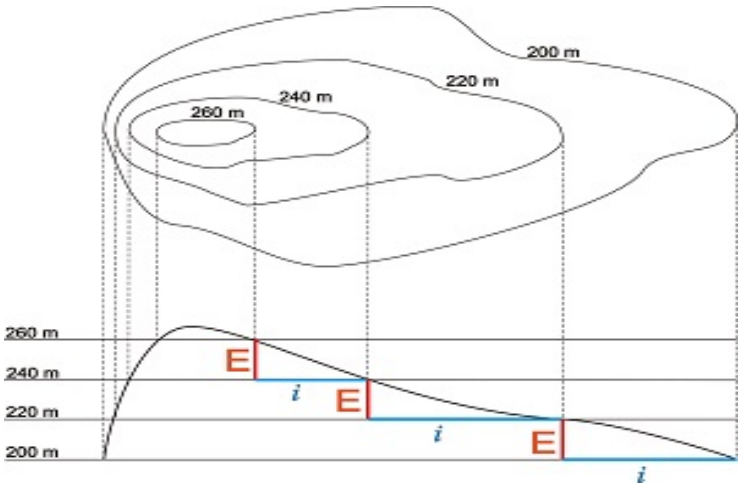

Figure 2. Contour map showing lines joining points of equal elevation on a surface

4.2.3. Site Investigation

For a hill-site construction, site investigation should be carried out in at least two stages. First stage consists of boreholes and sometimes also includes geophysical survey. The locations of the field tests should be carried out with an objective to obtain the overall subsurface condition of the site like general depth of soft soil, hard stratum and most important, the depth of bedrock. Normally the boreholes are spread out to cover the whole site and placed at areas of potential major cut and fill. Soil samples (disturbed and undisturbed) should also be collected from the boreholes to carry out laboratory tests for the necessary soil and rock parameters for preliminary geotechnical design of the slopes, foundations and retaining walls. In addition, the ground water profile should also be assessed. Long term monitoring of water table is also needed in sensitive and critical areas. The general information on the subsurface profile and properties will be useful when planning the cut and fill and formation of the platform because the depths of hard stratum and bedrock will have major influence on the cost and construction time of earthworks.

Once the preliminary layout of the hill-site development is confirmed, the detailed site investigation should be carried out to obtain the necessary information for detailed geotechnical designs. In the detailed site investigation field tests can be carried out at the following locations:

- Areas of major cut and fill.
- Retaining walls (Figure 3).
- Buildings or Structures with Heavy Loading.

Figure 3. A stone retaining wall

4.3. Layout

The planning of platform layout for hill-site development should attempt to fit the natural contour and reduce cut and fill of earthworks. If possible, try to avoid using retaining walls as this will be costlier than normal earthwork solution. It is also very important to orientate the building layout to minimize potential differential settlement especially if the buildings are on filled ground. This can be achieved by arranging the longitudinal axis of the building parallel to the contour lines of the original topography, in which the building is underlain by fill of uniform thickness and therefore less differential settlement. When using piles to support buildings on fill, the design engineer should evaluate negative skin friction (down drag) acting on the piles if the ground is going to settle with time. The slip-coating of the piles with bitumen coating or surcharging of the fill to eliminate future settlement are options to eliminate the negative skin friction.

4.4. Design of the Slopes

The phenomenon of slope failure transpires in much the same ways throughout the world with the basic causes do not differ greatly with geological and geographical locations. Therefore, the same methods of assessment, analysis, design and also remedial measures can be applied. The main difference is that in tropical localities, the climate is both hot and wet causing deep weathering of the parent rocks and the slopes are of weaker materials.

For man-made slopes, there are many factors that can contribute to slope failures:

- Improper design, analysis or construction.
- High intensity rainfall
- Lack of maintenance

Therefore, for the design of the slopes, proper information on soil properties, groundwater regime, geology of the site, selection of methodology for analysis are important factors that require attention from the Engineer.

4.5. Sustainable Development

Sustainable development is the continued ability of a society, an ecosystem, or any such interactive system to

function without exhausting key resources and without adversely affecting the environment. The construction technique should be developed with locally available, easily workable materials which are mostly environmental friendly (like timber, stone mud and bamboo) and have good climatic resistance and have little or negligible impact on environment of hill settlement. Though cutting of trees for obtaining timber will result in loss of precious vegetation, it needs to be suitably augmented by afforestation in hilly areas. In contrast to this, contemporary materials are manufactured from raw materials, which are available on particular locations and are transported to different parts of the country after manufacturing.

5. Design and Planning in Hilly Regions

The planning and design of structures on the contours has always been a challenge. Hence, the practice is to study the ridge lines and valley lines through imaginary but straight lines. The trick is to place the building parallel to the contour lines, not perpendicular, so get the maximum area with less cut and fill [5]. Design considerations in hills require extra sensitivity and care because of the delicate nature of terrain and ecosystem. Unlike plains, here a new dimension or a height variation to the ground poses additional problem to the entire exercise [6].

5.1. Physical Planning

- The planning on the hills is very restrictive as compared to the plains. The major factors that govern the planning are topography, climatic conditions, orientation, traffic movement, available usable spaces, sources of water supply, natural drains and paths.
- Gentle slopes are required so that the cost of site development is lessened. The roads for traffic movement are of gradual gradient. Less excavation is required to be done to maintain the ecological balance.
- Slope of the ground should not be more than 30º as far as possible even in rocky reaches to avoid instability problems, especially during severe earthquakes.
- Suitable clearance around buildings is necessary. Foundation of any part of building should not rest on filled up ground. On hills there should be clearance of about 40º in case of soil, soil mixed boulder, fractured rock zone, soft rock zone having outward dip, so that any slip, if occurs may not hit the building.
- Due to the cold climate, the southern slopes are preferred. The orientation of the houses is to maximize the penetration of the sun rays.
- The stress is also laid on the preservation of the green cover. The site should be developed in such a way that felling of trees is avoided as far as possible.
- Site susceptible to high winds, storms, floods and landslides should be avoided.
- Since the inner side of the cut slope may have higher bearing capacity, building should be so oriented and planned so as to enhance that higher load comes on inner side. Where the site seems to undergo unequal settlement, the site should be so planned and designed that the higher load comes on harder part of foundation and soil.
- Terrace in all around the building should have proper slope for efficient drainage. During the site development, terrace may be cut at 1:30 to 1:50 slope and may be trimmed at suitable slope after the completion of the building work.
- In the steep hilly zones, the stepped terraces will be much beneficial environmentally and economically, as they result in the least hill cutting and disturbance to the hill stability.
- Minimum clearance of 1.0 m to 1.5 m should be given between the hill face and the building wall to avoid dampness and also for proper light and ventilation.
- Top hill surfaces near the buildings should be properly treated to make it impervious as far as possible, possibly by thick vegetation or stone pitching (Figure 3).

5.2. Development of Critical Areas

- Physical development of a hill town is attributed to topography, climate, accessibility, availability of developable land, hilly tracks prohibiting large scale expansion of urban activities in ecologically sensitive areas.
- Hill geomorphology does not allow concentrated development of settlements. Hence the dispersal of settlement has to be encouraged.
- The sloping site may dictate higher building cost with regard to drainage and sewers, depending on the size of the project. If the sewerage system is uphill from the site, will you need to have pumping systems installed? If the system is downhill, you may need to slow flow down to the sewers. You will need to consider water run-off from the site and make sure you make sufficient measures to deal with surface water. Investigate soak aways and drainage channels to make sure your surface water is dealt with correctly and doesn't end up flooding your lower floor or the surrounding area.

5.3. Building Layout and Contour

The building should be placed along the contours to increase the stability of the structure and to cut down the cost on the site development [7]. The existing form of the terrain welcomes some building forms while rejects some (Figure 4). In hills building break the continuity of landscape and hence appear rigid, this can be controlled by giving horizontal and vertical devices like stilts, etc. (Figure 5).

When creating basements on sloped terrain, the walls are often subject to a lot of force from the surrounding banks of land and therefore becoming retaining walls. Structural engineers will need to be involved in the design of these structures, and detail design stage is important to ensure good water proofing. Another option is stepping the ground by using low level retaining walls, or gabion walls (Figure 6).

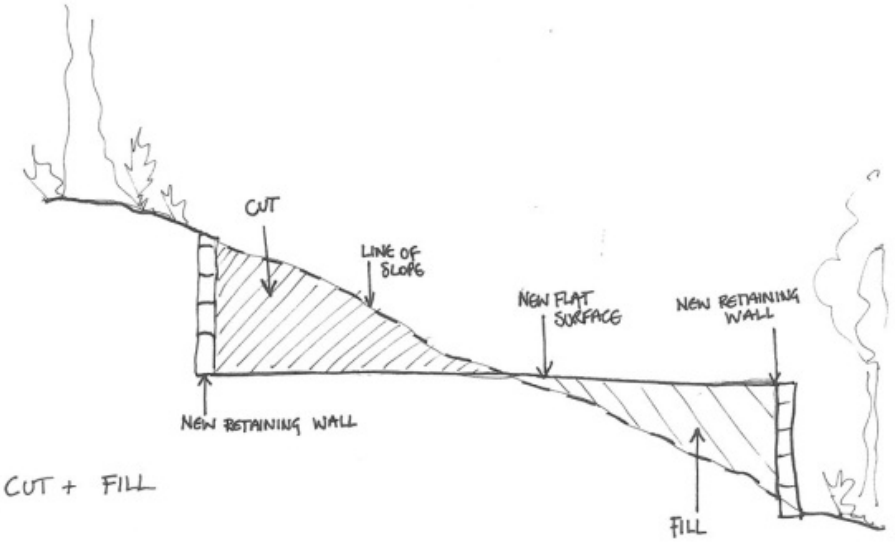

Figure 4. Cut and fill technique for developing flat surface.

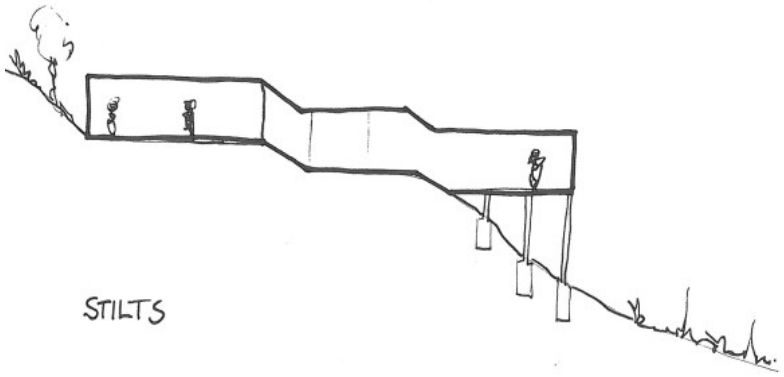

Figure 5. Building on stilts addresses the construction on steeply slope site.

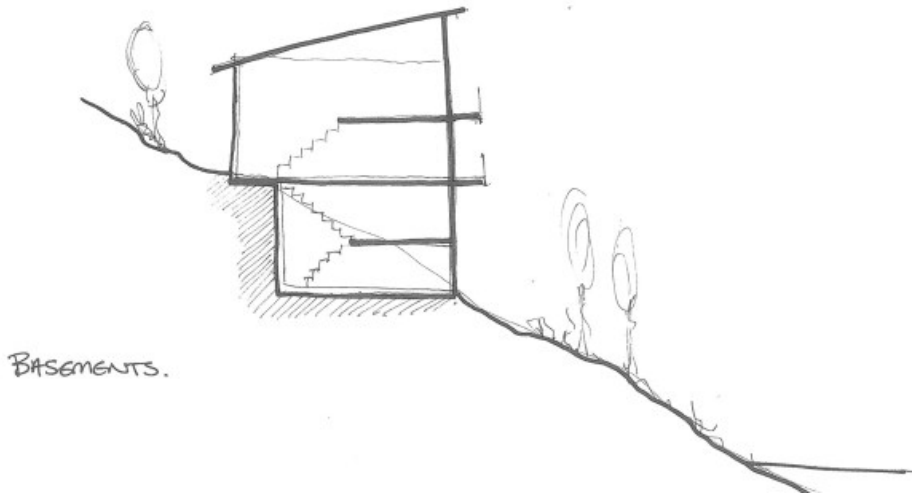

Figure 6. Stepping the ground slope to provide the basement

5.4. Building Context

- Development along contour - Similar to vernacular buildings, new buildings as far as possible should be designed along the contour to have minimum site development work.
- Compact size and opening along longer direction - Similar to vernacular buildings, new buildings should be compact, having small foot print and most of the openings/ windows should be provided along the length of building (longer side) and shorter side of building (width) should be kept intact without openings to have better seismic response.
- Minimal disturbance to natural environment and contextual development

- Like vernacular buildings, new buildings should be environmentally friendly, so that they should merge with the surroundings and cause minimum disturbance to natural environment. The use of locally available materials and development according to site and surrounding conditions will lead to contextual appropriateness, which are essential for environmental protection in and around hill settlements.

6. Building Design and Construction Considerations for Earthquakes in Hilly Regions

India on account of unique geo-physical setting is highly prone to earthquakes of varying intensities. The country has faced several devastating earthquakes in the past resulting in a large number of deaths and severe property damage. In recent years damaging earthquakes had been experienced in different parts of the country e.g. Assam (1988) M 7.2, Bihar- Nepal (1988) M 6.5, Uttarkashi (1991) M 6.6, Latur (1993) M 6.4, Jabalpur (1997) M 6.0, Chamoli (1999) M 6.8 and Bhuj (2001) M 6.9. The country has been classified into different seismic zones indicating the intensity of damage or frequency of earthquake occurrences. These zoning maps indicate broadly the seismic coefficient that could generally be adopted for design of buildings in different parts of the country [8]. Figure 7 shows the Seismic zones and intensity map of India.

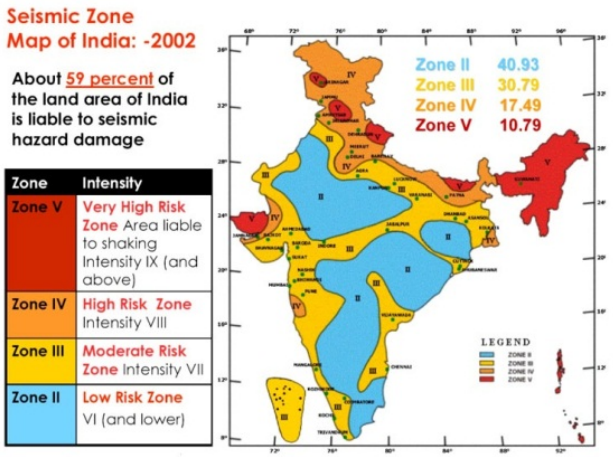

Figure 7. Seismic zones and intensity map of India

Some general earthquake guidelines with reference to design, construction and materials for hilly areas have been formulated [9]. They have been summarized as followings:

6.1. Design Considerations

- Plan of the building shall be compact, simple without any reentrant angles since they tend to concentrate shear forces during earthquake and severe the impact of damage on the built mass (Figure 8a and Figure 8b).

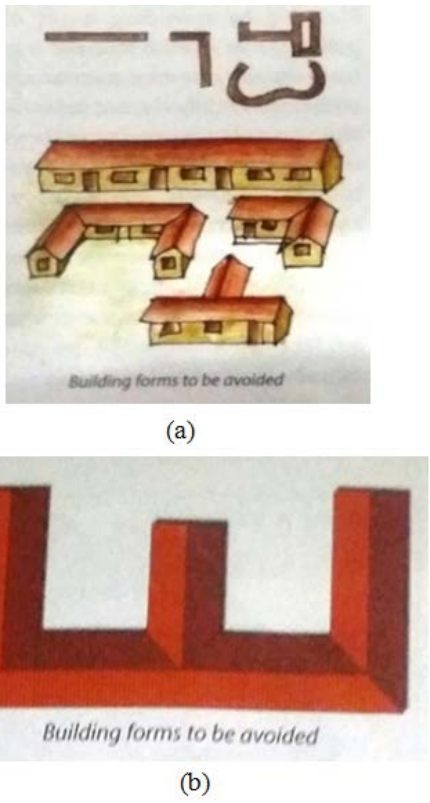

Figure 8. Building Forms which should be avoided

- In plan rectangular, square, circular shapes are preferred while very long, zigzag shaped buildings or even with courtyards and Y, T, U, L, X shapes for the building shall be avoided.
- In case it is unavoidable to change such a shape, then it is preferable to go for expansion joints at every change of geometry and inclusion of angles in shape so that each block retains symmetry and simplicity in shape (Figure 9).

Figure 9. Preferred building forms with expansion joints

- Elevation of the building or the vertical profile of the building shall also be simple, square and shall be uniform in weight avoiding sharp curves.
- Offsets in the elevation or wide cantilevers shall be avoided (Figure 10).

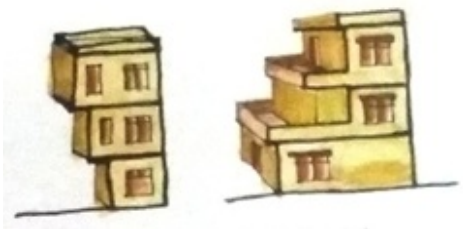

Figure 10. Projecting building forms should be avoided

- More than one staircase and more than one emergency exits shall be provided in case of multistoried buildings at most convenient points of access (Figure 11).

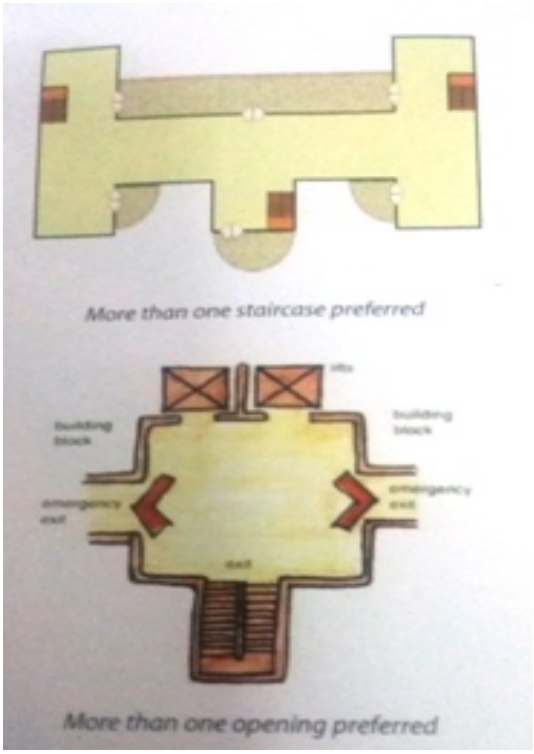

Figure 11. More than one staircase and emergency exit should be provided

- Distance between corner of wall and door, between door and corner of window and between corner of window and end of wall shall not be more than 0.6 m (Figure 12).

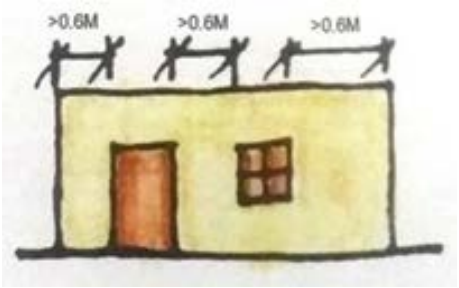

Figure 12. Preferred envelope of the building

- In case, the length of the room or the space is more than 6.0 m then, it is advisable to add pilasters at even and regular intervals (intervals of at least 3m.) since it adds to the strength of the built mass (Figure 13).

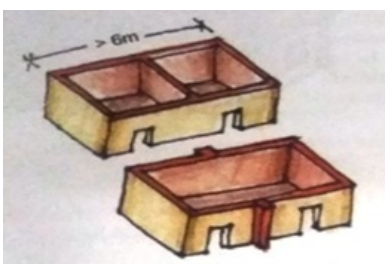

Figure 13. Pilaster of intermediate system to be preferred

- Plantation shall be kept at a minimum distance of 15m from the building (Figure 14).

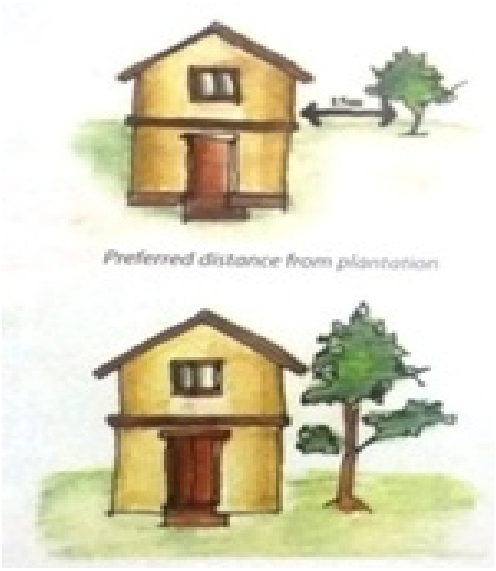

Figure 14. Plantation should be kept at a minimum distance of 15m

- Building on stilt shall be avoided which is often seen as favorable solution to parking problem since it disturbs the uniformity of distribution of load vertically (Figure 15).

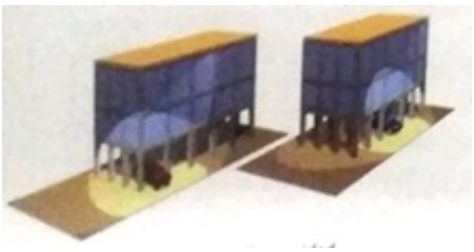

Figure 15. Buildings on stilts to be avoided

- Grouping of built masses shall not be such that collapse of one part of the building damages the other part (Figure 16).

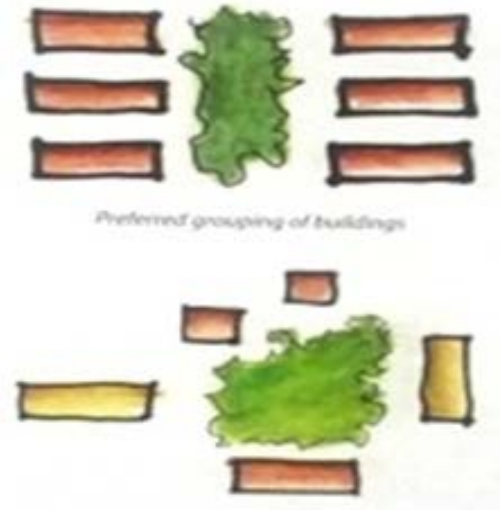

Figure 16. Preferred groupings of the building

- Height of each storey in the building shall not exceed 3.2 m in any case (Figure 17).

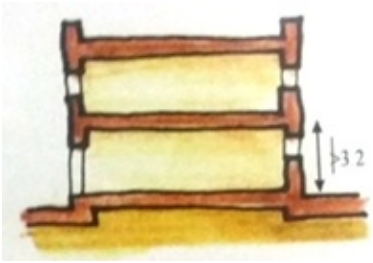

Figure 17. Clear height should not be more than 3.2 m.

6.2. Construction Considerations

- In case of rocky strata, the foundation shall not be based on rocky base directly instead it should be 0.15 m inside rocky base.
- In case of sandy or moorum soil the depth of the foundation shall be less than 0.5 m and width shall be 0.75 m (Figure 18).

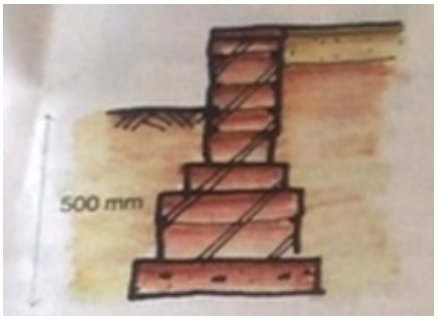

Figure 18. Medium to deep foundations should be preferred.

- Vertical joints in each course of the masonry shall be discontinued and avoided since it also weakens the strength of the masonry (Figure 19).

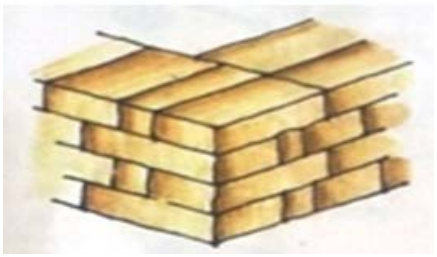

Figure 19. Masonry without continuous vertical joints recommended

- Walls shall never be made without a foundation base and baked bricks and stones shall only be used for foundation with minimum depth of 500m of the foundation. Unbaked bricks and coarse sand tend to settle down with time period and leads to instability of the foundations.
- Foundation thickness shall be appropriate. It shall be at least one and half times thicker than the wall.
- Buttresses between long walls shall be added and corner buttresses shall be preferred.
- Size of the door and window shall be kept small and seismic band shall be provided at least at plinth level, lintel level (Figure 20). Each storey shall be provided with a lintel band.

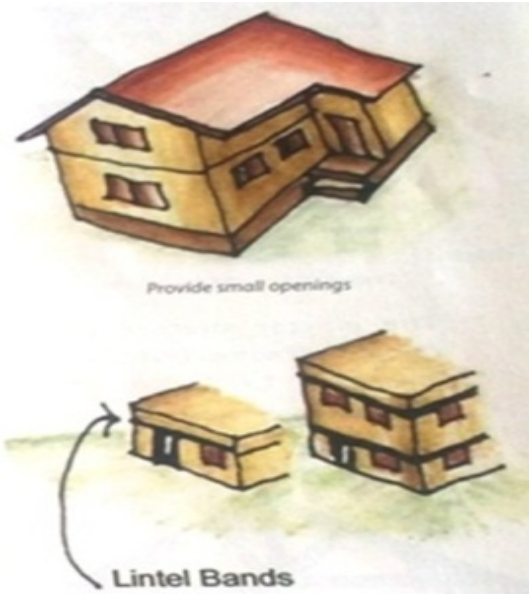

Figure 20. Small openings and lintel bands should be provided

- Wall length shall be less than 10 times the thickness of the wall and height shall be 8 times the thickness of wall.
- In case of trusses, bracing shall be done with use of bracings at bottom chord and in plane of slopes of truss (Figure 21).

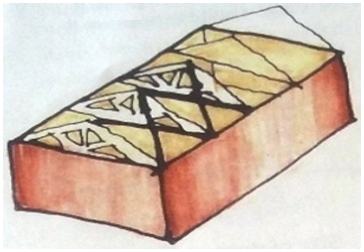

Figure 21. Bracing of roof truss should be provided.

- To make roof fireproof and waterproof, thatch shall be tied with adequate overlap and being tied tightly to the strong members and then plastered with mud.
- The mortar mixtures shall comprise of cement: sand - 1:6, lime: sand - 1:3, cement: lime: sand - 1:2:9.
- In case of gable wall, gable band shall be provided (Figure 22).

Figure 22. Gable band for gable wall should be provided.

- Regular and even grid shall be maintained with laying out at right angle to each other (Figure 23).

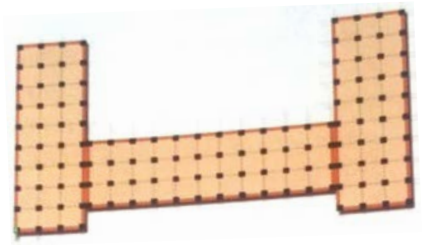

Figure 23. The structural grid system should be uniform

- Span of the beam shall not exceed 7m and not be less than 3m either (Figure 24).

Figure 24. The span of beam should not be more than 7m

- All opening at different floor shall be placed at same position throughout the various floors (Figure 25).

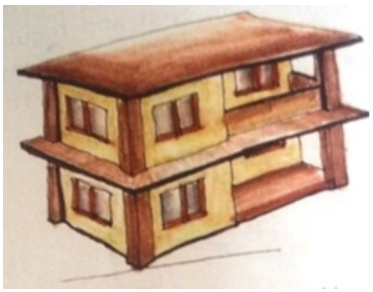

Figure 25. Provide opeing on same position on all floors

- Centerlines of columns and beams shall be meeting each other and they shall have nearly same width.
- Columns and walls shall be aligned in one straight line in all directions. All columns shall be subjected to same load and load distribution uniformity shall be there.
- Reinforcement shall be provided with minimum specified cover and maintained by non-corroding spacers (Figure 26).

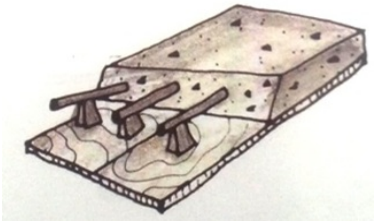

Figure 26. Proper reinforcement with non-corroding spacers should be provided

6.3. Material Considerations

- Heavy and loose materials shall be avoided on the roof and replaced by comparatively lightweight roofing materials.
- All members shall be tied and also with the wall to provide stability to the roof.
- The sloping roofs shall be provided with proper gutters and purlins to add to both stability as well as water discharge aspects for the roof.
- Generally slates, roofing sheets or other lightweight material shall be used and properly tied over the wooden rafters (Figure 27).

Figure 27. Lightweight roofing material should be provided

- In case of doors and windows, wood used shall be well seasoned. Ornamental and heavy wooden doors, very heavy fire wooden retarding plastics doors shall be avoided.
- Heavy stone masonry for walls shall be avoided.
- Tiles for walls or stone cladding etc. shall be avoided.

7. Conclusions

The building planning, design and construction in hilly regions is a challenging task. The construction techniques have to be used in proper way. Building structures of hilly regions has to be studied and understand properly for the construction in such type of topography. This paper analyses the general planning, design and construction considerations of buildings in hilly regions in India with special reference to earthquakes. Being regardless of natural potential in terms of available natural resources, topographical constraints, geography, geology, soil conditions, flora and fauna etc. there are certain problems in the sustainable development of the hilly region due to rapid urbanization.

The traditional construction techniques in hilly region are the outcome of its typical climatic conditions, landscapes, availability of raw materials and other natural resources. The vernacular practices and styles adopted in traditional hill settlements have a great potential to become the basis for new development and formulation of appropriate building regulations for hill settlements [10]. There is a need to understand the peculiar context of hill settlements for suitable modification of existing building regulations to make them appropriate for new development in hill settlements. These remedial, simple techniques and proposals regarding earthquake considerations shall be taken into consideration by concerned authorities and public and made mandatory for all constructions to be undertaken in future.

References

[1] Tiwari J. and Bansal A., Study of Building Structures & Construction Techniques in Hilly Regions: Hotel Dalhousie,

International Journal of Engineering Science and Computing, 7 (4), 2017.

[2] Kumar A., Poonam and Gupta A., Vernacular practices as basis for formulating building regulations for hilly areas Science, *International Journal of Scientific & Engineering Research*, 5(5), 2014.

[3] Deshmukh R., Earthquake consideration in hilly areas, *Architecture Time Space & People*, 7(9), September 2007.

[4] Building Construction in Hilly Regions: Site Selection, Planning and Design, [Online] available from http://www.theconstructor.org/construction/building-construction-hilly-region/13519 [Accessed November 14, 2020]

[5] Jain M., Singh I., Sharma D. C., Traditional Architecture and Planning Techniques in Himachal Pradesh, *Journal of Institution of Engineers*, Vol. 86, October 2005.

[6] Dave B., Thakkar J. and Shah M., Details of Resistance: Indigenous Construction System in Himachal Pradesh., *Context: Built, Living and Heritage, Journal of Development and Research Organization for Nature, Arts and Heritage*, 9(1), 2012.

[7] Wattas R. Interventions in Vernacular Himachal Pradesh', *Architecture + Design, Indian Journal of Architecture*, Nov.-Dec. 2000, New Delhi.

[8] NIDM, National Institute for Disaster Mitigation, 'Safety Tips', [Online] available from https://nidm.gov.in/safety_earthquake.asp [Accessed November 20, 2020]

[9] Chawhan V, *Construction Techniques in Hilly Regions*, unpublished Master of Architecture Thesis, Kurukshetra University, India, 2018.

[10] Sarkar, A. Study of Climate Responsive Passive Design Features in Traditional Hill Architecture of Khyah Village in Hamirpur, Himachal Pradesh, India for Indoor Thermal Comfort. *Journal of The Institution of Engineers (India): Series A*, 94 (1), 2013.