



TERRAIN-ADAPTIVE MULTI-LEVEL URBAN CONSTRUCTION IN HILLY TERRAIN

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Abstract : Hilly regions are urbanising quickly, and the usual practice of cutting and filling a hill to create flat land often leads to unstable slopes, blocked drainage and damage during monsoon rains and earthquakes. This seminar studies terrain-adaptive multi-level urban construction, in which buildings, roads and open spaces are arranged on terraces that follow the natural contours of the hill and are linked by stepped streets, ramps and lifts. The purpose of the seminar is to understand the engineering principles behind this approach and to present them through a scaled physical model. The methodology was study-based and model-based. It included a review of books, research papers, Indian Standards and government guidelines; a technical study of hilly terrain, slope stability, site investigation, urban planning, structural behaviour of buildings on slopes, foundations, retaining walls and drainage; a review of construction technology, sustainability practices and case studies; and the preparation of a scaled terrace model. Illustrative examples, explained in words, are given for slope stability, the short-column effect and a gravity retaining wall. The study shows that water is the main trigger of slope failure, that contour-following layouts with limited cut and fill reduce risk, that buildings on slopes need a regular configuration, shear walls and ductile detailing, and that foundations must reach firm ground. The approach needs more investigation, design effort and maintenance than conventional methods, but it gives lower long-term risk and a more sustainable settlement. The report ends with the project initiation: the problem statement, scope and objectives, stakeholders and the resources identified for the project work.

IndexTerms - terrain-adaptive construction, hilly terrain, multi-level development, slope stability, retaining walls, drainage, sustainability.

I. INTRODUCTION

1.1 Background

Hills and mountains cover a large share of the world's land and in India the Himalayan states, the Western Ghats (Sahyadri), the Eastern Ghats and the north-eastern ranges are all under growing urban pressure. As flat land near cities fills up, towns such as Shimla, Darjeeling, Gangtok and Mussoorie, and the hill suburbs of cities such as Pune, are expanding up their slopes. Population growth, tourism, infrastructure projects and the search for housing and views all push construction onto steeper ground.

Building on a hill is not the same as building on a plain. Gravity acts along the slope, rainwater runs fast and carries soil with it, foundations sit at different levels, and earthquakes and landslides can strongly affect the structure. The usual response has been to flatten the hill with heavy cutting and filling and then build as on a plain. This often leaves unstable slopes, destroys natural drainage and has been linked to many landslides and building failures during monsoon seasons and earthquakes.

The alternative studied in this report is **terrain-adaptive construction**: letting the shape of the land guide the layout, the structure and the construction method, so that the built form steps up the hill in several connected levels instead of fighting it. A **multi-level urban** arrangement places buildings, roads and open spaces on terraces that follow the contours, and connects them with stepped streets, ramps and lifts.

The problem statement, aim, objectives and scope of the work are described under Project Initiation (Section VIII).

1.2 Need for the Study

- Landslides and slope-related building damage are a recurring problem in Indian hill regions, especially in the monsoon.
- Hill buildings have shown poor performance in earthquakes when short columns, torsion and irregular configurations were ignored.
- Demand for housing and infrastructure in hilly cities continues to grow while safe, flat land becomes scarce.
- Civil engineering students need a combined view of structural, geotechnical, planning and construction aspects, which is often taught in separate subjects.

1.3 Key Terms Used in This Report

Table 1. Key terms used in this paper

Term	Meaning
Terrain-adaptive	Design and construction that follow the natural contours, geology and drainage of the site rather than reshaping the whole site.
Multi-level	A development arranged on several terraces or floors at different elevations, connected by roads, stairs, ramps and lifts.
Contour	An imaginary line joining points of equal elevation; closely spaced contours mean a steep slope.
Cut and fill	Excavating soil from the uphill side (cut) and placing compacted soil on the downhill side (fill) to form a level platform.
Terrace / bench	A flat or gently sloping platform formed on a slope to carry buildings, roads or open space.
Retaining structure	A wall or system that holds back soil and resists the lateral earth pressure.
Factor of Safety (FOS)	Ratio of resisting forces (or strength) to driving forces (or stress); $FOS > 1$ means stable in theory, and codes demand a margin above 1.
Colluvium	Loose soil and rock fragments that have moved down a slope under gravity; usually weak and unstable.

1.4 Concept of Terrain-Adaptive Multi-Level Construction

Terrain-adaptive construction treats the hill as a **structural and hydrological system**, not just as a surface to build on. Buildings, roads and open spaces are placed in bands that follow the contours, and each band forms a level of the town. Levels are linked vertically by stepped lanes, ramps, funiculars or lifts. The guiding principles are:

- **Follow the contours.** Roads and building rows run roughly parallel to contours, which keeps cuts and fills small and gradients gentle.
- **Minimum disturbance.** Cut and fill are limited to what each terrace needs. Steep, unstable and densely wooded zones are left undisturbed.
- **Safe foundations.** Foundations are taken to firm strata, never placed on loose fill or colluvium without treatment.
- **Water first.** A planned drainage network for surface and subsurface water is part of the design from day one.
- **Structure fits slope.** Stepped, split-level or stilt buildings suit sloping ground better than a large flat podium.
- **Stage and monitor.** Construction proceeds in stages and slopes are monitored throughout.
- **Sustainable materials and energy.** Local materials, vegetation cover and passive design reduce impact.

1.5 Conventional versus Terrain-Adaptive Approach

Table 2. Conventional and terrain-adaptive approaches compared

Aspect	Conventional (flatten and build)	Terrain-adaptive (multi-level)
Earthwork	Large cut and fill; many high unsupported slopes	Moderate cut and fill balanced per terrace; supported by walls
Drainage	Natural drains often blocked or diverted	Natural drains preserved and supplemented
Slope stability	High risk after heavy rain or earthquakes	Lower risk if designed and monitored
Vegetation	Mostly removed	Retained or restored (bio-engineering)
Roads	Steep straight alignments or switchbacks with large cuts	Contour-following roads with controlled gradient
Cost	Lower initial cost, high maintenance and risk cost	Higher design and structural cost, lower long-term risk
Character	Uniform, disconnected from landscape	Layered, with views, light and local identity

1.6 Hill Regions of India: Regional Context

Different hill regions of India present different combinations of slope, geology, rainfall and seismic hazard. The table gives an indicative picture; actual values must come from site investigation and the code maps.

Table 3. Hill regions of India: geology, hazards and typical construction

Region	Geology and slopes	Main hazards	Typical construction
Western Himalaya (Himachal, Uttarakhand)	Young, folded rocks; steep slopes; glacial and river deposits	Very high seismicity, landslides, cloudbursts, flash floods	Stepped RC and masonry buildings, stone walls, timber
Eastern Himalaya (Sikkim, Darjeeling)	Weathered rock and thick colluvium; very high rainfall	High seismicity, deep landslides, road cut failures	Stilt and step-back buildings, retaining walls
North-east ranges	Soft sedimentary rocks, heavy rainfall	High seismicity, landslides, erosion	Light timber, bamboo and RC frame
Western Ghats (Sahyadri)	Basaltic rock (Deccan Trap) with lateritic and weathered cover	Intense monsoon rainfall, shallow slides, erosion, rockfall	RC frame, stone and laterite masonry, terraced layouts

Region	Geology and slopes	Main hazards	Typical construction
Eastern Ghats and peninsular hills	Hard crystalline rocks, moderate slopes	Moderate seismicity, localised slides and erosion	RC frame with step foundations

1.7 Organisation of the Report

Table 4. Organisation of the paper

Section	Content
I. Introduction	Background, need for the study, key terms, concept of terrain-adaptive construction, comparison with conventional practice and regional context.
II. Literature review	Slope stability, seismic behaviour, retaining systems, planning, bio-engineering, summary table and research gap.
III. Technical study	Terrain, geotechnical aspects, planning, structural systems, foundations and retaining walls, drainage, worked design example and site checklist.
IV. Construction and sustainability	Construction methods, sustainable practices and case studies.
V. Project model	Meaning of the model, components, scale and labelling, steps of model making and limitations.
VI. Advantages and disadvantages	Benefits, limitations and challenges, and risk matrix for hill development.
VII. Conclusion	Summary of findings, conclusion, future scope and possible future developments.
VIII. Project initiation	Problem statement, scope and objectives, stakeholders, and platform, equipment and resources.
References	Books, standards, guidelines and papers.

II. LITERATURE REVIEW

2.1 Purpose and Approach of the Review

This section reviews the main bodies of knowledge that support terrain-adaptive construction: landslide and slope-stability science, seismic behaviour of buildings on slopes, retaining and slope-reinforcement systems, terrain-sensitive planning, bio-engineering and sustainable construction. Sources include classical textbooks, widely cited research papers, Indian Standards and government guidelines. The summaries are written in general terms for understanding; students should read the original sources before quoting any figures.

2.2 Landslides and Slope Stability

The scientific study of slope failure has a long history. Fellenius (1936) introduced the method of slices for circular failure surfaces, and Bishop (1955) improved it by accounting for forces between slices. Terzaghi's work on the mechanics of landslides established that water pressure and loss of effective stress are central to most failures. Varnes (1978), and later Cruden and Varnes (1996), gave the standard classification of landslides by type of movement (fall, topple, slide, spread and flow) and by material, which is still used by geological surveys and disaster management agencies.

Government guidelines apply this knowledge to practice. The National Disaster Management Authority of India has issued guidelines for landslide management that stress hazard zonation, early warning, regulation of construction in hazard zones, and proper drainage. Bureau of Indian Standards documents such as IS 14496 (landslide hazard zonation) and IS 14680 (landslide control) provide the technical basis. Hong Kong's Geotechnical Engineering Office developed a systematic slope-safety system after serious landslide disasters, with an inventory of man-made slopes, design standards and maintenance programmes; it is frequently cited as a model of how a dense city can live with steep terrain.

Relevance to this seminar: the literature agrees that rainfall, groundwater, slope angle and human cutting at the toe are the main controlling factors. This supports the terrain-adaptive emphasis on drainage, limited cutting and stable terraces.

2.3 Seismic Behaviour of Buildings on Slopes

Research on buildings on sloping ground has grown since damage in several Himalayan earthquakes. Studies such as Birajdar and Nalawade (2004) analysed step-back and setback–step-back buildings on slopes and reported that the unequal column heights lead to large variation in column shear and to torsional response. Singh and co-authors (2012) combined analysis with observations from the 2011 Sikkim earthquake, noting that hill buildings with irregular configuration, short columns and weak connections were more vulnerable. Murty and co-authors, in the widely used guidebook on earthquake behaviour of buildings published by GSDMA, explain the short-column effect, torsion, soft storeys and pounding in simple language and recommend regular, symmetric configurations with adequate wall or frame stiffness.

Indian codes (IS 1893 Part 1, IS 4326 and IS 13920) give the seismic design and ductile detailing framework, while the textbooks of Agarwal and Shrikhande and of Duggal present the theory in teaching form.

Relevance to this seminar: the literature supports equalising column heights, using shear walls, ductile detailing, keeping plan shapes compact, and providing seismic gaps between blocks. These ideas are applied in Section III.

2.4 Retaining Structures and Slope Reinforcement

Earth pressure theory dates back to Coulomb (1776) and Rankine (1857), and these remain the basis of retaining wall design in textbooks such as those of Das and Murthy. IS 14458 gives guidelines specifically for retaining walls in hill areas, including selection of wall type, design checks and drainage provisions. Modern developments include reinforced soil walls and geosynthetics, discussed in the work of Koerner and others, and soil nailing and rock bolting for cut slopes, which allow steep faces to be stabilised with limited excavation. The general conclusion of this literature is that retaining systems fail more often through poor drainage and foundation problems than through lack of structural strength of the wall itself.

2.5 Terrain-Sensitive Planning and Design

McHarg's book *Design with Nature* (1969) argued that land-use planning should begin with the natural processes of the site: geology, hydrology, soils, vegetation and slope. This idea underlies suitability mapping and zoning for hill development. The National Building Code of India and local hill-area development control rules limit building height, ground coverage and slope of developable land, and require setbacks from crests, toes and drainage lines. The Indian Roads Congress Hill Road Manual (IRC SP:48) provides the standard for gradients, hairpin bends and drainage on hill roads. Traditional hill settlements and agricultural terraces around the world show the same logic: stepped platforms held by stone walls with built-in drainage.

2.6 Bio-Engineering and Sustainable Construction

Studies of vetiver grass and other deep-rooted vegetation, including work by Hengchaovanich and co-authors, describe how roots add tensile strength to shallow soil and reduce erosion, at low cost. Bio-engineering is therefore recommended as a supplement to, and not a replacement for, structural stabilisation. Sustainable construction literature, including green building rating systems such as GRIHA and IGBC, stresses the use of local and low-carbon materials, water harvesting, passive design and minimum site disturbance. On hills these goals are closely tied to safety: preserving vegetation and natural drainage is both an ecological and a geotechnical measure.

2.7 Summary of Literature Reviewed

Table 5. Summary of literature reviewed

Source (author / year)	Area	Idea used in this seminar
Fellenius (1936); Bishop (1955)	Slope stability analysis	Method of slices and FOS concept for slope checks
Varnes (1978); Cruden and Varnes (1996)	Landslide classification	Landslide types and causes (Section III)
NDMA landslide guidelines; IS 14496; IS 14680	Hazard zonation and control	Zoning, no-build areas, drainage and monitoring
Hong Kong GEO, Geotechnical Manual for Slopes	Slope safety management	Systematic design, inspection and maintenance
Birajdar and Nalawade (2004)	Buildings on slopes, seismic analysis	Short-column effect and torsion in step-back buildings
Singh et al. (2012)	Sikkim 2011 earthquake observations	Vulnerability of irregular hill buildings
Murty et al. (GSDMA guide)	Earthquake behaviour of buildings	Regular configuration, shear walls, seismic gaps
IS 1893, IS 4326, IS 13920	Seismic design and detailing	Code framework for hill buildings
Rankine (1857); Das; Murthy; IS 14458	Earth pressure and retaining walls	Wall design, stability checks and drainage
McHarg (1969)	Planning with nature	Suitability mapping and zoning
IRC SP:48; NBC 2016	Hill roads and building regulations	Gradients, setbacks, safety provisions
Hengchaovanich et al.	Vetiver bio-engineering	Vegetative slope protection

2.8 Research Gap and Relevance of This Seminar

Most of the literature treats geotechnical, structural and planning aspects separately: slope stability papers rarely discuss urban layout, structural papers focus on the building alone, and planning guidelines often give limited technical detail on slope engineering. A student-level study that combines these into one chain, from site investigation to drainage, structure, construction and sustainability, and shows it through a physical model, is useful for understanding how a hill settlement should be planned as an integrated system. This is the gap that the present seminar addresses.

III. TECHNICAL STUDY OF TERRAIN-ADAPTIVE MULTI-LEVEL DEVELOPMENT

3.1 Characteristics of Hilly Terrain

3.1.1 Slope classes

Slope is expressed in degrees, as a percentage (rise/run $\times$ 100) or as a ratio such as 1V:2H. The classification below is indicative; local development control rules decide the exact limits for any site.

Table 6. Slope classes and typical suitability

Slope (degrees)	Approx. gradient	Typical suitability
0–5°	0–9 %	Flat to very gentle; normal development
5–15°	9–27 %	Gentle; terracing optional, normal foundations with local levelling
15–30°	27–58 %	Moderate; terracing, retaining walls and stepped buildings needed; detailed geotechnical study required
30–45°	58–100 %	Steep; development is restricted and needs special engineering; many authorities limit or prohibit it
Above 45°	Above 100 %	Very steep; generally unsuitable for building; keep as conservation or buffer zone

3.1.2 Engineering challenges

- **Slope instability:** landslides, rockfall, debris flow, soil creep and slumping, mostly triggered by rain and earthquakes.

- **Variable ground:** within a small plot the ground may change from hard rock to loose colluvium, so one foundation type cannot be assumed.
- **Heavy and concentrated rainfall:** high runoff velocity, erosion and rising pore water pressure.
- **Seismicity:** much of the Himalayan belt lies in the highest seismic zones; topographic amplification can increase shaking at ridges and crests.
- **Access and logistics:** narrow roads, steep haul routes and limited space for storing material and operating cranes.
- **Utilities:** water supply needs pumping uphill, sewers need gravity downhill, and pipelines must cross slopes safely.
- **Ecology:** hills are often watersheds and habitats; large cuts disturb both.

3.1.3 Common landslide types

Table 7. Common landslide types and typical causes

Type	Description	Typical cause
Rotational slide	Mass of soil moves along a curved surface	Weak, uniform soils; rising water table; toe cutting
Translational slide	Mass moves along a planar surface, often a weak layer or rock joint	Adverse joint orientation, thin soil over rock
Rockfall / topple	Blocks detach and fall or rotate from a steep face	Jointed rock, freeze–thaw, root action, vibration
Debris flow	Rapid flow of saturated soil, rock and water down a channel	Intense rain, steep drainage lines
Creep	Very slow downslope movement of surface soil	Seasonal wetting and drying; saturated clay

Landslide classification is usually based on the work of Varnes and later Cruden and Varnes; students can use these as standard references.

3.2 Geotechnical Engineering Aspects

3.2.1 Site investigation

A hill site must never be designed from a desk study alone. A staged investigation is usual:

1. **Desk study and reconnaissance:** topographic sheets, geological maps, landslide inventory, rainfall records, aerial or satellite images, and a walkover survey to spot old slide scars, springs, tilted trees and cracks.
2. **Topographic survey:** contour map at a suitable interval (often 0.5 m to 1 m for design), with natural drains and existing structures marked.
3. **Subsurface exploration:** boreholes, trial pits, Standard Penetration Tests (SPT), rock coring, and geophysical methods such as electrical resistivity or seismic refraction where useful.
4. **Laboratory tests:** grain size, Atterberg limits, unit weight, moisture content, shear strength (direct shear or triaxial), and for rock the unconfined compressive strength.
5. **Groundwater study:** location of the water table, springs and seepage zones, and piezometer readings through at least one monsoon if possible.

3.2.2 Shear strength of soil

Soil strength on a slope is described by the Mohr–Coulomb criterion. According to this criterion, the shear strength of soil has two components: the effective cohesion, which is the bonding between soil particles, and the frictional resistance, which depends on the effective angle of internal friction and on the effective normal stress acting on the failure surface. The effective stress is the total normal stress minus the pore water pressure.

When rain raises the pore water pressure, the effective stress falls and so does the strength of the soil. This is why most hill failures occur during or just after heavy rain.

3.2.3 Slope stability analysis

Slope stability is expressed through the Factor of Safety (FOS), which is the ratio of the shear strength available in the soil to the shear stress required to keep the slope in equilibrium. A slope with an FOS well above one is stable, while a slope with an FOS close to or below one is on the verge of failure.

For a shallow translational slide in a long uniform slope, the **infinite slope** model is used. In this model the factor of safety depends on the cohesion and friction angle of the soil, the unit weight of the soil, the depth of the failure plane and the slope angle.

For cohesionless soil, stability depends only on the friction angle of the soil and the slope angle, and the slope is on the verge of failure when its angle approaches the friction angle. Seepage parallel to the slope can reduce the factor of safety by roughly half in the worst case. A slope that appears acceptable when dry can therefore become unstable when saturated, which shows why drainage, vegetation and retaining measures matter so much.

Worked example (explained)

A layer of soil about 3 m deep, with moderate cohesion and an effective friction angle of 30°, lies on a slope inclined at 25°.

When the soil is dry, most of the resistance comes from friction between soil particles, and the cohesion adds a smaller contribution. Together they give a factor of safety of about 1.5, which looks acceptable.

If the soil becomes saturated with seepage parallel to the slope, the available strength drops and the factor of safety can fall below 1.0, which means the slope would fail. Hence the need for drains, vegetation and retaining measures.

For deeper or curved failure surfaces, the method of slices (Fellenius, Bishop) is used, and in practice engineers run software based on limit equilibrium or finite element methods. Typical minimum FOS values in practice are around 1.3 to 1.5 for permanent slopes under static conditions and a lower value (often 1.0 to 1.2) under earthquake loading; the project or code in use will fix the exact values.

3.2.4 Slope stabilisation measures

Table 8. Slope stabilisation methods

Method	How it works	Where suitable
Re-grading / benching	Reduces overall slope angle; benches intercept runoff and rockfall	Soil and weathered rock slopes
Surface and subsurface drainage	Removes water, lowers pore pressure	Almost every hill site
Retaining walls (gravity, cantilever, crib, gabion)	Resist earth pressure and support the cut or fill	Terrace edges, road cuts
Soil nailing	Closely spaced steel bars grouted into slope, with facing, form a reinforced mass	Cut slopes, temporary and permanent
Rock bolts and anchors, shotcrete	Pin unstable blocks and protect the face	Jointed rock slopes
Reinforced earth / geosynthetics	Layers of geogrid or strips reinforce fill and allow steep faces	Fill slopes and embankments
Micropiles / bored piles	Pass through unstable layer into stable ground	Active or marginal slides, foundations
Bio-engineering	Deep-rooted grasses (such as vetiver), shrubs and trees bind soil and reduce erosion	Shallow slopes, as a supplement to structural measures

Fig. 3.1 shows how the stabilisation measures described above work together on a typical hill slope: benching, catch-water and bench drains, soil nails with shotcrete facing, a retaining wall and vegetation cover.

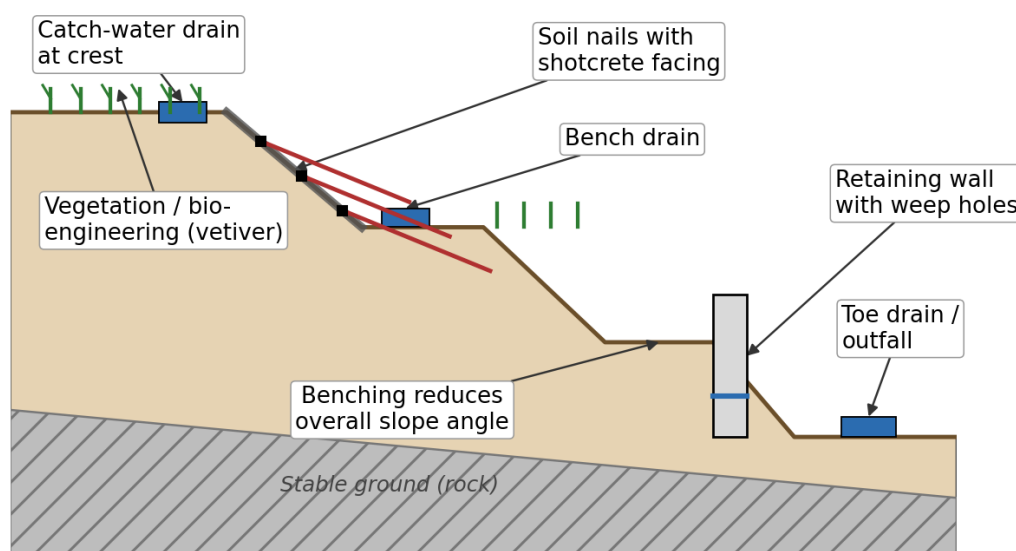


Fig. 3.1 Slope stabilisation measures on a hill slope (schematic, not to scale)

3.3 Urban Planning for Multi-Level Hill Development

3.3.1 Site suitability and zoning

Planning starts with a **hazard and suitability map**. The site is divided into zones according to slope, geology, drainage and vegetation:

- **Developable zone:** gentle to moderate slopes, stable ground, away from streams.
- **Restricted zone:** moderate-to-steep slopes or poor ground; only light structures, with full engineering support.
- **No-build zone:** steep slopes, active slides, drainage channels, springs, and dense forest, preserved as green buffers.

3.3.2 Layout of levels

Levels are planned as continuous bands along the contours. Each band normally holds a collector road with buildings on its uphill and downhill sides. A useful arrangement from lower to upper levels is as follows:

Table 9. Suggested use of levels in a terraced layout

Level (example)	Suggested use and reasoning
Base / lowest	Parking, markets, services, and storm-water collection. Easiest access to the main road.
Middle levels	Commercial and mixed-use, institutions, plus public transport stops that connect to upper levels.
Upper levels	Residential clusters with views and cooler air; lighter structures; strong protection from rockfall and runoff.
Crest / ridge	Parks, view points, water tanks, solar and telecom; avoid heavy building where ground shaking may be amplified.

3.3.3 Circulation and connectivity

- **Contour roads:** gradient usually kept to about 5–8 % for urban streets (steeper only on short stretches); hairpin bends only where unavoidable.

- **Vertical links:** stepped streets, ramps, lifts, inclined lifts, funiculars or ropeways connect levels, which lets pedestrians avoid long road detours.
- **Pedestrian priority:** walking routes with resting platforms every few flights, handrails, anti-slip surfaces and lighting.
- **Emergency access:** at least one road capable of carrying fire tenders and ambulances to every level, and clear evacuation routes.
- **Public transport:** shuttle buses or mini buses and parking at the lower levels reduce vehicles on steep roads.

3.3.4 Utilities

- Water supply by gravity from an upper tank where possible, and pumping with break-pressure tanks for tall systems.
- Sewers follow gravity down the slope with ductile iron or HDPE pipes with flexible joints, and manholes at all changes in direction.
- Separate storm-water drains, with energy dissipaters (steps or stilling basins) to control flow speed.
- Power and telecom ducts located in the road reserve and protected from slope movements.

3.3.5 Density and building form

A moderate density, cluster-style layout with step-back buildings is usually safer than a few isolated tall blocks. Height limits relative to slope, minimum setbacks from slope crest and toe, and limits on ground coverage keep loads on slopes low. Local regulations and the National Building Code of India (NBC) give requirements; always check the current development control rules for the site.

3.4 Structural Engineering Aspects

3.4.1 Building configurations on slopes

Table 10. Building configurations on slopes

Configuration	Description	Comment
Step-back (setback)	Floors step back up the slope so that each floor follows the ground	Good fit to terrain; irregular in plan and elevation; needs careful seismic design
Split-level	Floors at different heights within the same building	Fewer cuts; floors at offsets create complicated stiffness and diaphragm behaviour
Stilt / pile supported	Building rests on tall columns or piles on the downhill side	Minimum cut; long columns vulnerable to buckling and sway; needs bracing or shear walls
Podium and tower	Platform terrace carries buildings	Platform needs strong retaining and drainage; avoid over-height podiums
Cantilever over slope	Floor projects beyond the support	Limited to light, short cantilevers; check overturning and vibration

3.4.2 Seismic behaviour of hill buildings

Hill buildings are known to behave poorly in earthquakes when badly designed. Three effects are most important:

- **Short-column effect.** On sloping ground, columns on the uphill side are shorter than those on the downhill side. The lateral stiffness of a column varies inversely with the cube of its height, so a short column is many times stiffer than a long column of the same section; for example, a column of 3 m height is about **eight times** as stiff as a column of 6 m height. During shaking, the stiff short columns attract most of the shear and can fail in brittle shear.
- **Torsion.** Because the stiff short columns lie on one side, the centre of rigidity is far from the centre of mass. The building twists as well as sways, and corner columns are overstressed.
- **Pounding and differential movement.** Stepped blocks that are too close, or floors that differ in level, can strike each other. Adequate separation gaps or integral design are needed.

Illustration of the short-column effect

Consider two columns of the same section and material, fixed at both ends. Column A is 3 m tall and column B is 6 m tall.

Because stiffness depends on the cube of the height, column A is about eight times as stiff as column B.

If the floor moves sideways equally, column A therefore takes about eight times the shear force of column B. This is why designers make all columns of equal height, or provide shear walls, or isolate the short columns so they behave as longer ones.

Fig. 3.2 shows a building frame on a natural slope. The columns on the uphill side are shorter, so they are stiffer and attract most of the earthquake shear force.

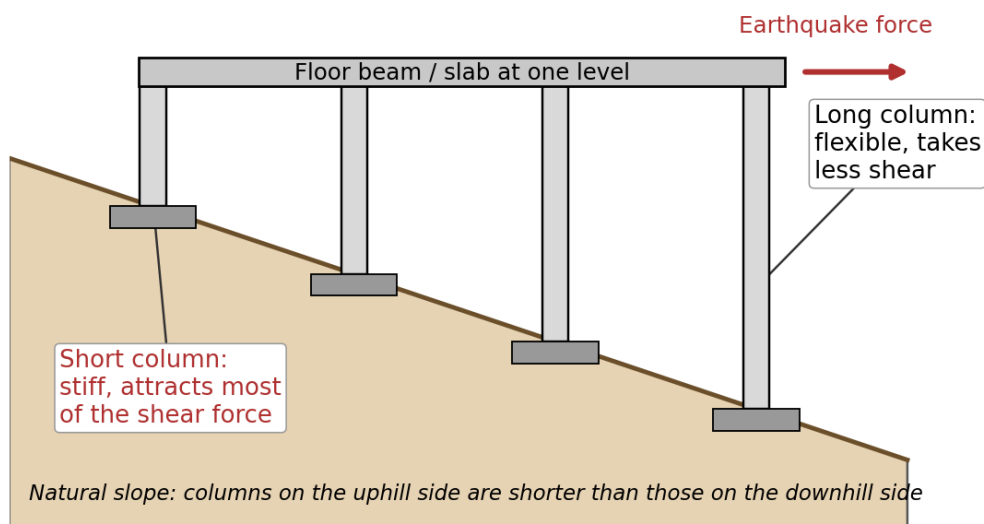


Fig. 3.2 Short-column effect in a building on sloping ground (schematic)

3.4.3 Design measures

- Keep plan shape simple and compact, with the centre of mass and stiffness as close together as possible.
- Use RC shear walls, preferably on the uphill side and around stair or lift cores, to reduce torsion and sway.
- Make column heights more equal by using plinth beams at different levels, or by using retaining or infill walls that are properly separated or properly integrated.
- Provide ductile detailing as per IS 13920, with closely spaced stirrups in short columns, over their full height.
- Provide seismic joints between blocks of different heights and stiffness.
- Choose light materials for upper floors (light-gauge steel, timber, hollow blocks, AAC) to cut seismic weight.
- Tie foundations together with plinth or grade beams so that the whole building moves as one unit.

Fig. 3.3 shows the reinforcement detailing of a column as per IS 13920, with closely spaced ties near the column ends and 135° hooks that confine the concrete core.

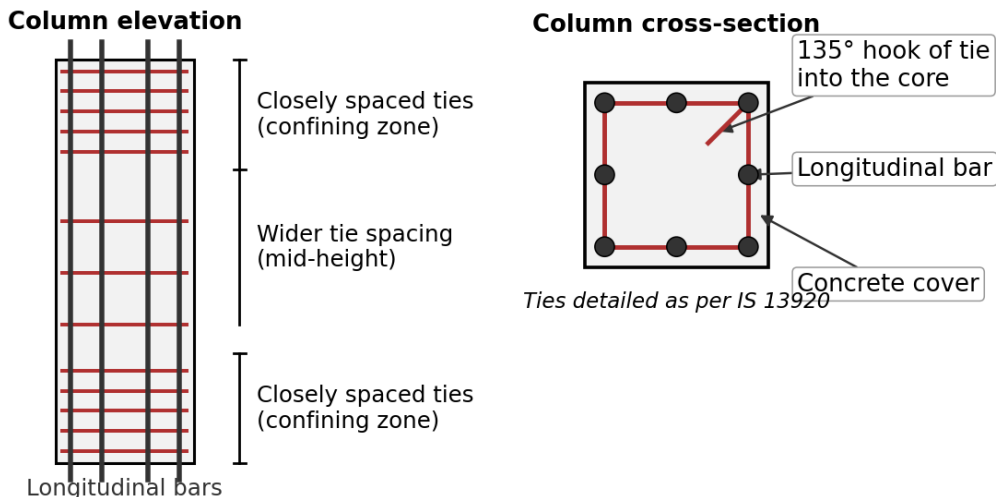


Fig. 3.3 Reinforcement detailing of a column: ties and cross-section (schematic)

3.4.4 Relevant Indian Standards

The following codes are commonly used in hill construction in India. Students should refer to the latest edition of each and cite exact clauses from the code itself.

Table 11. Relevant Indian Standards

Code	Subject
IS 456	Plain and reinforced concrete: code of practice
IS 800	General construction in steel
IS 875 (Parts 1–5)	Design loads (dead, imposed, wind, snow, special)
IS 1893 (Part 1)	Criteria for earthquake-resistant design of structures: general provisions and buildings
IS 4326	Earthquake-resistant design and construction of buildings: code of practice
IS 13920	Ductile design and detailing of RC structures subjected to seismic forces

Code	Subject
IS 1904 / IS 6403	Foundations: general requirements and bearing capacity of shallow foundations
IS 2911	Design and construction of pile foundations
IS 14458 (Parts 1–3)	Retaining wall for hill area: guidelines on selection, design and construction
IS 14680	Landslide control: guidelines
IS 14496	Preparation of landslide hazard zonation maps in mountainous terrains: guidelines
National Building Code (NBC) 2016	Planning, structural, services and safety provisions, including hill-area aspects

3.5 Foundations and Retaining Structures

3.5.1 Choice of foundation

Table 12. Foundation types for sloping ground

Foundation	Use on slopes	Precautions
Isolated or strip footing at stepped levels	Where competent soil or rock is close to the surface	Step footings so that the line joining the edges of adjacent footings does not exceed the safe angle; keep adequate edge distance from slope face
Raft	Moderately weak soils and uniform terrace platforms	Needs a stable platform and drainage; check overall slope stability
Bored cast-in-situ piles	Weak or filled ground over rock; stilt buildings	Socket into stable stratum below the failure surface; check lateral loads
Micropiles	Restricted access sites and marginal slopes	Group action and grouting quality control
Rock anchors and dowels	Foundations on rock	Check joints and weathering

A footing near the slope face has lower bearing capacity because the soil wedge in front of it is smaller. Foundations should be set back from the crest by an adequate distance (usually decided from analysis and code or local rules) and their depth measured from the lowest adjacent ground level.

Fig. 3.4 shows stepped footings on a sloping site, and Fig. 3.5 shows bored piles carried through weak soil into stable rock to support a stilt building.

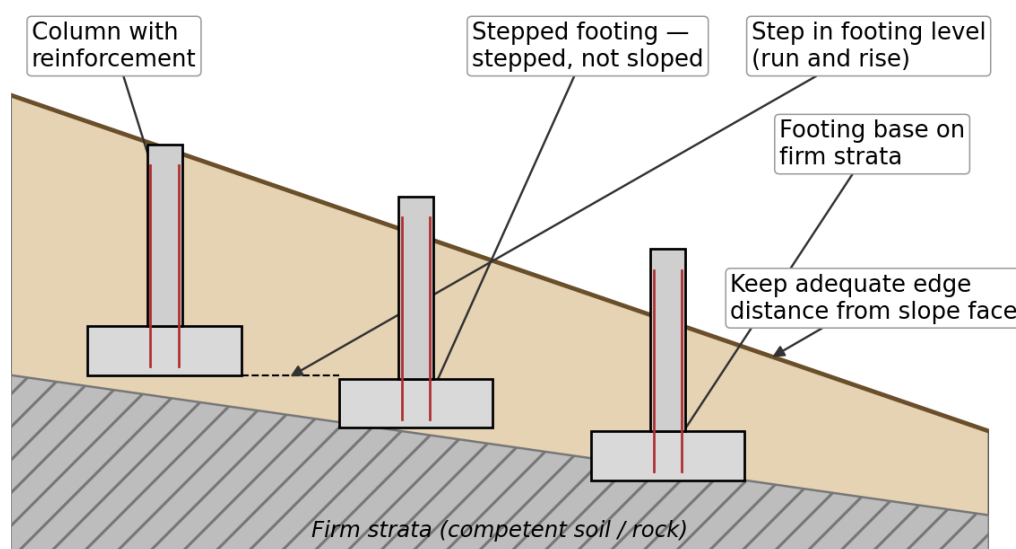


Fig. 3.4 Stepped footings on sloping ground (schematic)

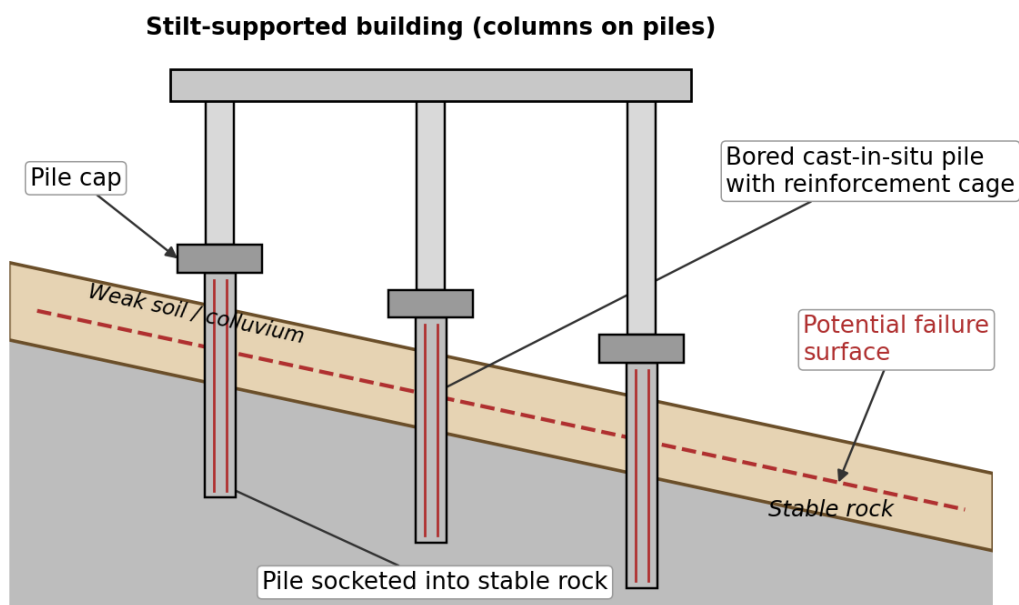


Fig. 3.5 Pile foundation for a stilt building on a slope (schematic)

3.5.2 Retaining walls

Retaining walls form the “steps” in a terraced hill development. Common types are gravity (stone masonry or plain concrete), cantilever RCC, counterfort, crib, gabion and reinforced soil walls. IS 14458 deals specially with hill-area walls.

Earth pressure

The earth pressure on a retaining wall is usually estimated with Rankine’s theory. For a smooth vertical wall retaining horizontal cohesionless backfill, the active earth pressure increases with the unit weight of the backfill and with the square of the wall height, and it decreases as the friction angle of the backfill increases. The resulting force, taken per metre length of wall, acts horizontally at one-third of the wall height above the base.

A surcharge (for example, a building or road above) adds pressure, and water behind the wall adds hydrostatic pressure which can nearly double the load. Therefore walls always need drainage.

Worked example (explained)

Consider a 4 m high wall retaining a granular backfill with a friction angle of 30° .

The active earth pressure acts as a horizontal force of about 48 kN for each metre length of wall, at a height of about 1.33 m above the base.

This force tends to overturn the wall about its toe. The weight of the wall and of the soil resting on it provides the resisting moment, and the wall must be proportioned so that this resisting moment exceeds the overturning moment by the required margin.

Stability checks

Table 13. Stability checks for retaining walls

Check	Requirement (typical values; confirm in the governing code)
Overturning	FOS about 2.0 or more against overturning about the toe
Sliding	FOS about 1.5 or more against sliding along the base
Bearing pressure	Maximum base pressure less than the allowable bearing capacity; no tension at heel for gravity walls (resultant in the middle third)
Global stability	Slope plus wall system has adequate FOS against deep-seated failure
Structural	Stem, heel and toe slabs satisfy bending and shear limits (IS 456)
Drainage	Weep holes, filter layer and backfill drain provided; free-draining backfill

Drainage details

- Granular backfill (gravel or crushed stone) behind the wall, separated from the soil by a geotextile or graded filter.
- Weep holes (about 75–100 mm diameter) at regular spacing, with a toe drain to carry the discharge away.
- A paved drain at the top of the wall to intercept surface water, so the wall is not loaded by runoff.

Fig. 3.6 shows the typical reinforcement and drainage arrangement of a cantilever RCC retaining wall.

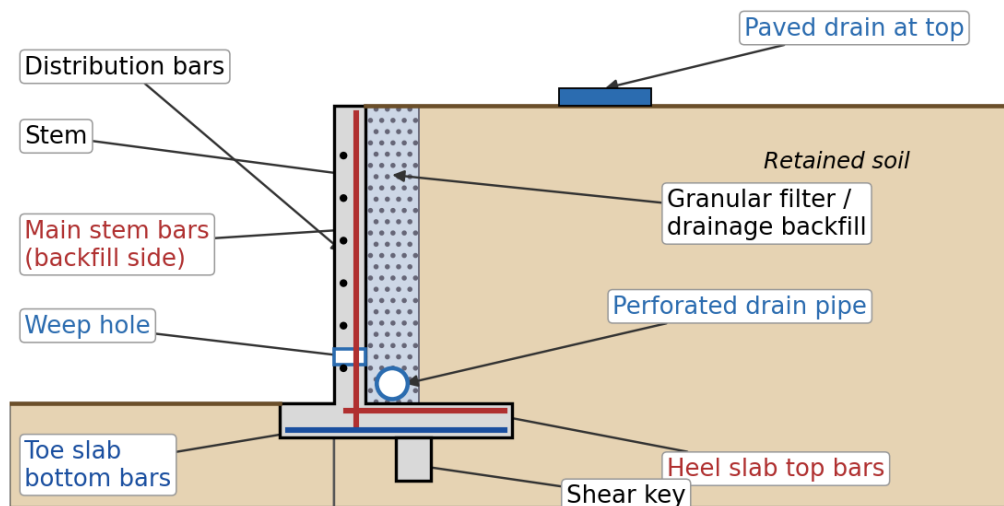


Fig. 3.6 Reinforcement and drainage of a cantilever RCC retaining wall (schematic)

3.6 Drainage and Water Management

Water is the most common cause of hill failures. A good drainage scheme is as important as the structure itself. Three levels of water control are used:

Table 14. Drainage systems and their purpose

System	Elements	Purpose
Surface drainage	Catch-water (intercepting) drains above the cut or crest, lined side drains along roads, cascade or stepped chutes, culverts and outfalls	Keep runoff away from slopes; guide it safely to natural streams
Subsurface drainage	Horizontal drains (perforated pipes drilled into slope), french drains, trench drains and filter layers	Lower the water table and reduce pore pressure in the slope
Storage and reuse	Rainwater harvesting tanks, recharge pits, detention ponds on lower levels	Reduce peak runoff, supply non-potable water, recharge groundwater

- Drains must be lined (stone, concrete or precast channels) to prevent erosion, and designed for the design storm discharge, usually estimated from the rainfall intensity, the catchment area and the runoff characteristics of the ground (the rational method).
- Outfalls should end in rock or a stilling basin, and not discharge on loose slopes.
- Maintenance is vital: choked drains and culverts are a frequent trigger of failures, so a regular cleaning schedule, particularly before the monsoon, should be part of the project.

3.7 Illustrative Design Example: Gravity Retaining Wall for a Terrace

The example below shows how the stability checks of Section 3.5 are carried out for a simple terrace wall. The values are assumed for illustration only and are not a substitute for design to IS 14458 and IS 456.

Given data

A terrace wall 3.0 m high is considered, with a rectangular masonry section about 1.8 m wide at the base. The masonry is assumed to have a unit weight of 22 kN/m³.

The backfill is horizontal and cohesionless, with a friction angle of 30° and a unit weight of 18 kN/m³. There is no surcharge, and the backfill is well drained.

The friction coefficient between the base and the ground is taken as 0.5. All checks are made for a one metre length of wall.

Table 15. Steps of the gravity retaining wall design example

Step	Description
1. Active pressure	The active earth pressure from the backfill is found from the friction angle of the soil, the unit weight of the backfill and the wall height. It comes to about 27 kN per metre length and acts horizontally at one-third of the wall height above the base.
2. Wall weight	The weight of the wall per metre length is found from its cross-section and the unit weight of masonry, and it acts through the middle of the base width. It is about 119 kN per metre length.
3. Overturning	The overturning moment of the earth pressure about the toe is compared with the resisting moment of the wall weight. The factor of safety is about 4, which is greater than the required minimum of 2.0, so the wall is safe against overturning.
4. Sliding	The friction available at the base is compared with the horizontal earth thrust. The factor of safety is about 2.2, which is greater than the required minimum of 1.5, so the wall is safe against sliding.

Step	Description
5. Position of resultant	The point where the resultant force meets the base is located from the net moment about the toe. The eccentricity is less than one-sixth of the base width, so the resultant lies within the middle third of the base and there is no tension at the heel.
6. Base pressure	The pressure under the toe and under the heel is found from the vertical load and its eccentricity. The maximum pressure, about 116 kPa, must be compared with the allowable bearing pressure of the founding stratum, and the minimum pressure remains positive.

Observation. If the wall were made considerably narrower, the resultant would move outside the middle third of the base and tension would develop at the heel. This shows how the middle-third rule controls the width of gravity walls. If the backfill becomes saturated and drainage fails, hydrostatic pressure adds to the earth thrust and the factors of safety fall sharply, which is why weep holes and filters are essential.

3.8 Site Selection and Planning Checklist

The following checklist can be used at the start of a hill development project.

Table 16. Site selection and planning checklist

Item	What to check	Why it matters
Slope map	Slope angles across the plot; areas steeper than the local limit	Decides developable and no-build zones
Geology and soil	Rock type, depth to rock, soil thickness, signs of old slides	Foundation type and stability
Drainage	Natural streams, springs, flow paths, catchment above the site	Layout of drains and safe setbacks
Groundwater	Water table, seepage zones, seasonal variation	Slope stability and wall design
Seismic zone	Zone from IS 1893 and local soil or topography effects	Design earthquake forces
Access	Existing road gradient, width, emergency access	Construction logistics and safety
Vegetation	Trees, slope cover, protected areas	Erosion control and ecology
Hazard history	Past slides, flood marks, damage to nearby buildings	Early warning of problem areas
Regulations	Hill-area rules, setbacks, height and FAR limits, environmental clearance	Legal compliance
Utilities	Water source, sewage disposal, power lines	Feasibility and cost

IV. CONSTRUCTION TECHNOLOGY, SUSTAINABILITY AND CASE STUDIES

4.1 Construction Technology and Methods

4.1.1 Earthwork and terrace formation

- **Cut-and-fill balance:** plan platforms so that excavated material is reused as compacted fill, which reduces hauling and disposal.
- **Benching:** when placing fill on a slope, cut steps (benches) into the existing slope so the fill is keyed in and does not slide along the interface.
- **Compaction:** fill is placed in thin layers (about 150–300 mm) and compacted to the specified density; loose end-tipped fill is unacceptable under buildings.
- **Short open cuts:** cut small heights at a time and support them immediately; do not leave large faces open during rain.
- **Sequence:** usually work from the top down for cuts, and from the bottom up for fills and walls, with drains installed first.

4.1.2 Construction logistics

- Access by temporary haul roads with proper drainage, or by light equipment such as mini excavators and tracked dumpers.
- Material lifting by tower cranes (on stable platforms), mobile cranes, chain hoists, monorails or small ropeways for steep sites.
- Local material stores on each terrace to cut vertical hauling.
- Concrete by ready-mix with pumping where access allows, or small batching plants at site.

4.1.3 Modern and light construction techniques

Table 17. Modern and light construction techniques

Technique	Benefit on hills	Note
Precast and prefabricated elements	Fast erection, less site work, fewer trucks in monsoon	Need crane access and good connections
Light-gauge steel frames	Low weight, lower seismic load, good for upper levels	Corrosion protection needed
Modular construction	Factory made rooms assembled on site	Transport on narrow roads is a constraint
Engineered timber and bamboo composites	Renewable, light, good seismic behaviour	Fire and moisture protection
AAC or hollow blocks, light infill	Reduce dead load and seismic mass	Check bond and out-of-plane stability
Shotcrete and soil nailing	Fast stabilisation of cuts	Quality control of grout and cover

Technique	Benefit on hills	Note
Geosynthetics and reinforced-soil structures	Steep fill faces with less concrete	Design by specialists

4.1.4 Monitoring and safety

- Install inclinometers, tilt meters, crack gauges, survey prisms and piezometers on critical slopes, and check them regularly, especially after heavy rain.
- Set trigger levels with clear actions: more frequent monitoring, work stoppage, evacuation.
- Protect workers from rockfall and trench collapse; avoid excavation during intense rain; follow safety codes (IS 3764 for excavation work and relevant labour-safety rules).

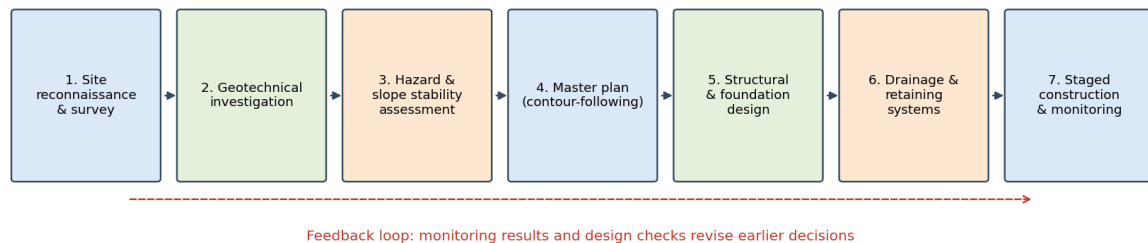


Fig. 4.1 Design and construction workflow for terrain-adaptive development

4.2 Sustainable Construction in Hilly Terrain

Sustainability on a hill is not only about green labels. It is about avoiding disaster, using resources wisely and keeping the hill fit to live on for future generations. Key strategies are:

Table 18. Sustainability strategies for hill construction

Area	Strategies
Land and ecology	Keep steep slopes, springs, streams and forest as no-build zones; plant native species; avoid cutting trees on slopes; preserve wildlife corridors.
Earthwork	Minimise cut and fill, reuse excavated material on site, avoid muck dumping into valleys and streams.
Materials	Use local stone, timber from certified sources, bamboo, fly-ash or slag-based cements, recycled aggregate; cut transport distances and embodied carbon.
Energy	South-facing glazing for passive solar gain in cold regions, natural ventilation, rooftop solar PV, solar water heaters, efficient insulation.
Water	Rainwater harvesting, grey-water reuse, low-flow fixtures, recharge pits and permeable paving.
Bio-engineering	Vetiver grass, brush layering, live fascines and tree belts protect shallow slopes at low cost.
Waste and construction practice	Segregate and recycle construction waste; control dust and noise; prevent silt-laden water from entering streams.
Green building rating	Rating systems like GRIHA and IGBC can guide choices and give a checklist.
Resilience	Design for climate extremes: higher rainfall intensities, cloudbursts and heat; include early-warning systems.
Important point for explanation A development is sustainable on a slope only if it is first safe . A very “green” building on an unstable slope is not sustainable. Safety, then low impact, then comfort and economy, is the correct order of priorities.	

4.3 Case Studies and Lessons

The following examples are discussed in general terms, to illustrate principles. Students should consult original sources and add data when presenting.

Table 19. Case studies and lessons

Place	Feature	Lesson
Indian hill towns (Shimla, Darjeeling, Gangtok, Mussoorie)	Historic compact settlements stepped along ridges and contours; later expansion into unstable slopes with high-density building	Early patterns suited the terrain, while unplanned densification and blocked drains led to repeated slope failures and building damage
Hill station developments in the Western Ghats	Planned hill communities with terraces and roads cut into slopes	Large-scale cutting and disturbed drainage have drawn criticism and legal scrutiny; shows importance of environmental assessment and hazard mapping

Place	Feature	Lesson
Hong Kong	Dense city on steep terrain with a government slope safety system after serious landslide disasters	Systematic slope inventory, design standards, maintenance and monitoring cut landslide risk sharply
Traditional terraced settlements and farming (Andes, Himalaya, Mediterranean coasts)	Stepped terraces with stone retaining walls and careful water channels	Centuries-old examples of terrain-adaptive thinking, with drainage built into the wall system
Hill roads and urban pockets after heavy monsoons	Slope failures at cuts, blocked culverts, saturated fills	Most failures link back to water and poorly supported cuts, so design for water first

V. PROJECT MODEL: DESCRIPTION AND CONSTRUCTION

This section describes the scaled physical model prepared for the seminar. The model is a scaled representation of the ideas studied in the earlier sections.

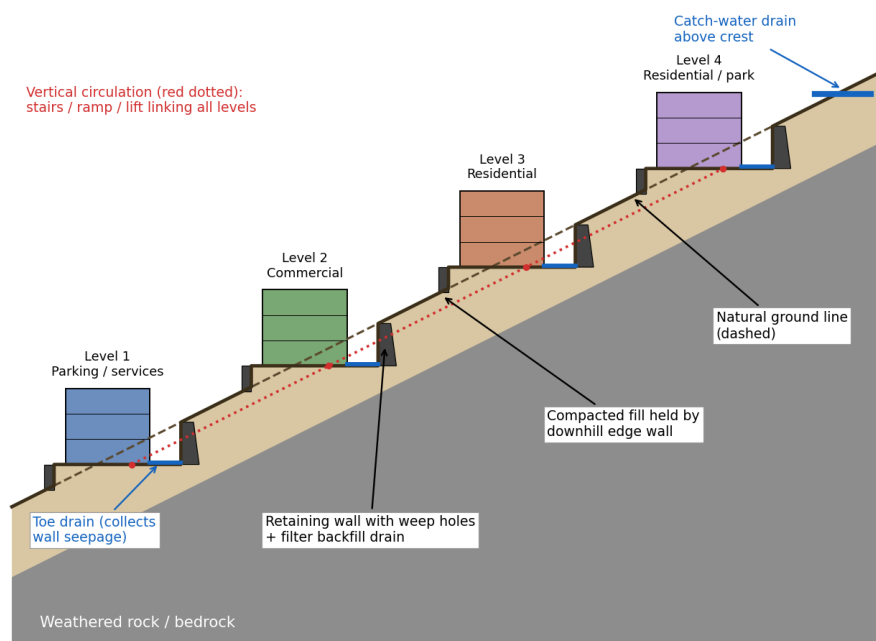


Fig. 5.1 Schematic cross-section of the concept shown in the model (not to scale)

5.1 What the Model Represents

The model shows a hill slope converted into a series of terraces (levels). Each level carries buildings and a road, is supported by a retaining wall on its uphill side, and is linked to the other levels by stairs, ramps or lifts. Drains run along the top of the slope and along each wall, finishing in the lowest-level collection area.

5.2 Model Components and Their Real-World Meaning

Table 20. Model elements and their real-world meaning

Model element	Typical model material	Real-world meaning
Contour base	Stacked layers of thermocol, foam board, cardboard or plywood cut along contour lines	Natural terrain; each layer is a fixed contour interval
Terraces	Flat cut-outs on the layers or added boards	Cut-and-fill platforms for each level
Retaining walls	Wooden strips, cardboard, balsa or clay with textured finish	Walls supporting the cut and fill edges
Buildings	Cardboard, foam, balsa or 3D-printed blocks	Step-back and split-level buildings; stilts for some
Roads	Black chart paper or thin sheet along contours	Contour-following roads at controlled gradient
Stairs, ramps and lift	Cardboard steps, thin sheet ramp, tower of box and thread	Vertical connectivity between levels
Drains	Blue thread or strips along crest and each wall	Catch-water drains, toe drains and outfalls
Vegetation	Sponge, moss or artificial grass and tree models	Bio-engineering and green buffers
Solar panels, tanks	Small panels and cylinders on roofs	Sustainable energy and water features

5.3 Suggested Scale and Labelling

- Choose a horizontal scale such as 1:200 or 1:500 and a vertical scale (it can be exaggerated, for example 1:100), and state clearly whether the vertical is exaggerated.
- Fix a contour interval (for instance, each layer = 2 m of real height) and write it on the model.
- Label each level, the retaining walls, drains, vertical circulation and the north direction; add a legend.

- Show the “before” profile by a line or a ghost layer of the natural ground, so viewers see how little the terrain was altered.

5.4 Steps for Making the Physical Model

1. **Select the terrain.** Take a contour map (real or imaginary) with a suitable contour interval, for example 2 m.
2. **Prepare contour layers.** Trace each contour on foam board, thermocol or cardboard and cut the layers carefully.
3. **Stack and glue the layers** from the lowest to the highest contour, checking alignment with registration marks.
4. **Form terraces.** Mark the platforms for each level and cut or add layers so that the platforms are level.
5. **Fix retaining walls** on the uphill side of each terrace and edge walls on the downhill side.
6. **Place roads** along the contours, with a gentle gradient, and add stairs, ramps and lifts between levels.
7. **Add buildings** in step-back, split-level or stilt form, with heights appropriate to the scale.
8. **Add drains** (blue thread or strips) along the crest, each wall and the lowest level.
9. **Add vegetation and sustainability features:** trees, grass, solar panels and rainwater tanks.
10. **Finish and label:** colour, legend, north arrow, scale, and names of levels and components.

5.5 Limitations of the Model

- The model is conceptual: it does not represent real soil behaviour, seepage or seismic response.
- The vertical scale is usually exaggerated to make terraces visible.
- Structural sizes (wall thickness, column sizes) are not to scale and no design is implied.
- For a real project, site investigation data, slope stability analysis and structural design to IS codes are essential.

VI. ADVANTAGES AND DISADVANTAGES

This section lists the main advantages and disadvantages of terrain-adaptive multi-level construction compared with the conventional flatten-and-build approach, and the hazards that must be managed on a hill site.

6.1 Advantages

- Lower risk of landslides and slope failures than uncontrolled cutting and filling.
- Preserves natural drainage, vegetation and landscape character.
- Makes use of otherwise unusable land and eases pressure on flat land and agriculture.
- Offers views, daylight and ventilation to many units, and a layered public realm.
- Can reduce earthwork and haulage cost when cut and fill are balanced.

6.2 Disadvantages, Limitations and Challenges

- Higher design effort: detailed investigation, slope analysis and structural design are essential.
- Higher unit cost of construction due to retaining structures, drainage and transport.
- Complex coordination between geotechnical, structural, planning and services teams.
- Access for elderly and disabled people needs lifts and ramps.
- Requires long-term maintenance and monitoring, and strong regulation so the system does not degrade.
- Limited by slope, ground and seismic conditions: some sites should simply not be built on.

6.3 Risk Matrix for Hill Development

Table 21. Risk matrix for hill development

Hazard	Typical cause	Main mitigation
Shallow landslide	Intense rain, saturated colluvium, toe cutting	Drains, vegetation, avoid toe cutting, retaining walls
Deep-seated slide	Weak layer, high water table, old slide mass	Detailed investigation, avoid area or use piles and drainage galleries
Rockfall	Jointed rock, steep face, root wedging	Rock bolts, catch ditches, barriers, scaling loose blocks
Erosion and gullying	Concentrated runoff on bare soil	Lined drains, energy dissipaters, turfing, bio-engineering
Earthquake damage	Irregular buildings, short columns, poor detailing	Regular plan, shear walls, ductile detailing, seismic gaps
Retaining wall failure	No drainage, weak foundation, surcharge	Weep holes, filters, adequate base, stability checks
Flash flood and cloudburst	Steep catchment and heavy rainfall	Setbacks from streams, adequate culverts, early warning
Settlement of fill	Loose fill, poor compaction	Layered compaction, benching, avoid building on uncontrolled fill

VII. CONCLUSION

7.1 Summary of the Study

The seminar studied how multi-level urban development can be adapted to hilly terrain. The main findings of each section are summarised below.

Table 22. Key findings of the study

Section	Key findings
I. Introduction	Hill urbanisation is increasing; flattening hills raises landslide and damage risk; terrain-adaptive design follows contours and limits disturbance.
II. Literature review	Slope failure is controlled mainly by water, slope angle and toe cutting; hill buildings suffer from short columns and torsion; retaining walls fail mostly through drainage and foundation problems; research on integrated planning is limited.
III. Technical study	Detailed investigation is essential; slope FOS must be checked for dry and wet conditions; layouts should follow contours with controlled road gradients; buildings need regular configuration, shear walls and ductile detailing; foundations must reach firm ground; drainage is the first priority.
IV. Construction and sustainability	Balanced cut and fill, benching, compaction, prefabrication and monitoring reduce risk; sustainable practice means safe, low-impact and resource-efficient development.
V. Project model	The model shows terraces, retaining walls, drains, roads and vertical links, and communicates how the concept works.
VI. Advantages and disadvantages	Benefits are lower landslide risk, preserved drainage and landscape, and better use of scarce land; drawbacks are higher design and construction cost, coordination effort, maintenance needs and limits on very steep or unstable sites.
VIII. Project initiation	The problem statement, aim, objectives, scope, stakeholders and resources for the project work were identified.

7.2 Conclusion

Terrain-adaptive multi-level construction treats a hill as a system of geology, water, vegetation and people. By following the contours, limiting cut and fill, providing strong drainage, designing buildings that respect slope and seismic behaviour, and using careful construction and monitoring, it is possible to build safe and attractive urban areas on hills. The approach asks for more investigation and design effort than conventional flat-land methods, but this is paid back through lower risk and longer service life. For civil engineers, the main message is that on a hill the ground, the water and the structure must always be designed together.

7.3 Future Scope

- Applying GIS and remote sensing to prepare slope, geology and drainage maps for real hill sites.
- Using software for slope stability (limit equilibrium or finite element) and for seismic analysis of step-back buildings, to extend the illustrative examples of this report.
- Testing the model concept on a real local site, for example a hill slope near Pune, with site investigation data.
- Studying cost comparison between conventional and terrain-adaptive layouts.
- Studying instrumentation and low-cost sensor networks for landslide early warning.
- Exploring prefabrication, light steel and timber systems for hill housing.

7.4 Possible Future Developments

- Remote sensing, LiDAR and drone surveys, combined with GIS-based hazard mapping.
- Real-time sensor networks and early-warning systems for rainfall-triggered landslides.
- Low-carbon concrete, bio-cement and engineered timber for light, sustainable structures.
- Digital twins and BIM to coordinate terrain, structure and services.

VIII. PROJECT INITIATION

Project initiation records what the project will do, why it is needed, who is concerned with it and what is needed to carry it out. This section sets these points out for the project work that follows from the seminar topic: a scaled physical model of a terrain-adaptive, multi-level settlement on a hill slope.

8.1 Description of Problem Statement

Conventional flat-land methods applied to hill sites produce large unsupported cuts, loose fills and blocked drainage lines. These raise the risk of slope failure, increase maintenance costs and damage the landscape. There is a need for a planning and construction approach in which geotechnical safety, structural behaviour, drainage, accessibility and sustainability are considered together from the start.

Project problem statement: to prepare a scaled physical model of a terrain-adaptive multi-level settlement on a hill slope, showing how terraces, retaining walls, drainage, roads, vertical links and buildings can be arranged to follow the natural contours, and to explain how this arrangement reduces the risks of conventional cutting and filling.

8.2 Scope and Objectives

8.2.1 Aim and objectives

Aim: to study the principles of terrain-adaptive multi-level urban construction in hilly terrain and to present them through a physical project model.

Objectives:

1. To understand the various characteristics and engineering challenges in hilly terrain.
2. To study stability ,site investigation and stabilisation measures.
3. To planning principles for multi-level development along contours.

8.2.2 Scope and methodology

The seminar is a study-based and model-based project. It does not include a full design of a real site and the illustrative examples are explained in words. The work followed these steps:

1. **Literature and code study:** books, research papers, Indian Standards and government guidelines (Section II).
2. **Concept development:** identifying principles and design components of terrain-adaptive construction (Section I and 3).
3. **Technical study:** geotechnical, planning, structural, foundation and drainage aspects (Section III).
4. **Construction and sustainability review:** methods, case studies, advantages and limitations (Section IV and 6).
5. **Physical model:** preparation and explanation of a scaled terrace model (Section V).

8.3 Stakeholders

Stakeholders are the people and organisations who take part in the project, who are affected by it or who have an interest in its result. The main stakeholders of this project are listed below.

Table 23. Stakeholders and their interests

Stakeholder	Role and interest in the project
Students (project team)	Carry out the study, prepare the report and the model, and present the work.
Project guide / faculty	Guides the work, reviews progress, certifies the report and takes part in assessment.
Head of Department and institute	Approve the work and provide library, laboratory, workshop and computer facilities.
MSBTE and examiners	Set the course requirements and assess the report, model and presentation.
Residents and users of hill towns	Final beneficiaries of safer hill development; their needs for housing, access and safety shape the concept.
Town planners and local authorities	Frame hill-area development rules, setbacks and approvals that the concept must respect.
Engineers and contractors	Civil, geotechnical and structural engineers and builders who apply the design and construction methods.
Disaster-management and environmental bodies	Concerned with landslide hazard, ecology and sustainable use of hill land.

8.4 Platform, Equipment and Resources Identification

The platform, equipment and resources identified for the project work are listed below. Items may be changed to match what the group actually uses.

Table 24. Platform, equipment and resources identified

Type of resource	Items identified	Use in the project
Software and digital platform	MS Word and PowerPoint; Google Earth or a free GIS tool such as QGIS; AutoCAD or hand drawing; MS Excel	Report writing and presentation, terrain and contour study, layout drawings, stability and retaining-wall studies
Model materials	Thermocol or foam board, cardboard, plywood, balsa strips, clay, chart paper, thread, sponge or artificial grass, adhesive, paints	Contour layers, terraces, retaining walls, buildings, roads, drains and vegetation of the model
Tools and equipment	Scale, measuring tape, cutter or hot-wire cutter, scissors, set squares, glue gun, sandpaper, brushes	Cutting layers, assembly and finishing of the model
Reference resources	Indian Standards (IS 1893, IS 4326, IS 13920, IS 14458 and others), NBC 2016, IRC SP:48, NDMA guidelines, textbooks and research papers	Technical study, illustrative examples and literature review
Human resources	Project team, guide, subject teachers, workshop and laboratory staff	Guidance, review and help with model making
Facilities	Institute library, computer laboratory, internet access, workshop or model-making space	Collecting references, preparing drawings and building the model

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