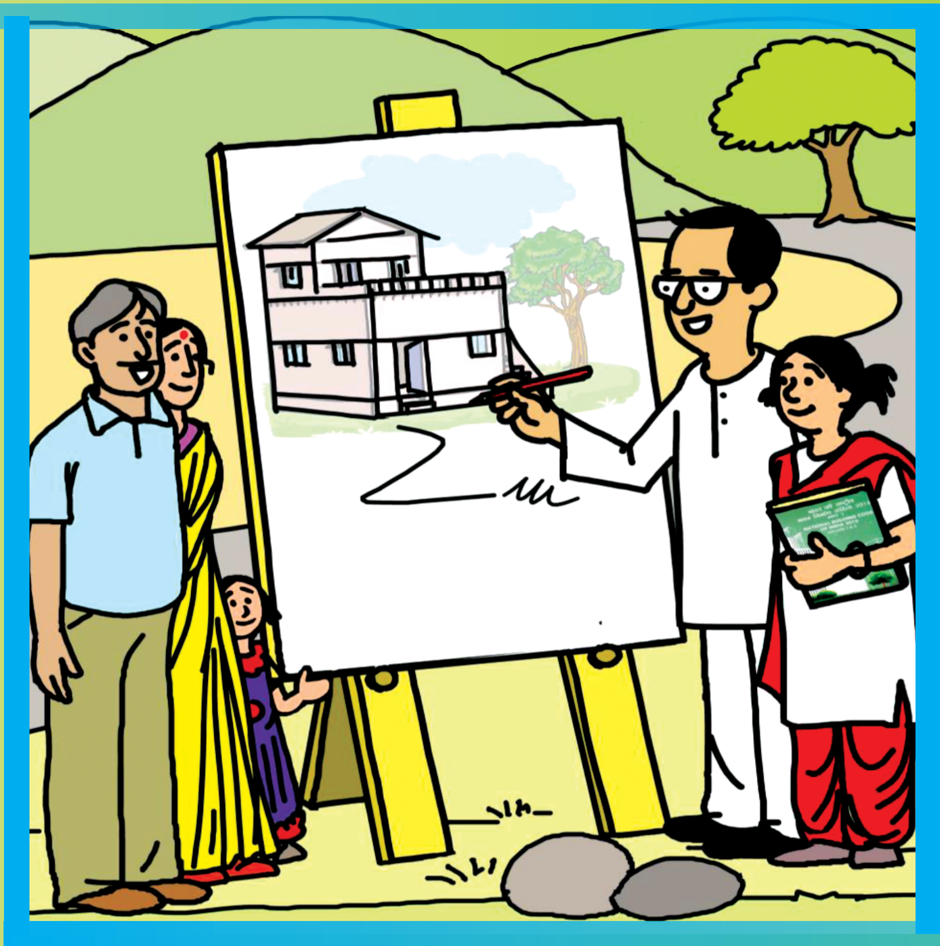
सत्यमेव जयते



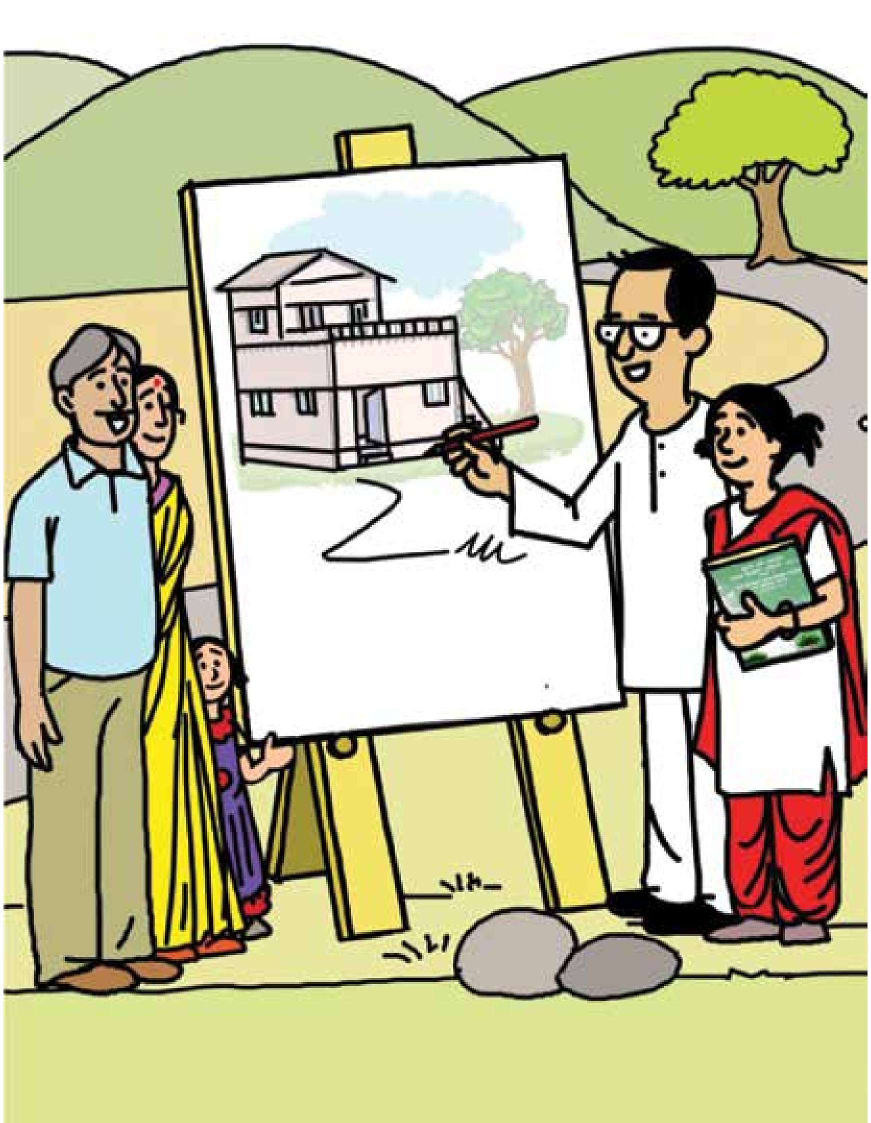
SIMPLIFIED GUIDELINES

for Earthquake Safety of Buildings from National Building Code of India 2016

मानकः पथप्रदर्शकः

National Disaster Management Authority
Government of India

Bureau of Indian Standards
Government of India



Simplified Guidelines

for Earthquake Safety of Buildings from National Building Code of India 2016

National Disaster Management Authority
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Government of India

सत्यमेव जयते

प्रधान मंत्री
Prime Minister

संदेश

राष्ट्रीय आपदा प्रबंधन प्राधिकरण (एनडीएमए) द्वारा 'राष्ट्रीय भवन संहिता 2016 से भवनों की भूकंप सुरक्षा के लिए सरलीकृत दिशानिर्देश' तैयार किए जाने के बारे में जानकर प्रसन्नता हुई।

आपदा-प्रबंधन के सन्दर्भ में तत्परता और तैयारी महत्वपूर्ण हैं। राहत और बचाव अभियानों की अगुवाई से लेकर क्षमता निर्माण की दिशा में एनडीएमए के सतत् और समर्पित प्रयास सराहनीय हैं।

विकास की नित नई ऊंचाइयों को छूते भारत में आज आधारभूत संरचनाओं का तेजी से निर्माण हो रहा है। सबके लिए आवास के संकल्प की सिद्धि के लिए लगातार प्रयास जारी हैं।

भूकंप का विषय लोगों की सुरक्षा से सीधा जुड़ा है। इस विषय पर नवीनतम तकनीक के अधिकाधिक इस्तेमाल से लेकर सार्वजनिक जागरूकता और स्थानीय ज्ञान के संयोजन जैसे सभी पक्षों पर समग्र प्रयासों को बढ़ावा देना आवश्यक है।

एनडीएमए इस दस्तावेज के द्वारा भूकंप प्रतिरोधी निर्माण और भूकंप से सुरक्षा को लेकर जानकारियों और दिशानिर्देशों को सहज तरीके से लोगों तक पहुँचाने का प्रयास कर रहा है।

मुझे उम्मीद है कि भवन निर्माण, खरीद और रखरखाव के दौरान ध्यान दिए जाने वाले अहम् पहलुओं पर सचित्र दिशानिर्देश से मिलने वाली जानकारी इस प्राकृतिक आपदा के प्रति लोगों को सजग और तत्पर बनाने में प्रभावी योगदान देगी।

एनडीएमए को इस प्रयास के लिए बधाई व शुभकामनाएं।

(नरेन्द्र मोदी)

नई दिल्ली
भाद्रपद 11, शक संवत् 1943
02 सितम्बर, 2021

श्री संजीव कुमार
सदस्य सचिव
राष्ट्रीय आपदा प्रबंधन प्राधिकरण
एनडीएमए भवन, ए-1, सफदरजंग एन्कलेव
नई दिल्ली- 110029

अमित शाह

गृह मंत्री
एवं
सहकारिता मंत्री
भारत सरकार

सत्यमेव जयते

संदेश

मुझे यह जानकर प्रसन्नता हो रही है कि राष्ट्रीय आपदा प्रबंधन प्राधिकरण (एन.डी.एम.ए.) ने "भारत की राष्ट्रीय भवन निर्माण संहिता, 2016 के आधार पर भूकंप से भवनों की सुरक्षा हेतु **सरलीकृत दिशा-निर्देश**" तैयार किए हैं। भूकंप से सबसे ज्यादा नुकसान भवनों के गिरने से होता है। इसलिए, इस तरह की विनाशकारी घटनाओं से अपने भवनों को सुरक्षित रखना और भवनों को भूकंप प्रतिरोधी बनाना अत्यावश्यक है ताकि भूकंप से कम से कम या कोई क्षति न हो।

इन दिशा-निर्देशों में भारत की राष्ट्रीय भवन निर्माण संहिता, 2016 का सारांश है, जिसे चित्रात्मक चित्रण के रूप में प्रस्तुत किया गया है। इनमें उन महत्वपूर्ण पहलूओं, उप-नियमों, सामान्य गलतियों को उजागर किया गया है, जिन्हें घर का निर्माण करते अथवा खरीदते समय ध्यान में रखने की आवश्यकता है।

मुझे विश्वास है कि ये दिशा-निर्देश लोगों द्वारा उनके घरों का निर्माण करने एवं उन्हें सुरक्षित तथा भूकंप प्रतिरोधी बनाने में लाभकारी साबित होंगे और इनसे भूकंप प्रतिरोधी भारत के विजन को साकार करने में मदद मिलेगी।

मैं, राष्ट्रीय आपदा प्रबंधन प्राधिकरण और इससे जुड़े अन्य लोगों को भूकंप के परिणामों के बारे में लोगों के मार्गदर्शन हेतु सरलीकृत दिशा-निर्देश तैयार करने के लिए बधाई देता हूँ।

धन्यवाद सहित !

(अमित शाह)

कार्यालय : गृह मंत्रालय, नॉर्थ ब्लाक, नई दिल्ली-110001
दूरभाष : 23092462, 23094686, फैक्स : 23094221
ई-मेल : hm@nic.in

Preface

This *Simplified Guidelines* is prepared with *Earthquake* hazard in mind, and is expected to guide current and potential home owners towards reducing losses in future in the aftermath of the negative fallout of this natural event. It provides details based on the *National Building Code of India 2016* (released by the Bureau of Indian Standards, Government of India) to those who are *constructing* a house and who are *buying* a flat in multi-storey buildings, which are made of either *masonry* or *reinforced concrete* (*RC*). This *Guide* focuses to address this aspiration of potential home owners, and provides the basic information that they should have when *constructing individual houses* or *buying flats in multi-storey buildings*.

This *Guide* provides the basic information on five aspects related to construction or purchase of a house, namely:

(1) *About NBC 2016* – Its applicability and use,

(2) *Site* – Suitable Site to Construct a House,

(3) *Architectural Form* – Appropriate Geometry and Sizing of a House,

(4) *Structural Safety* – Quality of Materials for Constructing a House and Special Engineering Details of a House, and

(5) *Regularity Mechanism* - Competent Hands (Professionals & Artisans) to Construct a House, and Role & Responsibility of Stakeholders.

The aspects mentioned in this Guide are the *minimum requirements* that have to be complied with while constructing a house; this select information is in no way to be considered either *comprehensive* or *complete*. The *Guide* is intended to reduce the most commonly made mistakes while constructing houses and answer *Frequently Asked Questions* while constructing a house. Pictorial characters, *Dadaji* and *Munni*, used in the illustrations, walk readers of the *Guide* through the *good practices*, and caution them on possible pitfalls.

The development of *an individual house* or *a multi-storey building with many flats* in each of them requires attention to *siting*, *planning*, *designing*, *constructing*, *maintaining* and *retrofitting* of houses. This *Guide* addresses select aspects related to these. And, even these aspects are dealt with a limited scope of informing the *Home Owners* of essential information that they need to possess before constructing or buying a house. Thus, this *Guide* is in no way complete with all details that professionals may need to *site*, *plan*, *design*, *construct*, *maintain* and *retrofit* houses.

The *Simplified Guidelines* were developed under the guidance of a Working Group constituted by NDMA. The contents of this *Simplified Guidelines* were scripted by Sri S. Arun Kumar [*Head (Civil Engineering), Bureau of Indian Standards, New Delhi*], Sri Ajay P. Chourasia (*Senior Principal Scientist,* CSIR *Central Building Research Institute*, Roorkee), Sri Sanjay Pant *[Deputy Director General (Standardization-II), Bureau of Indian Standards, New Delhi*], and Prof. C. V. R. Murty (*Professor, Department of Civil Engineering, Indian Institute of Technology Madras*); and illustrated by Sri Rajkumar Patel (*Jaipur*). These *Simplified Guidelines* are prepared under the aegis of the *Bureau of Indian Standards* and the *National Disaster Management Authority*, Government of India.

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Acknowledgements

Earthquakes and Cyclones disrupt *lives*, *livelihoods* and *infrastructure*. Preventing them from affecting *dwelling units* is a *small* yet significant step towards building disaster resilience. The continued support of Sri Sanjeeva Kumar, *Member-Secretary*, NDMA, and Sri Kamal Kishore, Lt.Gen. Syed Ata Hasnain *(Retd.)*, Sri Rajendra Singh and Sri Krishna Vatsa, *Members*, NDMA, was crucial in the timely completion of this *Guide*.

NDMA acknowledges the contribution of the following *Working Group* Members constituted for the development of these Simplified Guidelines. Prof. C. V. R. Murty (*Prof., IIT Madras*), Sri Sanjay Pant *[Deputy Director General (Standardization-II), Bureau of Indian Standards, New Delhi*], Sri S. Arun Kumar [*Head*

(Civil Engineering), Bureau of Indian Standards, New Delhi], Sri Ajay P. Chourasia (*Sr. Pr. Scientist*, CSIR *Central Building Research Institute*, Roorkee) and Sri Reginald J. Sinclair *(GM, CREDAI, New Delhi)* and Sri Rajesh Khare *(CE, CPWD, New Delhi) and* Sri S. C. Mehrotra *(Representative of IAStrucE, New Delhi)*

Sri Jayanta Roy Chowdhary, *Deputy Director General (Standardization – I), Bureau of Indian Standards*, has played a *key role* in conceptualising and giving technical inputs in development of this Guide. Also, Sri Pramod Kumar Tiwari, *Director General,* BIS, has provided technical and administrative support. NDMA gratefully acknowledges the same.

Ms. Sreyasi Chaudhuri, *Joint Secretary (Mitigation) and* Sri K. Uma Maheswara Rao *Joint Advisor (Mitigation)* NDMA, were instrumental in guiding and supporting the development of this Guide. Sri Javed Iqbal, *Jr. Consultant (Earthquake)*, NDMA and Sri Mahendra Meena *former Sr. Consultant (Earthquake)*, and Ms. Dirgha Singh, *Research Associate*, CSIR-CBRI, have provided technical and administrative support.

CSIR Central Building Research Institute (CBRI), Roorkee, also provided administrative support in the development of this *Guide*; NDMA gratefully acknowledges the same.

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Contents

1

NBC 2016

1.1 What are the factors to be considered in the construction of a House?

The factors to be considered in the construction of a house are:

(1) *Safety,*
(2) *Functionality,*
(3) *Sustainability,*
(4) *Aesthetics, and*
(5) *Economy.*

In the above list, the order of priority is non-negotiable in the first three factors; *Safety, Functionality* and *Sustainability* (in that order!!) are *NOT* negotiable in *any* building. The only choice is between *Aesthetics* and *Economy*. If the owner wishes to make the house with more finishes *for aesthetic appeal*, one can pay more *money*.

Clearly, while constructing the building, safety should be on top.

National Building Code of India 2016
Part 2: Administration
Part 4: Fire and Life Safety
Part 6: Structural Design
Part 7: Construction Management, Practices and Safety
Part 8: Building Services
Part 11: Approach to Sustainability


Safety


Functionality

Sustainability

Factors to be considered when constructing a House


Aesthetics


Economy

1.2 What are the steps involved in the construction of a house?

Steps involved in the construction of a house are of two types, namely:

(1) *Regulatory*, and
(2) *Technical*.

The sequence of steps to be undertaken is:

Step	*Activity*	*Type*
1	Get *Land Clearance Certificate* and get the land marked by the Officer of the *Revenue Department* of the State Government	Regulatory
2	Identify and appoint an *Architect/Civil Engineer* for Planning and Architectural Design	Regulatory
3	Identify and appoint a *Structural Engineer* for Structural Design	Regulatory
4	Undertake *Architectural Design* of the Building	Technical
	(a) *Functional Planning & Design*	
	(b) *Services Design*	
	(c) Finishes	
5	Undertake *Structural Design* of the Building	Technical
	(a) *Structural system*	
	(b) *Structural design & detailing*	
6	Identify and appoint an *independent Structural Engineer* for *Peer Review* of Structural Designs, if building is residential and less than 15m in height	Regulatory
7	Undertake the *Peer Review* of Structural Design	Technical
8	Get the *Good for Construction* drawings prepared	Technical
	(a) Architectural Drawings by the *Architect*	
	(b) Structural Drawings by the *Structural Engineer*	
9	Identify and appoint a *Contractor*	Regulatory
10	Identify and appoint a *Construction Project Management Agency*	Regulatory
11	Seek *Building Permit* approval from *Municipal Authority*	Regulatory
12	Undertake quality construction of the House	Technical
13	Undertake *quality assurance* of the construction by the *Construction Project Management Agency*	Technical
14	Seek *Occupancy Certificate* from the *Municipal Authority* on completion of the work	Regulatory

National Building Code of India 2016
Part 2: Administration
Part 3: Development Control Rules and General Building Requirements
Part 7: Construction Management, Practices and Safety

Success of constructing a House
hinges on **ALL** Stakeholders involved in the process
– **some known faces, but many unknown faces**.

1.3 Which part(s) of the *National Building Code (NBC), 2016* are essential for earthquake resistant design and construction?

The *Owner* and other *Principal Stakeholders* should refer all the parts of **NBC 2016**, but Parts 2, 4, 6 and 7 are of prime importance from safety standpoint. In particular, Parts 2, 4, 6 and 7 of **NBC 2016** are essential for design and construction of buildings, namely:

Part 2 : Administration

Part 4 : Fire and Life Safety

Part 6 : Structural Design

Part 7 : Construction Management, Practices and Safety

National Building Code of India 2016
Part 2: Administration
Part 4: Fire and Life Safety
Part 6: Structural Design
Part 7: Construction Management, Practices and Safety

Referring to relevant parts of the **National Building Code 2016** is necessary – especially by the Architects and Engineers.

1.4 If a house is designed in accordance to NBC 2016, will it be damaged during earthquakes?

The primary intent of the earthquake resistant design provisions of **NBC 2016** is to *prevent collapse* of structures, and thereby protect human and animal lives. Under severe intensity of ground shaking, damage is likely to occur in the structural members of normal houses.

Severity of *earthquake ground shaking* underneath the house varies depending on the size of the earthquake and the distance of the house from the epicentre of the earthquake. As per the philosophy of earthquake resistant design:

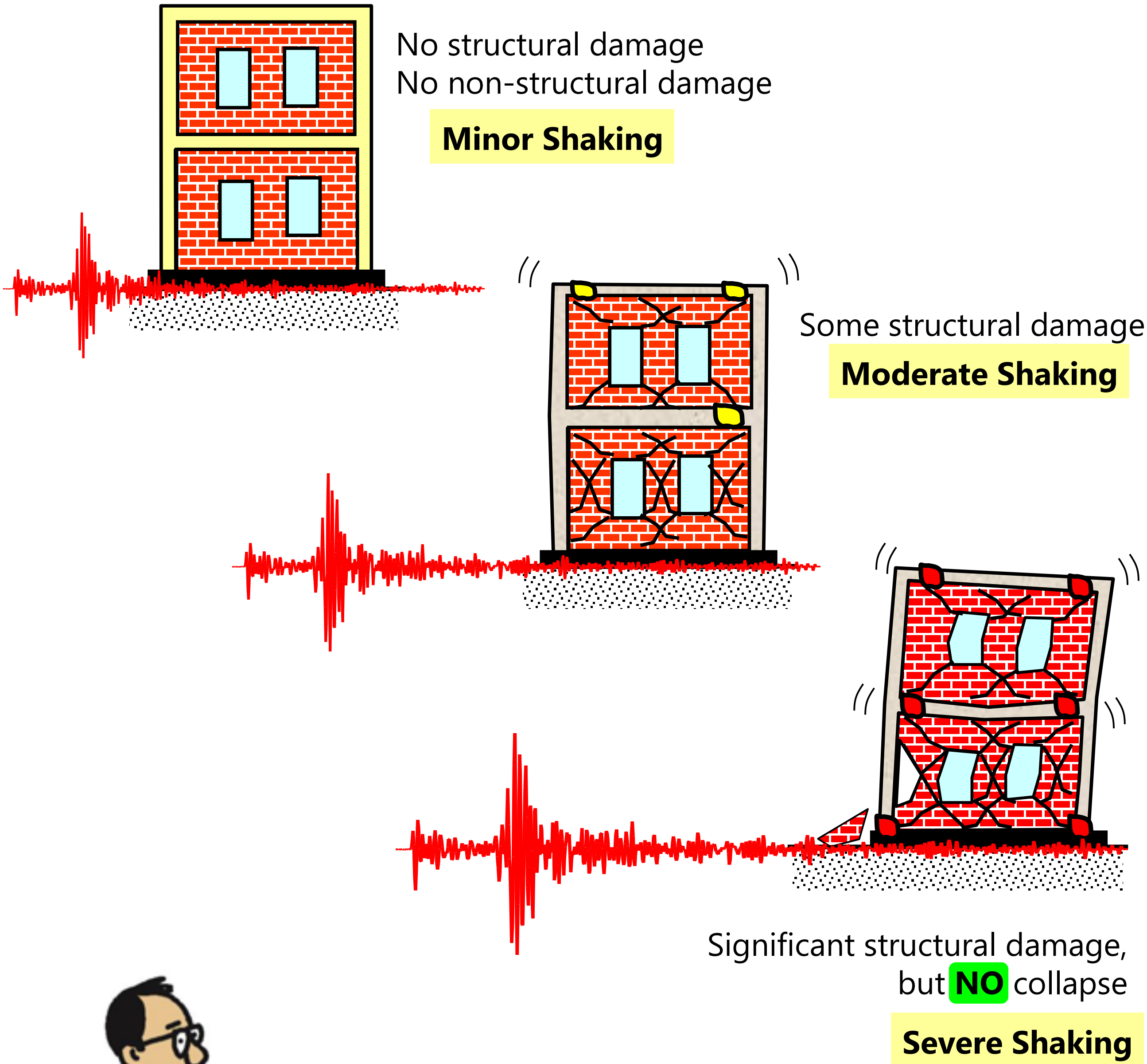
(1) Under *minor (but frequent) shaking*, structural members should not be damaged.

(2) Under *moderate (but occasional) shaking*, structural members may sustain repairable damage; and

(3) Under *strong (but rare) shaking*, structural members may sustain severe (even irreparable) damage, but the house should *not collapse*.

Different types of structural damage can occur in houses during earthquakes. Therefore, the main focus in the design of houses is ensuring that the said structural damage is of *acceptable type* and at *acceptable locations*. For example, in a reinforced concrete frame building with unreinforced masonry infill walls in the bays between beams and columns, the vertical separation cracks are acceptable between columns and masonry walls, but the diagonal cracks cutting across the columns are not acceptable.

National Building Code of India 2016
Part 6: Structural Design



Amount of damage varies at different levels of earthquake ground shaking; also, it is different in different types structures

1.5 If the earthquake resistant design requirements of *NBC 2016* are complied with, will the house cost more?

The cost of construction with earthquake resistant measures is marginally *higher*. The additional initial cost required could be about 3-4% higher in residential building and 2-3% higher in office buildings. This increase is essential for incorporating *earthquake resistant features* in structural elements and making them robust to resist earthquake shaking.

The consequence of not incorporating *earthquake resistant features* in houses is collapse and loss of life; while the loss of the building can be monetarily quantified, the *value of life* cannot be. Hence, **SAFETY First** should be the motto in houses, which are designed to resist earthquake ground shaking.

National Building Code of India 2016
Part 6: Structural Design
Part 7: Construction Management, Practices and Safety

To **protect lives**,
some extra cost **should be paid** for
earthquake resistant constructions.

1.6 Is it mandatory to comply with the requirements of *NBC 2016* in the construction of a new house?

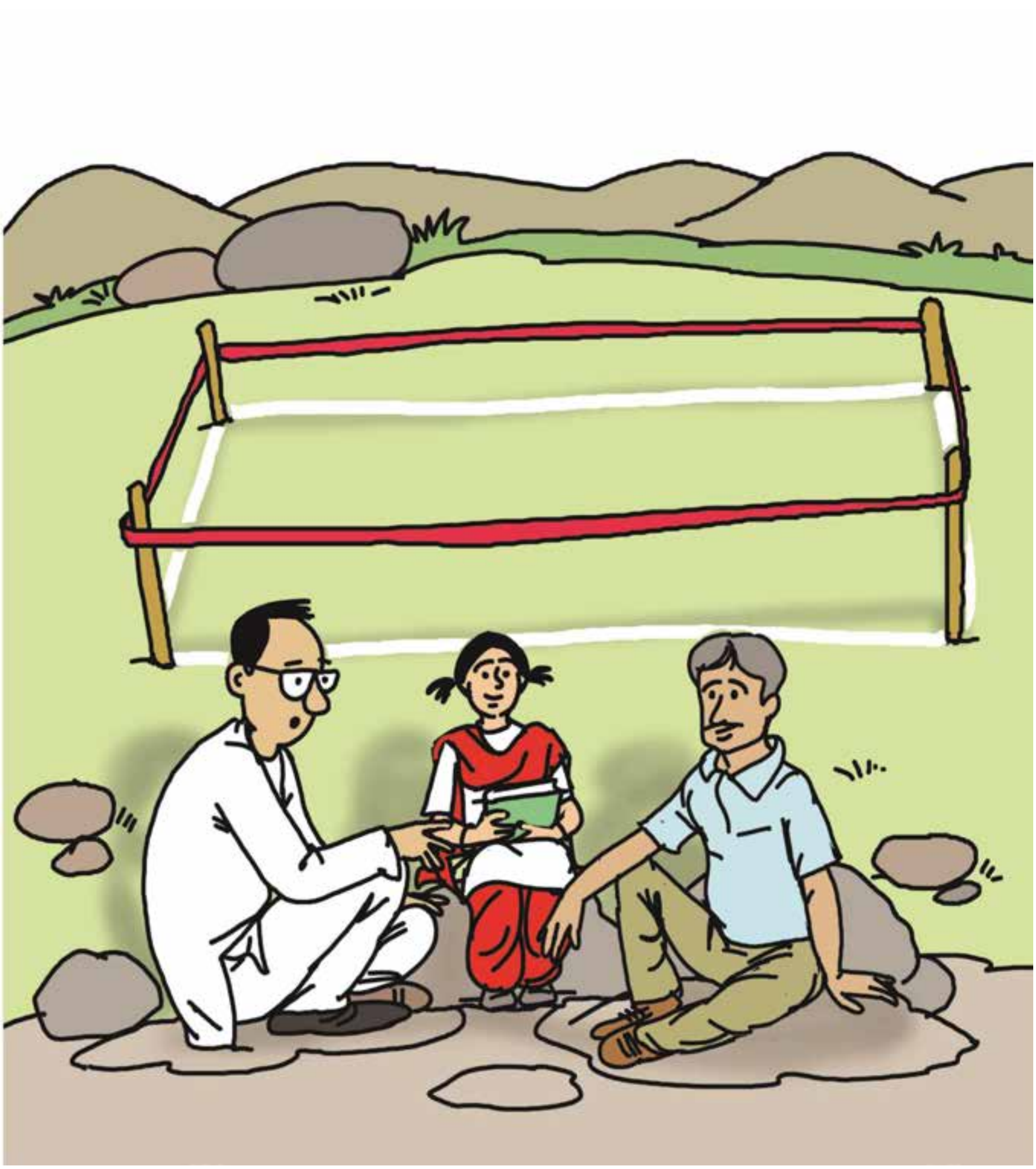
By itself, complying with the requirements of **NBC 2016** is *not mandatory* in construction of new house. But, complying with the requirements of **NBC 2016** is *mandatory*, if:

(1) The *Municipality*, *Municipal Corporation* or *Development Authority* (of the jurisdiction in which the house is to be built) adopts **NBC 2016** in total or its parts in its *Development Control Rules* and *Building Bye-Laws*; and

(2) The Owner adopts **NBC 2016** in total or its parts in its *contract* signed between the *Contractor* and the *Owner*.

It is in the interest of the Owner to refer all parts of **NBC 2016** before construction of a new house. Generally, the local *Building Bye-Laws* or local *Building Regulations* suitably adopt **NBC 2016**, particularly its *safety* related chapters. This should be verified by the Owner.

National Building Code of India 2016
Volume 1
Volume 2



NBC 2016 **should be complied with**.

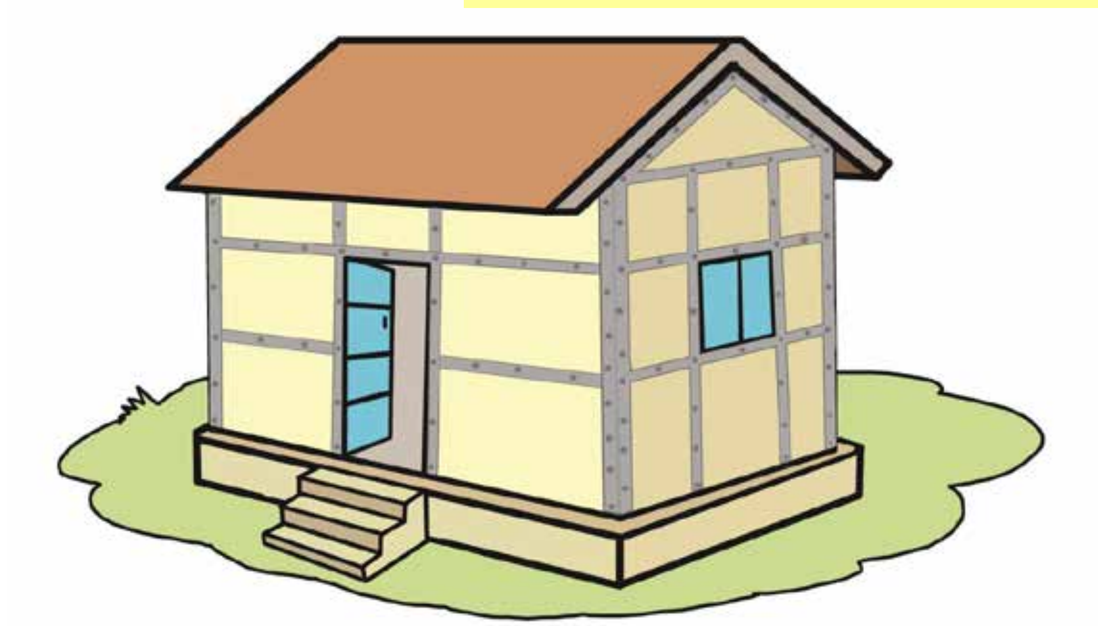
1.7 What should be done to make an existing house earthquake resistant and compliant with requirements of *NBC 2016*?

If the house constructed earlier is not in accordance with the requirements of **NBC 2016**, then consult the *competent* Structural Engineer to verify the structural safety of the building. Check if the *Municipality*, *Municipal Corporation* or *Development Authority* has empanelled structural engineers, then a *competent* one amongst them could be appointed. The said Structural Engineer should do necessary calculations in keeping with **NBC 2016** and determine the safety of the house.

If the house is found to be *deficient structurally*, the Owner should undertake to *retrofit the house*. A competent Structural Engineer can help make it *structurally safe* by adopting different techniques of *structural strengthening*. If the owner has limited funds, the *retrofit* can be performed in stages – *first* those most critical structural elements that affect the structural safety of the house the most, and *then* the remaining ones.

National Building Code of India 2016
Part 6: Structural Design
Part 7: Construction Management, Practices and Safety

Earthquake Resistant Features **should be provided in Houses**.

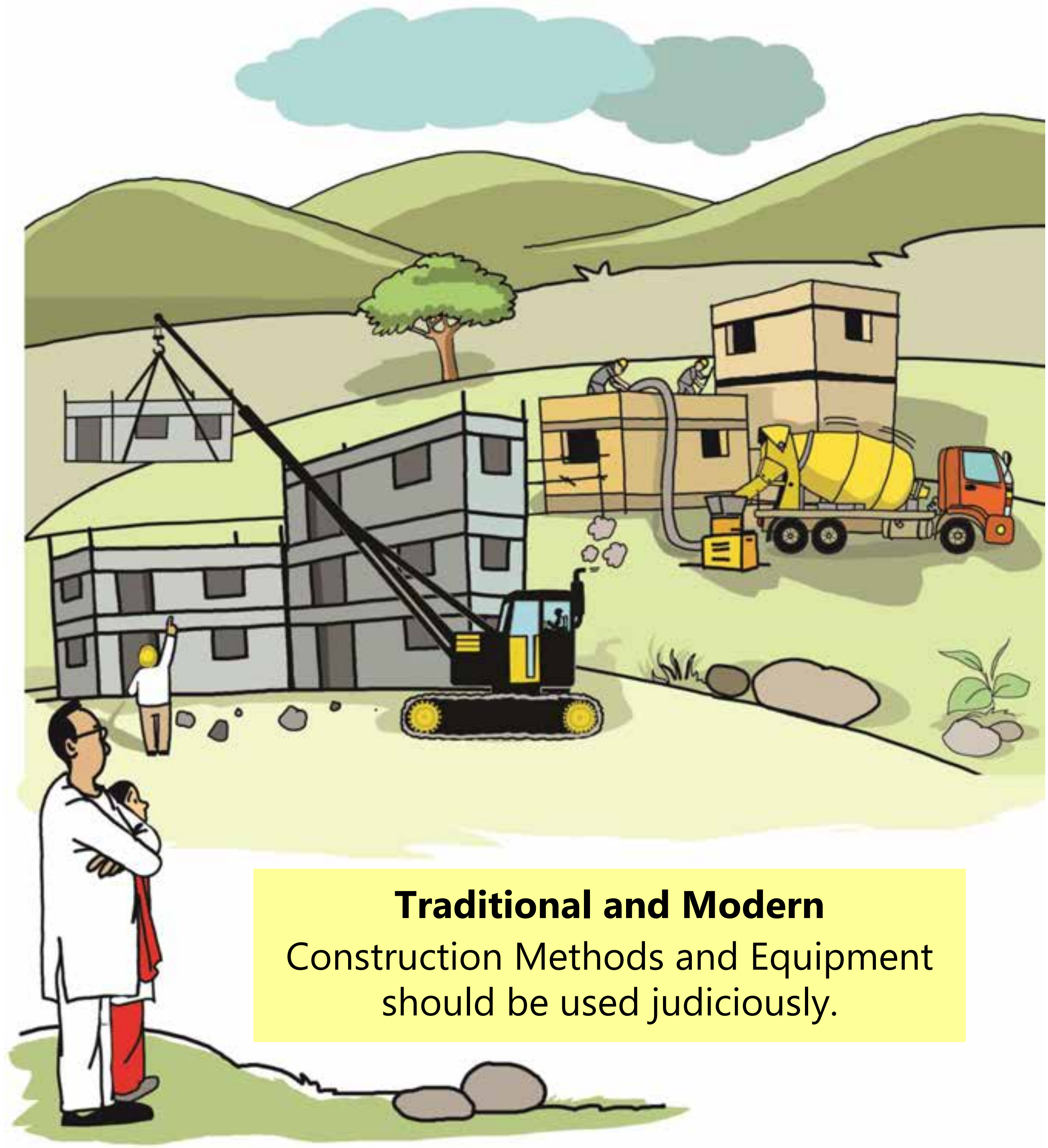


1.8 Will using modern materials and latest construction technology make the house safe?

A house can be made structurally safe, only if it complies scrupulously with all provisions of **NBC 2016** through proper siting, architectural planning, structural design, construction and periodic maintenance. This is possible with *traditional materials* and *conventional construction technologies* as well as *modern materials* and *latest construction technologies*.

Use of modern materials and/or latest constructional technologies can improve the *quality* and *safety* of the house, only if it is constructed properly. The construction using modern technology should be carried out only under the supervision of a *competent* structural engineer.

National Building Code of India 2016
Part 3: Development Control Rules and General Building Requirements
Part 5: Building Materials
Part 6: Structural Design
Part 7: Construction Management, Practices and Safety



Traditional and Modern
Construction Methods and Equipment
should be used judiciously.

2

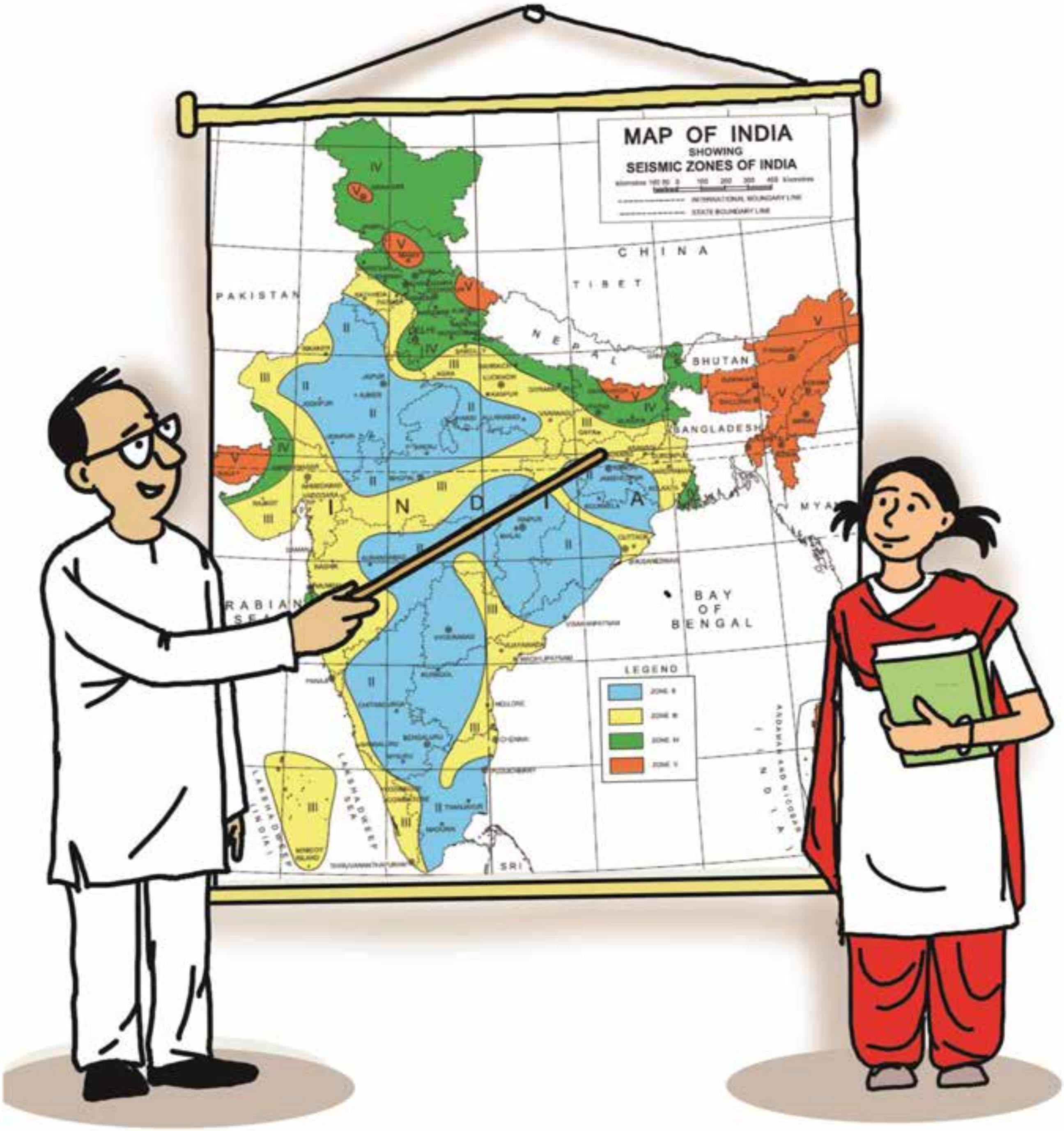
Site

2.1 How to know in which Seismic Zone a house is located in?

A *Seismic Zone Map* of India is published in the Indian Standard IS 1893 (Part 1): 2016, which is presented in *NBC 2016 (Part 6)*. India's landmass is categorized into four *Seismic Zones*, namely *Seismic Zones II, III, IV and V*. The Seismic Zones indicate generally the severity of earthquake ground shaking experienced in that zone during past earthquakes in India. Areas that experienced an intensity VI or less on MSK Scale of earthquake ground shaking are placed under Seismic Zone II, intensity VII under Seismic Zone III, intensity VIII under Seismic Zone IV, and intensity IX or more under Seismic Zone V. Thus, Seismic Zone V is the most severe.

Thus, knowing the longitude and latitude of the location of the house, the *Seismic Zone Map* of India can be used to determine the Seismic Zone in which the house is located.

National Building Code of India 2016
Part 6: Structural Design



Seismic Zone Map helps us know the severity of the ground shaking likely at a site during earthquakes.

2.2 What are the factors that can cause soil liquefaction at a site during earthquake shaking?

The factors that make a site vulnerable to liquefaction during strong earthquake shaking are:

(1) Soil stratum with poorly graded fine-grained cohesionless soil, like sand with most particles of same size,

(2) High ground water table, and

(3) Occurrence of an earthquake of large magnitude in the near vicinity of the site, and that too for a long duration.

When these conditions are met with, the solid soil suddenly becomes liquid soil. This is called *soil liquefaction*. In the liquid state, the Archimedes Principle comes into force – *the weight of the liquid displaced by a body floating in a liquid is the weight of the floating body*. This implies that when the said soil below a heavy object placed close to the ground surface or below a light object buried at large depths below ground surface, is shaken by an earthquake of large ground intensity for an extended period of time, the heavy object may sink and the light object is thrown upwards. Therefore, structures built on earth can sink, float, tilt or even collapse when soil underneath them liquefies.

If the above factors are likely at a site, a competent Geotechnical Engineer should be consulted. She/He will examine the type of soil and the height of water table, and thereafter do the required calculations. If the calculations show that liquefaction is expected at the site, two options are available, namely:

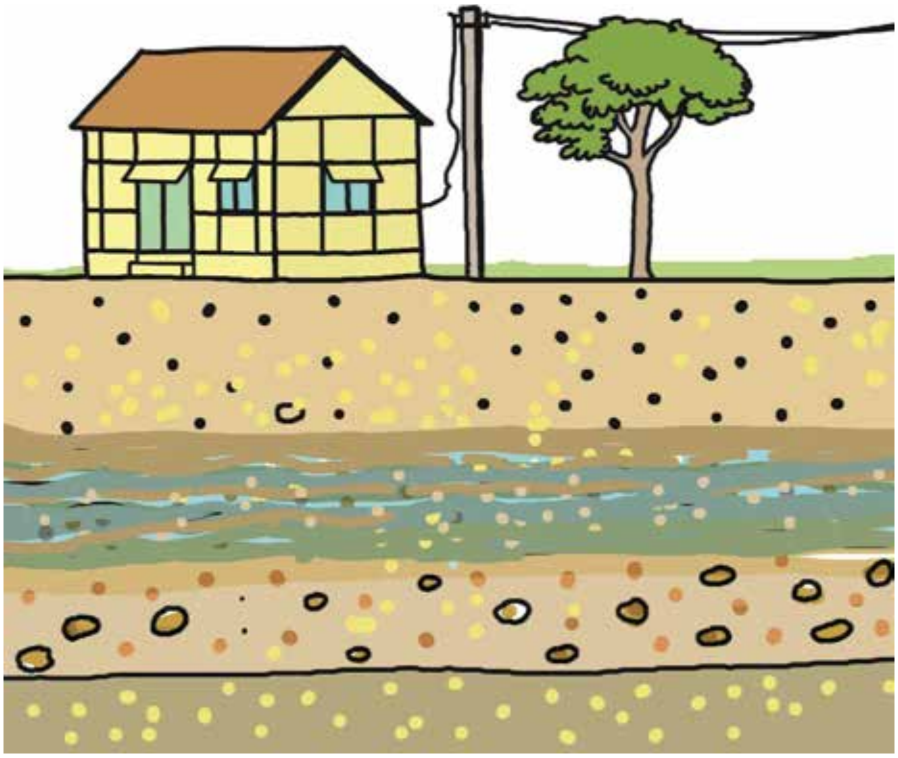
(1) Strengthen the soil underneath, and

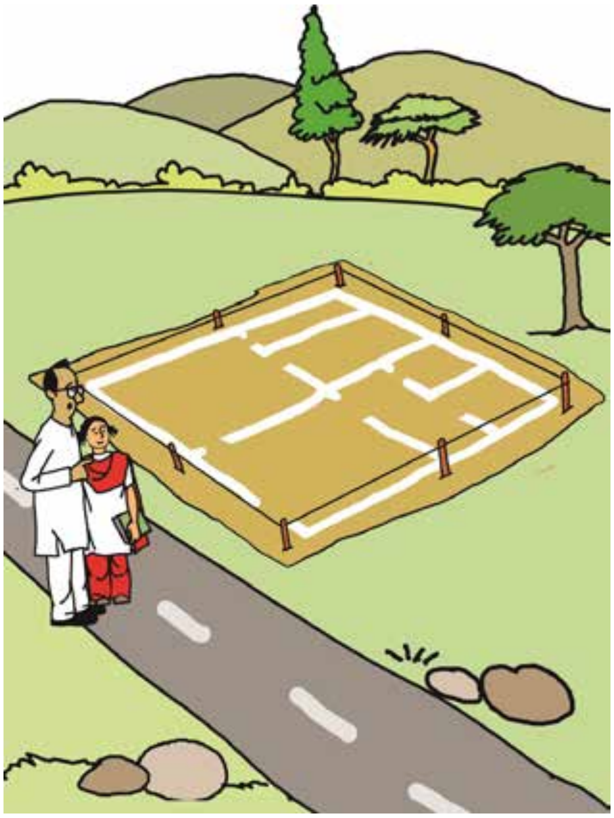
(2) Adopt pile foundations, if feasible.

Both of these options can be expensive, and may not give satisfactory results, if the earthquake shaking exceeds the design value. Thus, in general, it is best to choose sites that do not liquefy during strong earthquake shaking.

Further, the said liquefaction hazard affects the potential for *landslides*. Also, when undertaking seismic microzonation, both liquefaction potential of a site and landslide hazard at that site should be integrated, when arriving at the land use zoning. This aspect should be addressed by the *Municipal Authority*.

National Building Code of India 2016
Part 6: Structural Design





Liquefaction is a widespread phenomenon – Sand, water and strong shaking cause it.

2.3 How to ascertain if a hill slope will suffer a landslide?

As a general rule, hills slopes that are made of soft soils and have slopes steeper than 30^{o} are vulnerable to landslides. The problem is aggravated in soft soils even with slopes less than 30^{o}, if the soil is moist. Thus, at locations where there is perennial rainfall, the soft soil slopes may creep slowly. It is important to look out for fissures in the ground, especially in summer months.

But, if the hill slope is made of hard rock, there are two possibilities:

(1) Rock layers dipping *along the slope of the hill*, and

(2) Rock layers dipping *into the body of the hill*.

The former causes perennial landslides, especially if the site is close to an earthquake fault. Determining the vulnerability of a site to landslides is a critical activity before permitting development on such sites. Competent Rock Mechanics Engineers and Geotechnical Engineers should be consulted to determine the vulnerability of a site to landslides. They are required to do field investigations to determine the properties of the soil layers, ascertain the level of moisture in the soil, and undertake relevant engineering calculations, before concluding if the hill slope will sustain landslide.

In any case, it is best to make only *light weight* houses on hill slopes.

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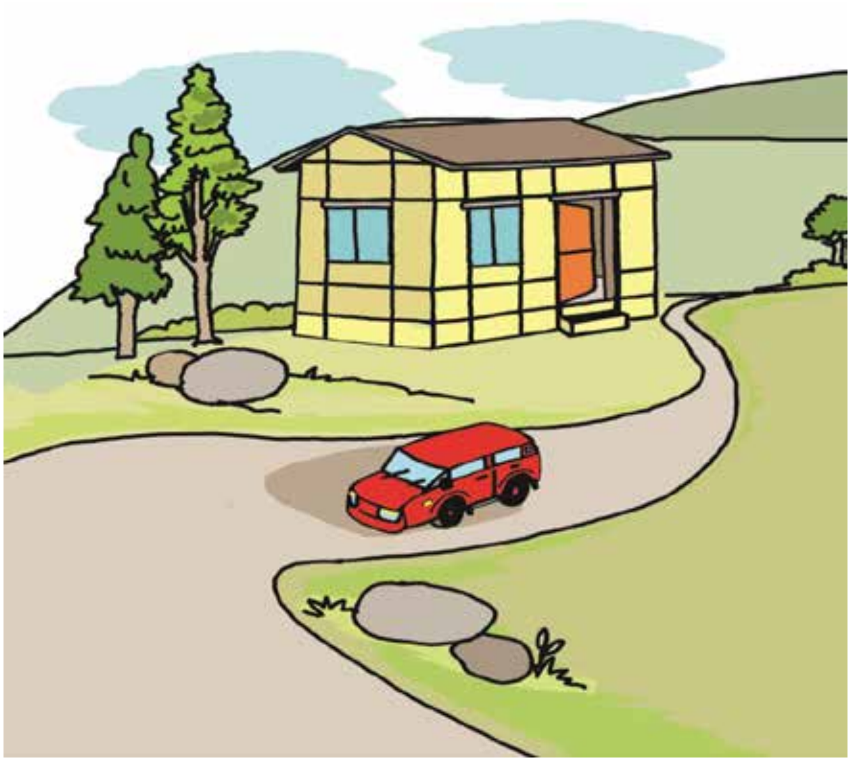
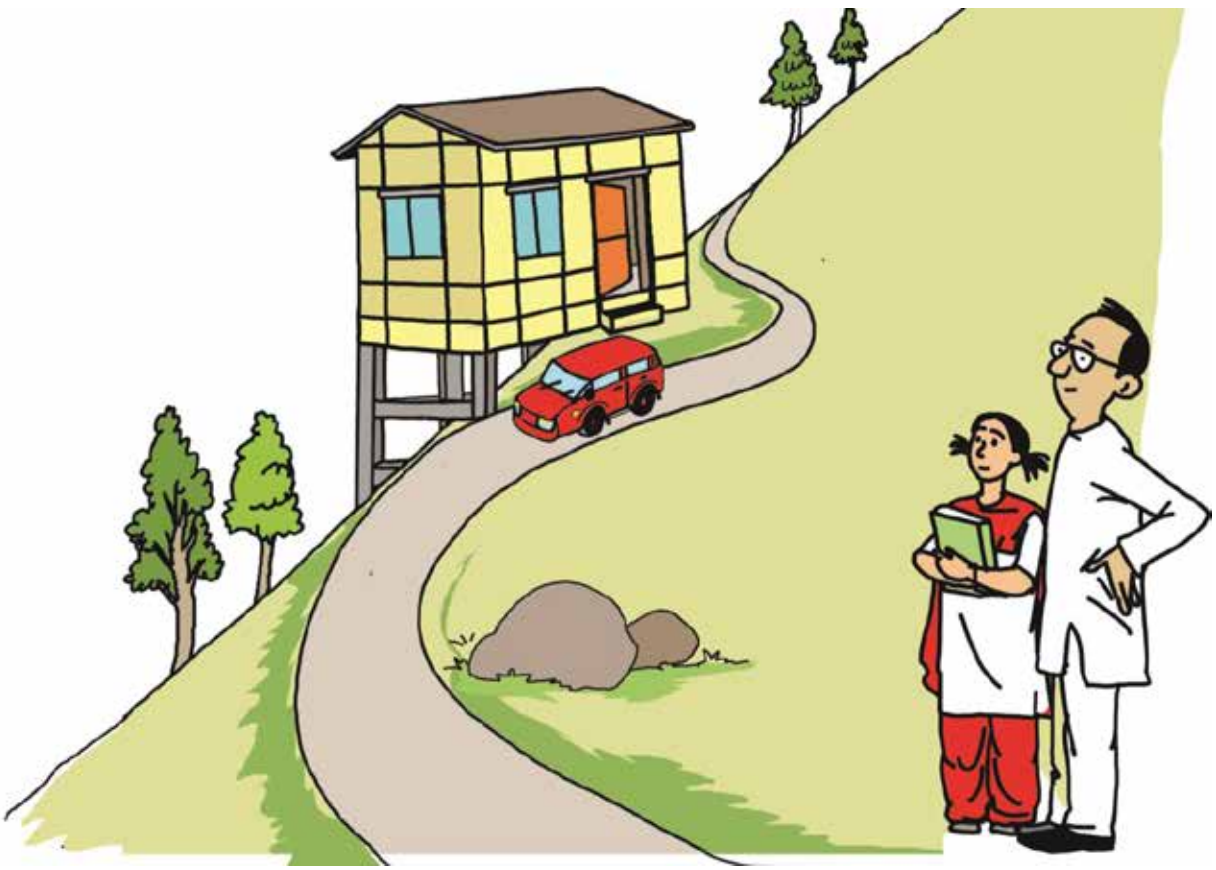


More than **30º slopes** are steep slopes.
Houses on steep hill slopes should be **small.**



2.4 What is the acceptable sequence of construction on hill slopes?

When constructing on hill slopes, three basic tenets should be followed, namely:

(1) The sequence of construction of buildings along a hill slope should be started *preferably* at the bottom of the hill to the top of the hill;

(2) The uphill buildings should have significantly smaller mass than those downhill; and

(3) The horizontal distance between the subsequent structures at different elevations should be at least *3 times* the difference in their founding levels, if not more.

The exact relative positioning of the new building should be determined by Competent Geotechnical Engineers and Rock Mechanics Engineers, only after undertaking detailed field studies to ascertain the characteristics of the hill slope.

If a new building is constructed downhill with respect to an existing building, then the excavation for new construction may lead to a landslide on uphill side. This puts to risk the existing uphill building. Also, multi-storeyed buildings with more weight should be constructed on downhill, while lighter weight buildings should be constructed uphill.

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Houses at lower levels should be built **first**.
Also, houses built uphill should be **small**.

2.5 What precautions should be taken when constructing an earthquake resistant house in hilly regions?

Before seeking to ensure structural safety, a building on a hill slope should be safe-guarded against:

(1) Landslide of the hill slope on which the site is located,
(2) Debris rolling down from uphill of the site,
(3) Sliding of the site, if it rests on loose or fragmented rock layers or on ground that is expected to slide; and
(4) Flowing waters on the natural waterway along the hill slope.

After the above factors are addressed, the structural design of the buildings should include the following:

(1) The entire house should be built at one level with a flat base, to the extent possible. In extreme case of sloping base, the angle of slope should be reduced to a minimum (much less than 30°), at least below the building.
(2) If the building is to be built on an inclined ground having slope angle more than 30°, the foundation design is crucial. The foundation structural system, the founding level, anchoring of the foundation into competent rock and monolithic connection between the superstructure and foundation are some aspects to be addressed.

The competent *Structural Engineer* should work closely with the competent *Geotechnical* and *Rock Mechanics Engineers*.

If the above aspects are not addressed, the building is unsafe. As a consequence, constructions become unsafe on the uphill or downhill side of such an existing unsafe building. Also, the following additional measures should be undertaken:

(1) Leave sufficient horizontal distance between existing buildings and new construction, so that any excavation does not expose/damage the foundation of existing buildings. If not done, possibility arises of the toppling of the uphill building, and subsequent cascading effects.
(2) Provide protection measures (like a retaining wall) against direct impact of unforeseen rolling debris of small size, and a landslide prevention measure at the uphill building.
(3) Provide proper drainage around the building to discharge the storm water.

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In new developments, houses at lower levels should be built **first**. Also, houses built uphill should be **small**.

2.6 How to know if the site is suitable for resting the foundation of a building on a hill slope?

Typically, the overall geometry of *foundation system* is triangular below the floor level of the building. The basic principle to be followed here is that this triangular portion should be made very stiff. When the hill slope is *shallow*, this triangular portion could be made of masonry. But, when the hill slope is *steep*, it should be made of *moment frames* with braces (made either of wood or reinforced concrete), *moment frames with structural walls* (both made of reinforced concrete), or just *structural walls* (made of reinforced concrete).

The *dip* of the underlying layers of soil determines the suitability of the site. When the soil layers *dip outwards* (parallel to the hill slope), the site is *not acceptable* for constructing structures on them. On the other hand, when the soil layers *dip inwards* (perpendicular to the hill slope), the site is *acceptable*. But, even if the building is resting on an acceptable site along a hill slope, the following measures should be taken:

(1) Sufficient distance should be left between existing buildings and new construction, so that any excavation does not expose/damage the foundation of existing buildings, or cause sliding of ground due to large thrust on uphill/downhill. If not done, possibility of toppling of building one over the other exists.

(2) Provide protection measures (retaining wall) against landslides for protecting the exposed cuts of the hill slopes.

(3) Provide proper drainage around the building to let the storm water run off without affecting the foundations.

These measures shall be undertaken in consultation with a competent *geologist* and *geotechnical engineer*. The *House Owner* should contact the *Municipal Authority* for identifying these professionals available in the neighbourhood.

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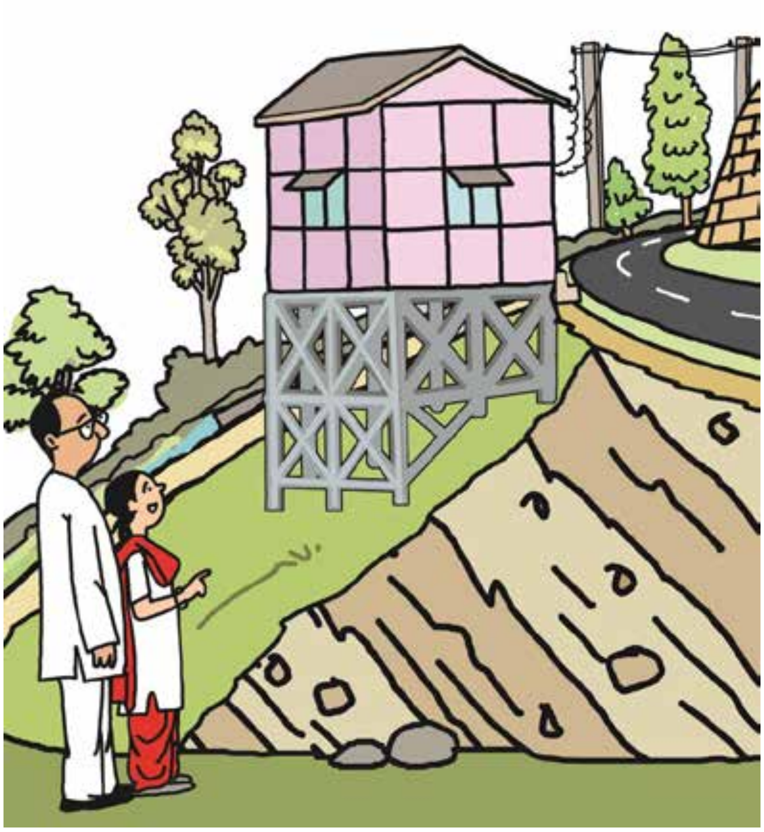
Part 6: Structural Design
Part 7: Construction Management, Practices and Safety



Houses should be built preferably on those hill slopes where the geological layers of rocks slope **into the body hill**, and not along the hill slope.

2.7 Is soil investigation necessary before constructing a house? Who should be contacted for the same?

It is necessary before the construction of the house. Soil investigation is undertaken to obtain information about the physical characteristics of soil/ rock in the underlying soil strata at the site. It is a *below-ground* investigation, wherein the soil/rock mass is sampled at different levels, and tested to physical, chemical and engineering properties and characteristics of sub-layers. In particular, it is required to:

(1) Arrive at a suitable foundation type for the size of the house, and

(2) Form the basis for design and construction of a safe house.

A *competent* Geotechnical Engineer should be contacted for conducting such soil investigation at the site, *before beginning* to design the house. Of course, the Geotechnical Engineer should examine the possibilities of *liquefaction* and *landslides* also, before certifying the site to be acceptable for construction. In some cases, the Geotechnical Engineer may decide to *not undertake* soil investigation, if sufficient authentic documented data **and** *personal* experience are available in the immediate neighbourhood of the proposed house site to suggest that such an investigation is not required. Also, in case of plot areas less than 500 m^2, buildings up to 5 storeys or 16 m in height, a *Civil Engineer* can perform the role of a *Geotechnical Engineer*.

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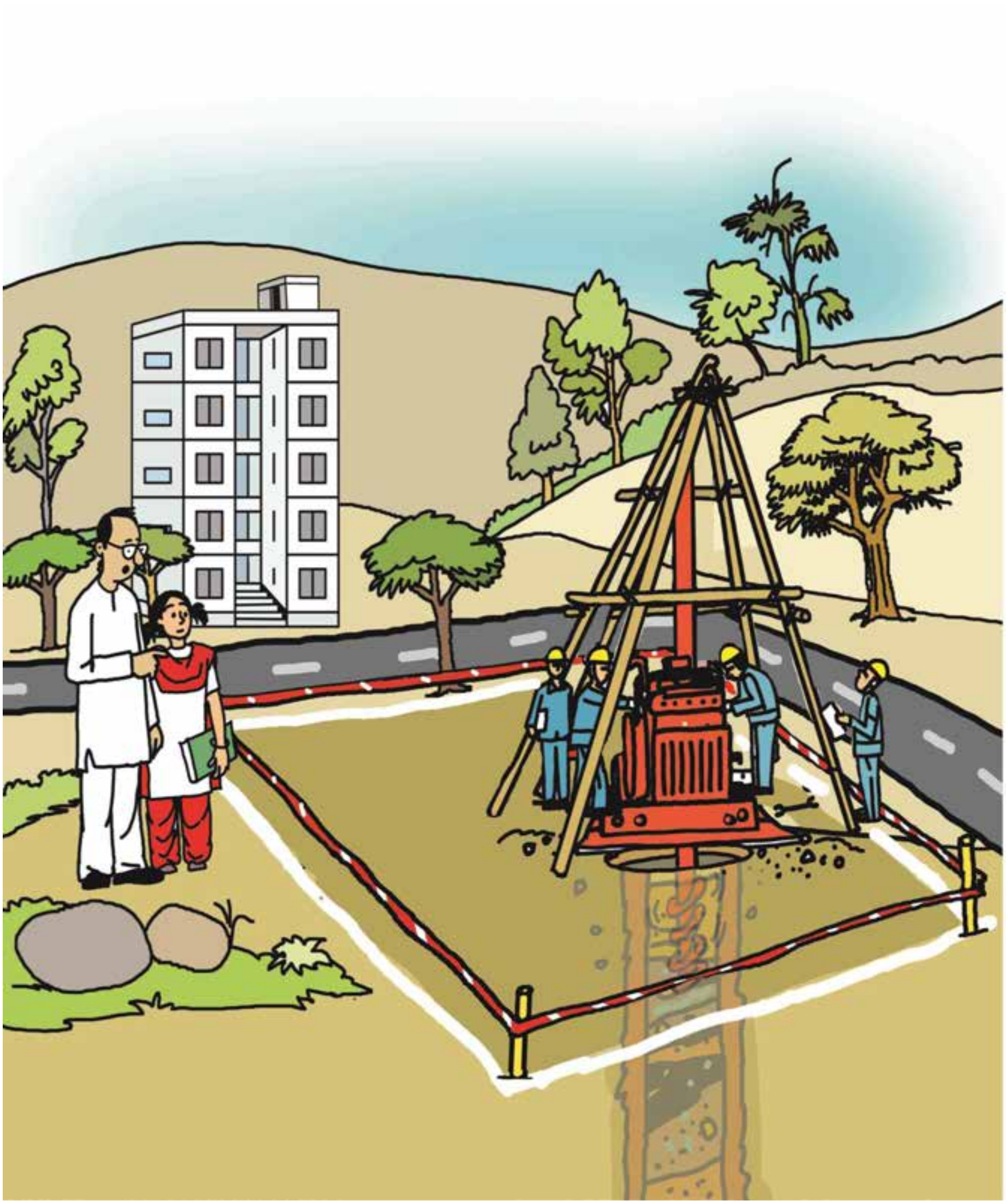

Soil Investigation is the most important step in the process of constructing the house.
It is **mandatory**.

2.8 What precautions should be taken to protect a building during earthquake shaking, if it is resting on sloping ground?

Most constructions in the hilly region are built with masonry; some are built with reinforced concrete. To protect a building on hill slopes, the following steps are critical:

(1) Do not build on hill slopes that are:

(a) Likely to slide, and

(b) Under the threat of rolling debris or unsafe uphill building.

(2) Do not build on natural waterways.

(3) Avoid building on steep hills with slopes *more than* 30^o. When mandatory to build on slopes *more than* 30^o, the building should be small and detailed engineering is required.

(4) Anchor the building properly to the foundation, and the foundation to a hard stratum of the ground underneath.

(5) Avoid:

(a) Long plan buildings, and

(b) Buildings having their parts resting at different levels and connected at multiple levels.

Construct small sized units, each of it completely rested at one level.

(6) Construct from bottom of the slope to the top of the slope.

(7) Ensure that materials used (such as brick and mortar) should be of good quality and should follow the standards laid down by **NBC 2016**.

National Building Code of India 2016
Part 3: Development Control Rules and General Building Requirements
Part 7: Construction Management, Practices and Safety

Do not interrupt **natural waterways**. Build retaining walls to prevent local failure of **uphill slopes**, and even to protect the waterways.

2.9 A new 40-storey building is being constructed on flat ground adjacent to an existing 4-storey building. Is the 4-storey building safe?

If a new 40-storey building is to be constructed next to an existing 4-storey building, then a number of factors should be considered to protect the *adjoining existing structures*. These include:

(1) If the soil stratum is flexible and weak at the site where the 40-storey building is to be constructed, then the 40-storey building should be built at a horizontal distance *a* of at least 3 times its foundation depth *H* from the existing structure on the adjoining plot of land.

(2) If the soil stratum is capable of holding up vertically when the foundation pit is dug at the site where the 40-storey building is to be constructed, the side walls of the foundation pit of the 40-storey building should be protected during the entire phase of construction and even afterwards. During excavation for the foundation of the 40-storey building, the adjoining soil should be protected from collapse, if not it will cause subsidence of the adjoining existing 4-storey building. Well-designed shuttering and shoring should be provided, which is extended downwards as the construction depth increases. Stiff concrete structural walls may be required to be built to protect the vertical cut faces of soil stratum, along the perimeter of the foundation pit.

(3) Tall buildings require deep foundations, involving use of construction equipment causing excessive vibration and impact. The vibration levels generated by these equipment should be such that neither the adjoining buildings and structures are affected structurally, nor the persons living or working in those structures are put to personal discomfort.

(4) Before the start of construction, careful engineering planning is required, including pre-construction surveys, design calculations on safety and project coordination with neighbouring properties.

(5) During construction, additional care is required, including vibration monitoring, neighbouring building movement monitoring, and overall due diligence.

Hence, in such projects involving new foundation systems in an urban setting, competent *Geotechnical Engineers* along with *Structural Engineers* should play a critical role.

National Building Code of India 2016
Part 3: Development Control Rules and General Building Requirements
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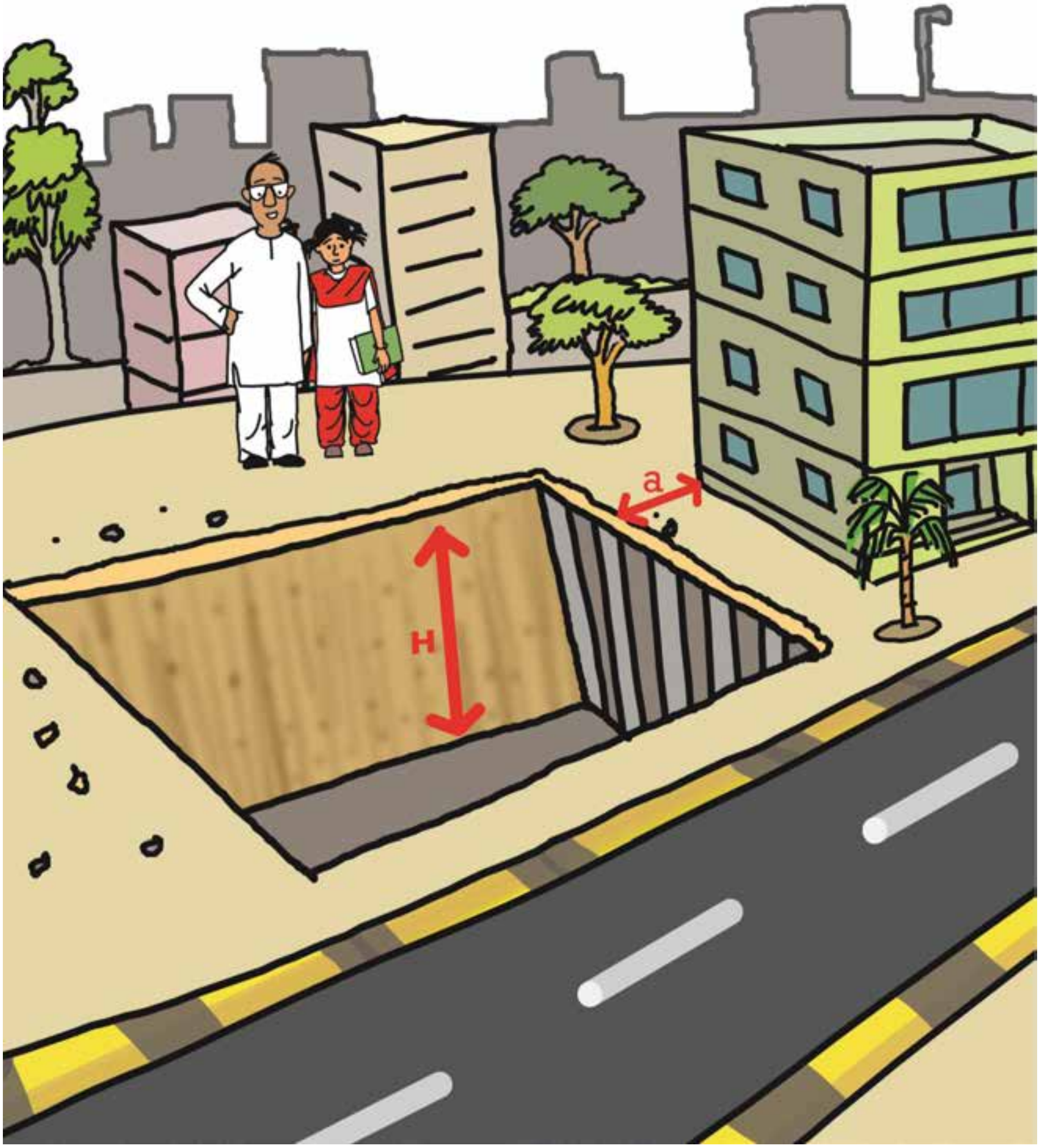


When the horizontal distance **a** from the adjoining building is less than **3** times the depth of foundation **H**, the matter needs formal attention of **Structural** and **Geotechnical Engineers**.

3

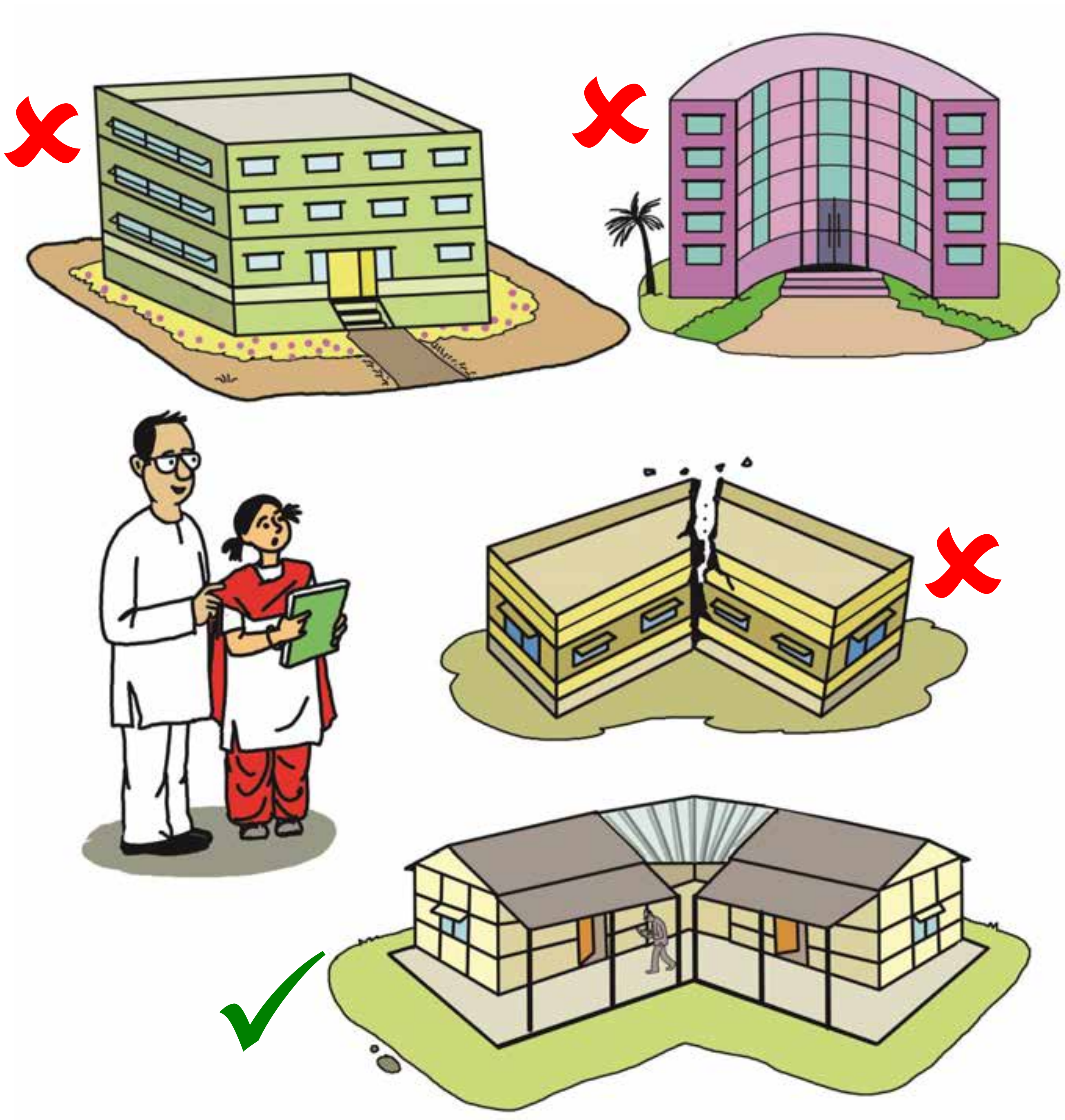
Architectural Form

3.1 What is the preferred shape of an earthquake resistant building?

Buildings that are *symmetrical* and *regular* in *plan & elevation* are considered suitable for earthquake-resistant construction. Hence, buildings should be as close to being symmetric as possible. And therefore, if the sizes of the structural members of the building are chosen accordingly, then buildings will translate uniformly in the two horizontal directions in plan during earthquake shaking, and will not twist. This is the desired behaviour.

Square or *rectangular* plan shaped buildings ensures least damage during the strong earthquake ground shaking. *Square* plans are better than *rectangular* plans, because they are structurally efficient. *Rectangular* plans are better than *L-shaped* plans. This does not mean that all building must be square. But, it is essential to know implications of design and take appropriate actions to counter the negative effects of choosing such shapes. Any shape other than a square or rectangle is expected to sustain more damage. But even in a rectangular plan shape, the length of the building should be less than 3 times its width.

The commonly used plan shapes (like *T*, *L* and *C*) with non-rectangular plan are functionally convenient but structurally poor. If at all such shapes are required, special attention should be made to strengthen the corners; a competent *Structural Engineer* should undertake this work. Alternately, the building L-shaped in plan can be made of two separate rectangular units with a connecting flexible junction.



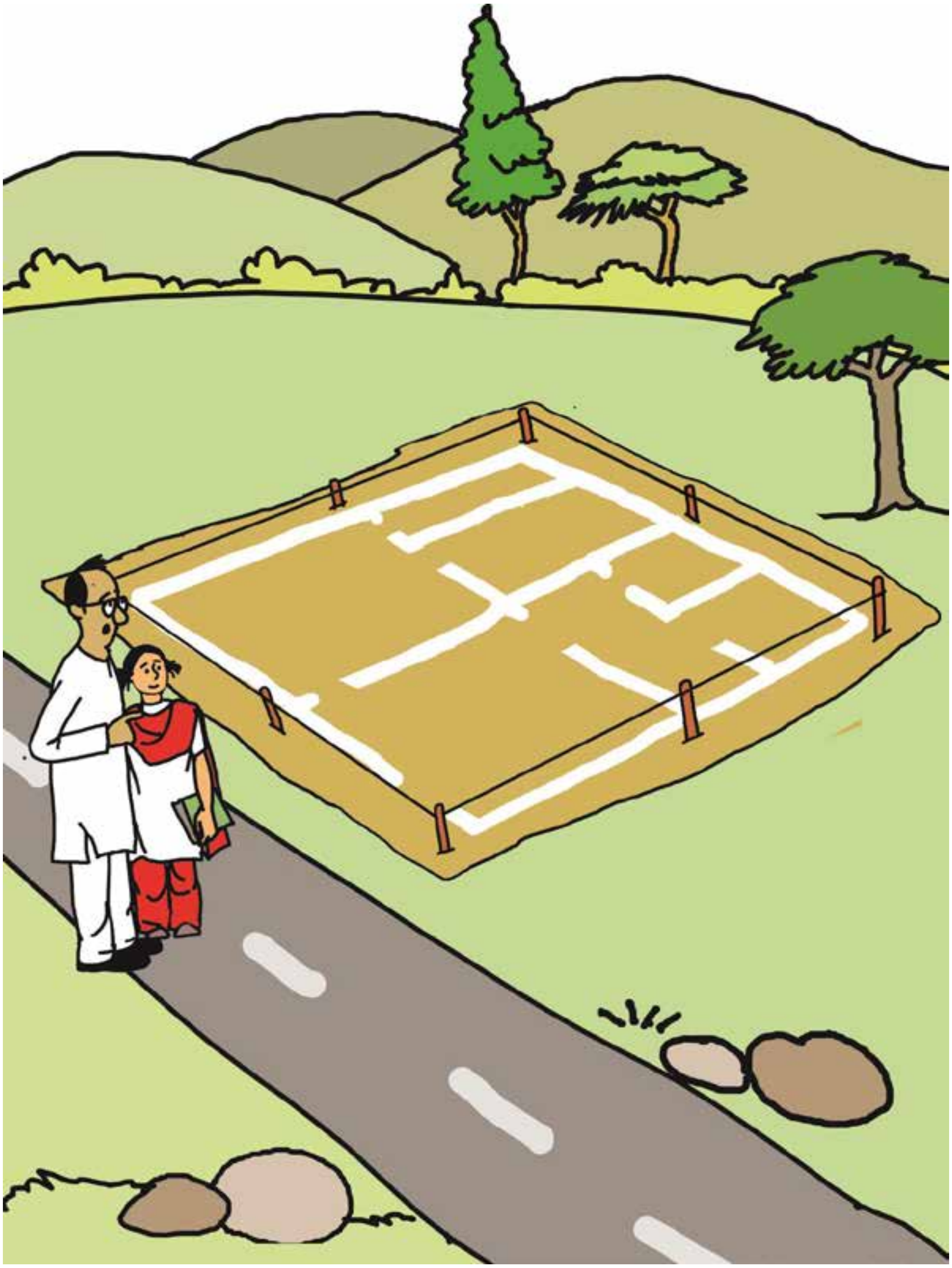
Simple shapes perform best during strong earthquake shaking.

3.2 What are the minimum sizes of rooms and floor-to-floor heights in an earthquake resistant building?

Minimum sizes of the habitable house are indicated in **NBC 2016** (Part 3); these are based on functional considerations. *Clause 12 Requirements of Parts of Buildings* of NBC 2016 (Part 3) requires the area of a single-room habitat to be at least $9.5\ m^2$, and the room width to be at least *2.4 m*. In case of a two-room habitat, area of one room should be at least $9.5\ m^2$ (with room width of at least *2.4 m*) and of the other at least $7.5\ m^2$ (with room width of at least 2.1 m).

The minimum floor height is required to accommodate persons standing on the floor, objects hanging from ceilings and some clearance between the two from safety consideration. In general, a minimum clear height of 2.75 m is required between floors; it is measured from the top surface of floor to the lowest point of the ceiling. In buildings with pitched roof, the *average height* of room should be at least 2.75 m. Further, the minimum clear headroom under a beam, folded plates or eaves should be 2.4 m.

National Building Code of India 2016
Part 3: Development Control Rules and General Building Requirements



Minimum room sizes given in NBC 2016 are based on **circulation** and **functional requirements**. They should be adhered to.

3.3 What should be the minimum height of the plinth of a house from natural ground level?

Generally, the finish floor level of the house is raised from surrounding ground/road levels to protect from dampness which may seep in due to direct contact from the ground. Also, ensuring at least a minimum relative height of the finished floor level helps in protecting the content of house from flooding. This raised height above natural ground or road level is called as *plinth height*.

The minimum height of the plinth depends on three factors. The *plinth level* should be at least 450 mm above:

(1) *Natural ground level* at the site of the house,

(2) *Average road level* adjoining the house, or

(3) *High flood level* of the area, whichever is higher.

In this regard, the Owner should consult a competent Civil Engineer before starting the construction work. Diligent implementation of the requirements of *NBC 2016* should be undertaken through proper supervision. Clearly, if a plot of land is vulnerable to flooding during rains or cyclones, such land should not be used for constructing any house, building and structure, whatsoever its function is. Such land should be left as open fields; at best, some play fields may be created there.

National Building Code of India 2016
Part 3: Development Control Rules and General Building Requirements
Part 10: Landscape Development, Signs and Outdoor Display Structures

Plinth height above natural ground level should reflect the **High Flood Level** in the neighborhood of the site and the likely **Road Level** in the distinct future.

3.4 What are ideal sizes and locations of openings for door and windows in a house?

The door and window openings in wall may weaken the walls. Hence, they should be as small, and as far away as possible from wall-to-wall junctions. Ideally, they should be centrally located. Competent *Architects* / *Civil Engineers* will help in determining these aspects.

In residential buildings, normally doors are of 2,100 mm high and 900 mm wide. The minimum size of window is 600 mm wide. These sizes can be increased in increments of 300 mm as per functional and architectural needs, up to 2,400 mm in width and 1,800 mm in height. The door and window openings should be positioned at least 450 mm away from wall corners or junctions. **NBC 2016** recommends the following normal sizes:

(1) *Door Openings*:

Main door : 1,050 × 2,100
Kitchen : 900 × 2,100
Toilet : 750 × 2,100

(2) *Window Openings*:

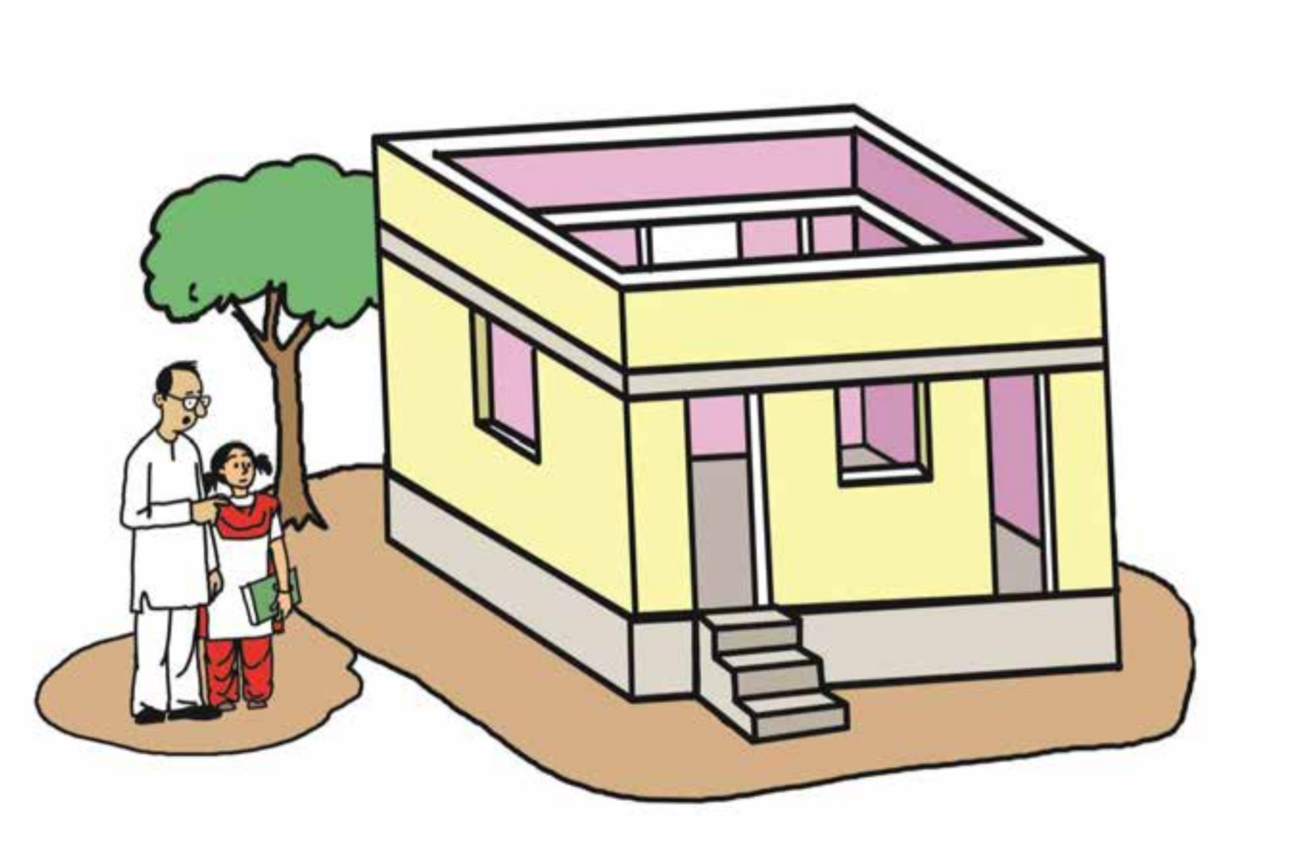
$1/10^{th}$ of floor area of room for hot-dry climate;
$1/6^{th}$ of floor area of room for warm-humid climate;
$1/8^{th}$ of floor area of room for temperate and composite climate; &
$1/12^{th}$ of floor area of room for cold climate

The windows should be located on the opposite walls, facing one another, to provide good cross-ventilation.

In masonry houses, the top levels of all door and window openings in a storey should match. This will facilitate the provision of a continuous lintel band over them, which is a major requirement of earthquake resistant masonry buildings.

Masonry arches should NOT be used in buildings in earthquake-prone areas. Normally, arches are meant only to carry compression arising from gravity (vertical loading). But, if used in earthquake-prone areas, bending is imposed on them during reversed lateral earthquake shaking; they cannot carry this because they lack capacity to resist *tension forces* arising from bending. Thus, they perform poorly in earthquakes. Therefore, masonry arches should not be built in earthquake-prone areas.

National Building Code of India 2016
Part 3: Development Control Rules and General Building Requirements
Part 8: Building Services



Openings should be as **small** as possible.

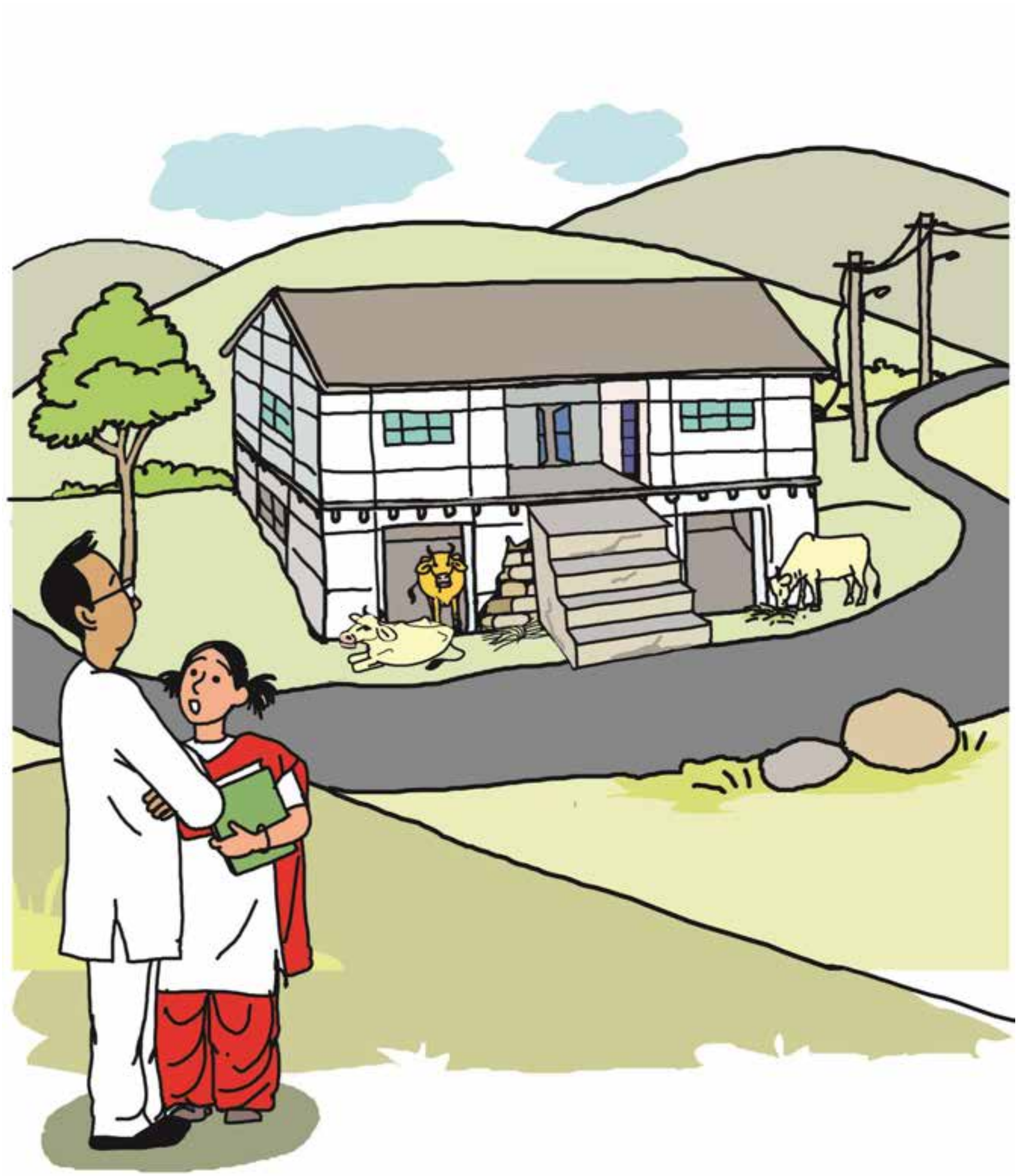
3.5 How should the basements be built in masonry houses constructed on shallow hill slopes?

Make use of space in the lowest storey of the house created by the sloping ground as a part of the house. In particular:

(1) It is preferable to make this space a granary or storage area of the house, or for *cattle & fodder*. This will reduce the mass in the upper storey of the building, and thereby make the building lighter.

(2) This space should have little or no opening in the walls, except the access doors. The openings should be stiffened.

National Building Code of India 2016
Part 3: Development Control Rules and General Building Requirements
Part 6: Structural Design



The basements (goth / kutheri) should have **minimal openings**, and their location should match with those in the storey above.

3.6 What are the precautions to be taken in the foundation of earthquake resistant buildings?

Purpose of the foundation is to transfer the structure loads safely to the underlying soil. Depending on geotechnical conditions and the loads appearing from the building above, suitable systems should be chosen for the structural configuration of the superstructure and foundation. Generally, small houses up to 3 stories require *shallow foundation* having individual footing, if the soil is stiff and strong. *Tie Beams* connecting the tops of the footings of the columns help reduce the differential lateral movement of columns during strong earthquake shaking. In tall buildings, *deep foundations* are required to be constructed.

In buildings on slopes, the foundation requires special attention. It should be made stiff by the use of diagonal braces or concrete walls. This is a critical aspect of the safety of buildings built on hill slopes. Formal engineering calculations are required; a *competent* Structural Engineer should be appointed for this.

National Building Code of India 2016
Part 6: Structural Design

Footings of columns of RC frame buildings should be held together with **tie beams**. And, the sloped foundation of houses on steep slopes should be **made stiff**.

4

Structural Safety

4.1 Which structural systems are acceptable for construction of earthquake resistant buildings?

Three basic structural systems commonly used in buildings are:

(a) *Frame Buildings,*

(b) *Braced Frame Buildings*, and

(c) *Structural Wall Buildings.*

These can be made of natural materials (like stone and timber), burnt clay bricks, fly ash bricks, reinforced concrete and structural steel. Of these combinations, the acceptable earthquake resistant structural systems are:

(1) *Frame Buildings* made with Steel or RC Frames,

(2) *Braced Frame Buildings* made with Steel Frames and Steel Braces,

(3) *Braced Frame Buildings* made with RC Frames and RC Braces,

(4) *Braced Frame Buildings* made with RC Frames and RC Structural Walls,

(5) *Braced Frame Buildings* made with Steel Frames and RC Structural Walls,

(6) *Wall Buildings* made with Steel Walls,

(7) *Wall Buildings* made with RC Walls,

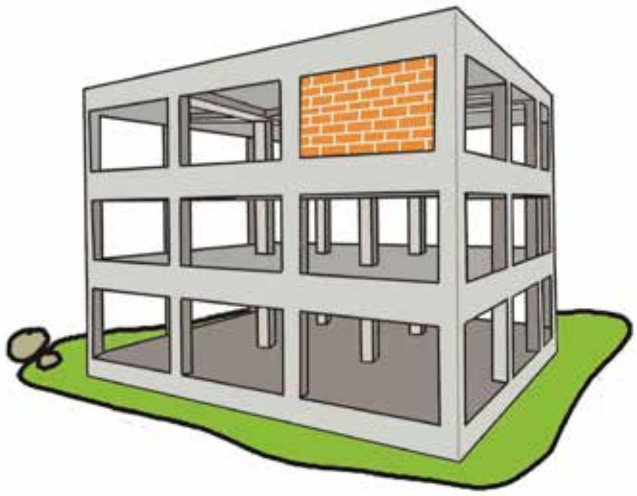
(8) *Wall Buildings* made with Confined Masonry used in low-rise buildings,

(9) *Wall Buildings* made with Reinforced Masonry used in low-rise buildings, and

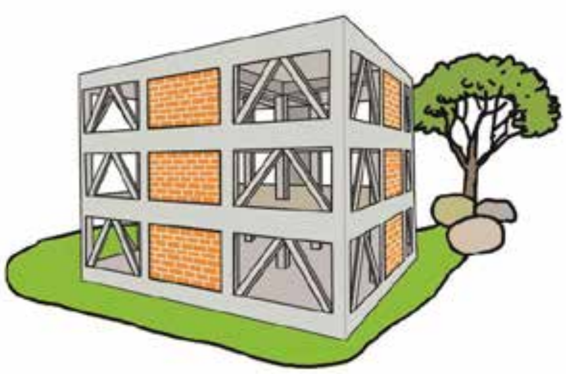
(10) *Wall Buildings* made with reinforced masonry walls and bands.

Mere selection of acceptable structural systems for construction of building will not guarantee earthquake resistance in buildings; they should be designed by competent *Structural Engineers* with inputs from *Geotechnical Engineers*, and constructed by competent *Civil Engineer*.

National Building Code of India 2016
Part 6: Structural Design



Earthquake Resistant RC Buildings should have **RC Structural Walls** or **RC Structural Braces**, and small Masonry Buildings should have **bands**.



4.2 How to choose a structural system for a building to be constructed in earthquake prone areas?

The choice of structural system depends on the natural hazards likely to occur at the site of the building, number of floors to be constructed, *etc*. For instance, in earthquake prone areas, buildings should be light in weight, while in wind prone areas, they should be massive. Also, *unreinforced masonry* buildings and *non-engineered concrete frame* buildings have poor tension force carrying capacity to resist reversals of loading during earthquake ground shaking; such buildings have performed poorly during past earthquakes. Hence, such systems should not be adopted in earthquake prone areas.

Any structural system chosen should be engineered to resist the loads imposed on it. The best structural systems are those that emulate:

(a) The principal features of the *traditional constructions* built in that region over centuries, and

(b) The *standardised good practices* of certain structural systems providing good response during strong earthquake shaking. For example, the performance of concrete frame buildings having structural walls in them has been found to be exceptionally suitable for buildings in earthquake prone areas.

Further, the cost of a building construction depends on the extent of use of the locally available materials and skills. The use of these materials should be maximized to the extent possible.

The *minimum sizes* of members of buildings recommended by **NBC 2016** are based on considerations of *structural safety*, *durability* and *fire resistance*. **NBC 2016** provides values for different structural members based on:

(1) Experimental studies conducted in the past on structural behaviour, and performance of buildings during past earthquakes,

(2) Experimental studies conducted in the past on durability of structures, and performance of buildings over last 4 decades in different environmental exposures, and

(3) Experimental studies on structural components and sub-assemblages with respect to fire loading, and lessons from fire accidents in buildings. The capacity of a member to resist fire is reflected by its *fire resistance rating*.

National Building Code of India 2016
Part 4: Fire and Life Safety
Part 6: Structural Design

Traditional constructions practised for centuries in a region offer valuable pointers on which structural system is most suitable for that region.

4.3 Where and how should the rooftop water tanks be secured?

Large capacity water tanks should be placed as much towards the center of mass of the building as possible; this will avoid torsional effects from being induced in the building. Also they should be secured against *sliding* and *overturning* by snugly connecting them to the vertical elements of the structural system of the building, *e.g.*, columns or structural walls made of reinforced concrete. They *should not be connected* to slender masonry parapet walls.

Many small capacity water tanks also are used (which are placed on roof tops) to supply water to individual households. Commonly, such tanks are made of plastic with different capacity ranging from 300 litres to 2,000 litres. During strong earthquake ground shaking, such water tanks are likely to slide, rock and/or topple, if not secured properly to the structural system of the building. This may cause potential threat to life and property, apart from interruption in water supply to the houses after the disaster. Hence, water tanks on roof tops should be secured by connecting them to RC columns in RC frame buildings, to RC structural walls in RC frame buildings with RC structural walls, and to RC slabs in *masonry buildings*. These connections should be strong enough to carry the inertia forces generated in the tanks during the strong shaking.

Similarly, to avoid breaking of pipes from water tanks, the joints and bends of distribution line should be made of flexible segments.

National Building Code of India 2016
Part 6: Structural Design
Part 9: Plumbing Services

Water Tanks should be anchored to the **main load bearing members.**

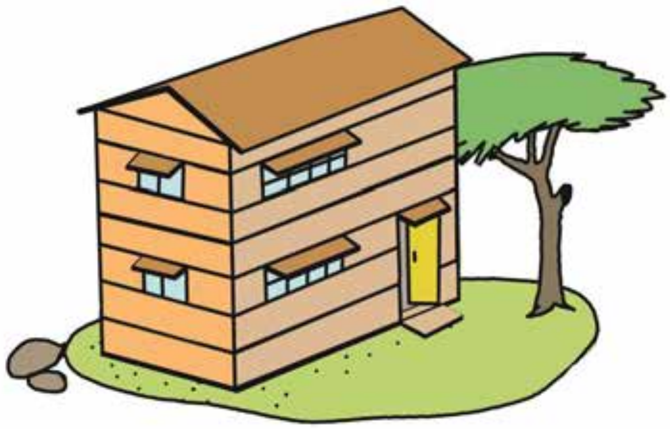
4.4 How can Masonry Buildings be made capable of withstanding earthquake shaking?

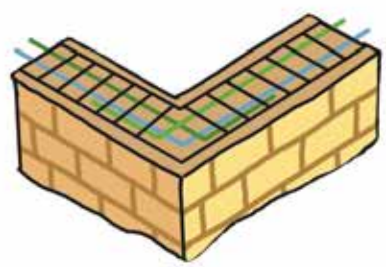
Unreinforced masonry buildings have collapsed in every past earthquake where intensity of ground shaking was large. Hence, *unreinforced masonry buildings* should not be built in earthquake-prone areas. If masonry buildings have to be made capable of withstanding strong earthquake shaking, they should necessarily be *reinforced*.

Masonry buildings can be *reinforced* in two ways, namely:

(a) Providing *steel reinforcement bars* along vertical and horizontal directions in the regular masonry courses, which is traditionally done with horizontal RC elements, called *seismic bands*, and vertical RC elements; and

(b) Adopting the concept of *confined masonry*, which is done by first building the straight lengths of the masonry walls of 1m lift of the whole building, and then pouring concrete to form the vertical *tie columns* and horizontal *tie beams* around the masonry wall segments of the whole building.





Reinforced Concrete Bands are mandatory in Masonry Buildings in all seismic zones.

4.5 Which masonry bond is preferred in the construction of an Earthquake Resistant Masonry house?

Three brick masonry bonds are widely used in construction of walls in India, namely:

(1) *English Bond*: It has one course made of *two stretcher bricks* adjoining each other *along the full length* of the wall, and the next course made of only *header bricks*, such that one header brick is centered on the *stretcher brick* of the lower course.

(2) *Flemish bond:* It has each course made of *two stretcher bricks* adjoining each other *and one header brick* repeated in the *same sequence along the length* of a course, and the same sequence staggered in the next course such that the *header brick* is centered on the *stretcher brick* of the lower course.

(3) *Rat-Trap Bond*: It has two stretcher bricks placed on edge and parallel to each other, both at the extreme edges of the wall making a hole in between, and then a header brick again placed on edge.

Of all the bonds, the *Flemish Bond* alone is recommended for use in earthquake resistant construction. It gives a strong masonry wall. *Rat-Trap Bond* is the weakest, because it has $2/3^{rd}$ area of the wall to resist shear force and the rest a hole. This bond *should not be used* in earthquake prone areas.

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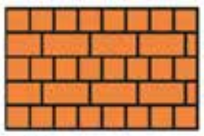
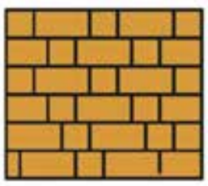
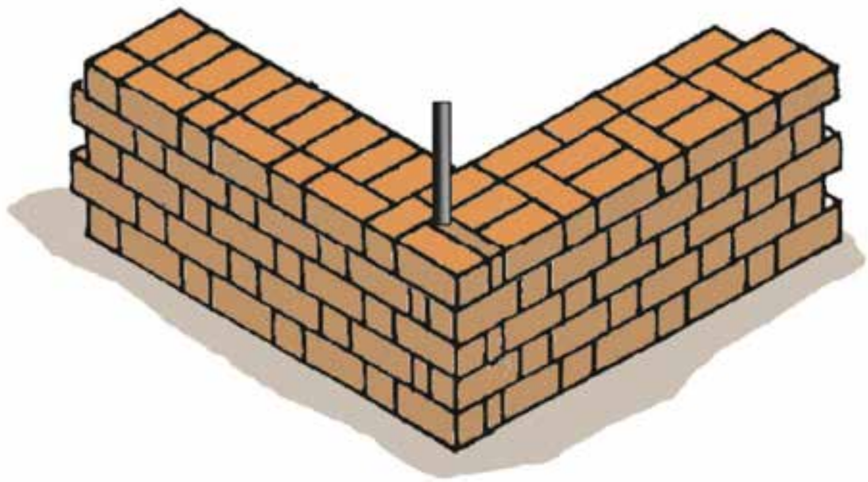
Part 6: Structural Design

English Bond







Flemish Bond is recommended for use in Masonry Buildings.

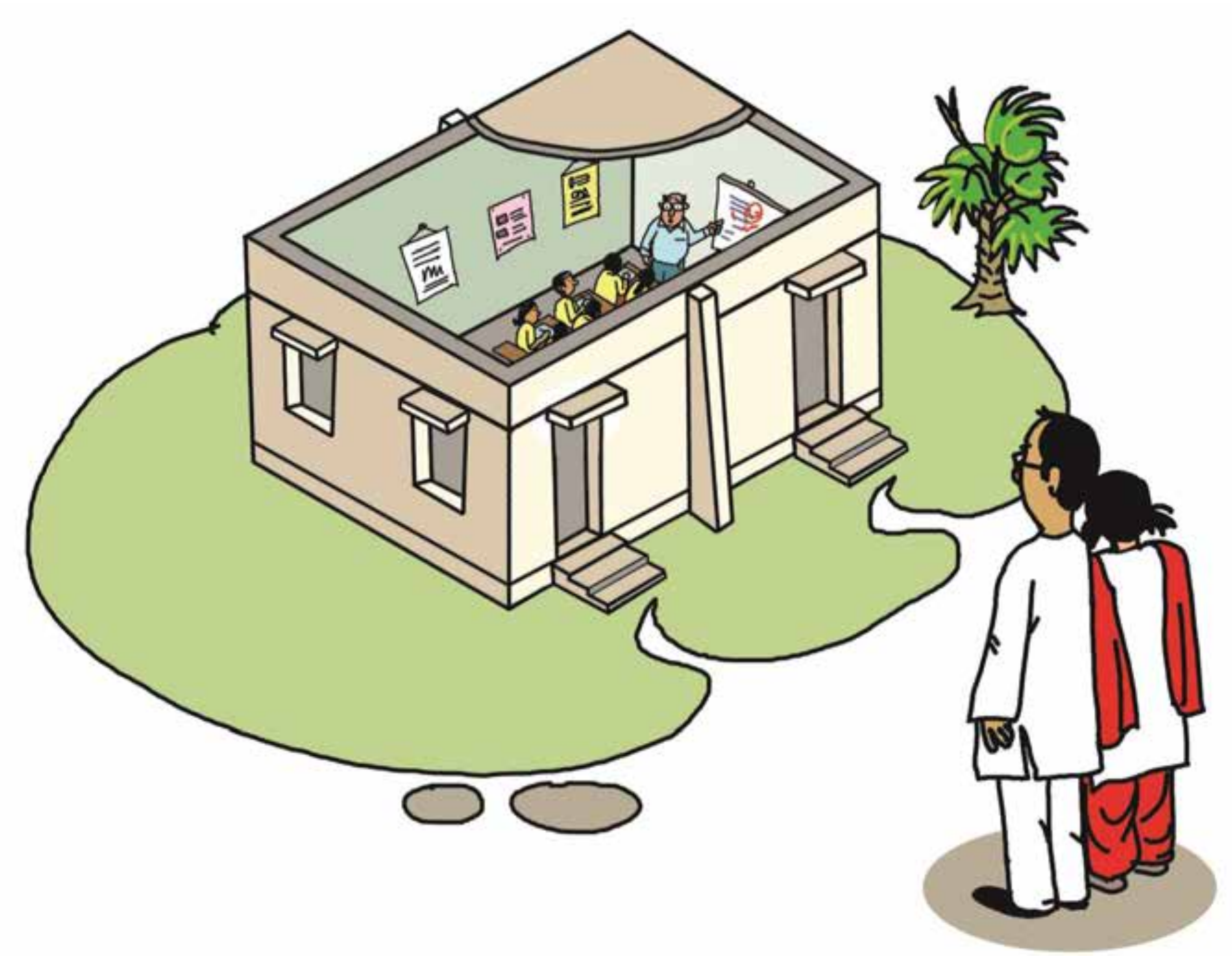
4.6 What should be the thickness of masonry walls in masonry wall buildings?

Ideally, the thickness of the masonry wall should increase downwards along the height of the building; providing the same thickness along the height of multi-storey buildings is unsafe. The way this should be examined is through the slenderness ratio along the height. Typically, the unsupported height to thickness ratio for earthquake resistance should be less than 14. The thickness of the wall in a load bearing masonry reinforced buildings should be at least 230 mm. Multi-storeyed load bearing reinforced masonry buildings may need thicker walls. Use of half-brick (115 mm) thick load bearing walls is not acceptable; they collapse catastrophically.

The choice of the mortar depends on the strength of the masonry unit. The principles for choosing units and mortars in earthquake resistant masonry are as below:

(1) The strength of the masonry unit should be at least 7.5 MPa.

(2) The mortar should be *softer* (*i.e., stiffness*) and *weaker* (*i.e., strength*) than the masonry unit. This makes the masonry fail softly in the mortar, with distributed cracking in the masonry member. Thus, mortar types having *cement*, *lime* and *sand* are preferred in earthquake resistant constructions.



Long Masonry Walls should be supported laterally with **buttresses of full wall height**.

4.7 How many types of Earthquake Bands are used to reinforce the masonry buildings?

Masonry buildings are made earthquake-resistant by the use of *earthquake bands*. In general, earthquake bands are provided at five levels, and are named after their locations as:

(1) *Plinth Band*,
(2) *Sill Band*,
(3) *Lintel Band*,
(4) *Roof Band*, and
(5) *Gable Band* (or *Eaves Band*).

These bands provide four main actions, namely:

(a) Connecting together all walls of buildings;
(b) Breaking large masonry panels into smaller ones;
(c) Achieving integral box action of the masonry building;
(d) Redistributing the horizontal inertia forces generated at the roof levels to the walls in the lower levels, whose areas keep reducing and increasing depending on the openings; and
(e) Providing stability to masonry walls against out-of-plane collapse of walls under the vertical loads.

Often, the *Plinth Band* is combined with the *damp-proof course*, provided at the plinth level. In addition to the above benefits of providing bands, this band helps in preventing the propagation of cracks in the plinth masonry from travelling upwards into the masonry wall. Again, the *Lintel Band* is combined with the lintels needed over every door and window openings in masonry buildings.

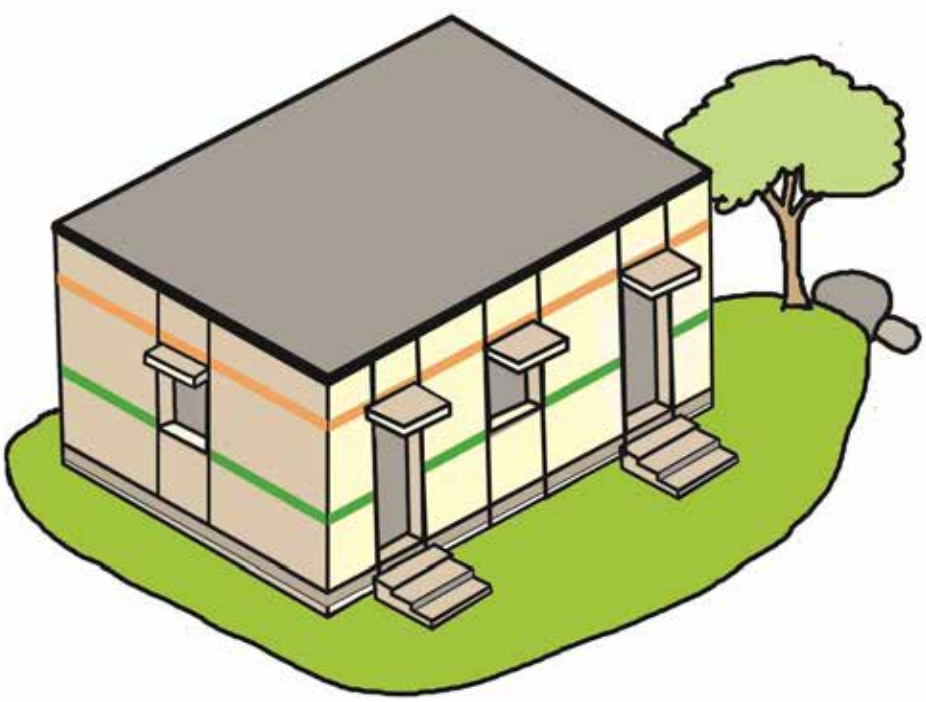
In normal constructions, the said *Earthquake Bands* refers to *horizontal bands* made of *reinforced concrete*; they should be of at least 75mm thickness, have the specified number of steel reinforcement bars, and be detailed in the prescribed way. In *traditional constructions*, these bands are made of *wood*. When the intensity of earthquake ground shaking is expected to be severe, even *vertical reinforcement* is required in masonry walls. Here, two strategies are used, namely:

(1) Providing steel reinforcement bars directly in the masonry courses, and
(2) Providing vertical RC bands.

The latter is efficient in construction and gives *good* earthquake performance.

National Building Code of India 2016
Part 6: Structural Design

In areas prone to **strong** earthquake shaking,
Vertical RC Bands also are required
in addition to the basic **Horizontal RC Bands**.



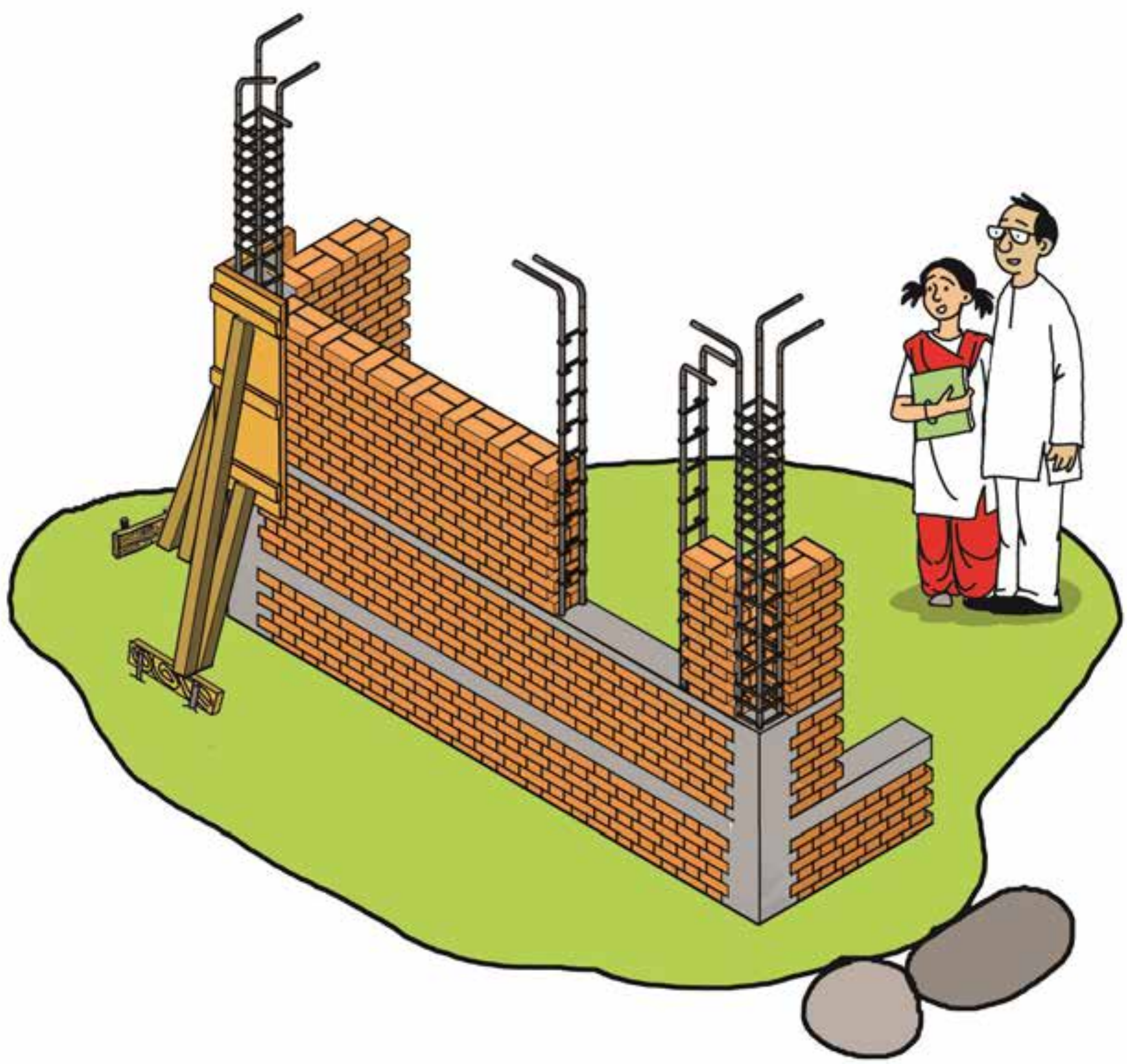
4.8 Are Confined Masonry Buildings different from normal Masonry Buildings with RC earthquake bands?

Yes, *Confined Masonry Buildings* are different from normal reinforced masonry buildings with RC bands. They are *improved versions* of masonry buildings with horizontal and vertical RC bands, with *some critical differences* in detailing and construction sequence. The main differences are:

(1) In normal masonry buildings, *first* the vertical RC bands are made and *then* the masonry walls are constructed between the vertical RC bands. But, in Confined Masonry Buildings, *first* the masonry walls are constructed pre-placing vertical reinforcement bars and leaving needed spaces for the vertical RC bands, and *then* the concrete is poured in-situ for the vertical RC bands. In both cases, the horizontal RC bands are made the same way.

(2) In normal masonry buildings, the vertical RC bands are made smooth, and the masonry walls are constructed between these smooth surfaces of adjoining vertical RC bands. But, in Confined Masonry Buildings, the masonry walls are constructed leaving toothed wall ends, and the concrete is poured in-situ for the vertical RC bands along with the space in the toothing left in the masonry walls. The concrete poured in the toothing creates good inter-lock between the masonry walls and tie-columns.

In *Confined Masonry* Buildings, the vertical RC bands are called as *Tie-Columns* and the horizontal RC bands as *Tie-Beams*.



Confined Masonry construction is **much better** than unreinforced Masonry construction with earthquake bands.

4.9 What are the special features of Confined Masonry Buildings?

Confined masonry buildings consist of the following salient elements:

(a) *RC floor and roof slabs*, which transmit both vertical gravity loads and lateral earthquake induced forces to the walls below.

(b) *Masonry walls with toothed ends*, which carry the vertical load and lateral inertia forces induced during earthquake shaking;

(c) *Confining RC elements*, namely Tie-Columns and Tie-Beams, which break the large masonry walls into smaller panels and provide the necessary tensile strength and ductility to the building; and

(d) *Plinth beam* and *foundation elements*, which carry the loads from the superstructure to the soil underneath. The Tie-Columns will start at the top of the bed-block of the plinth masonry.

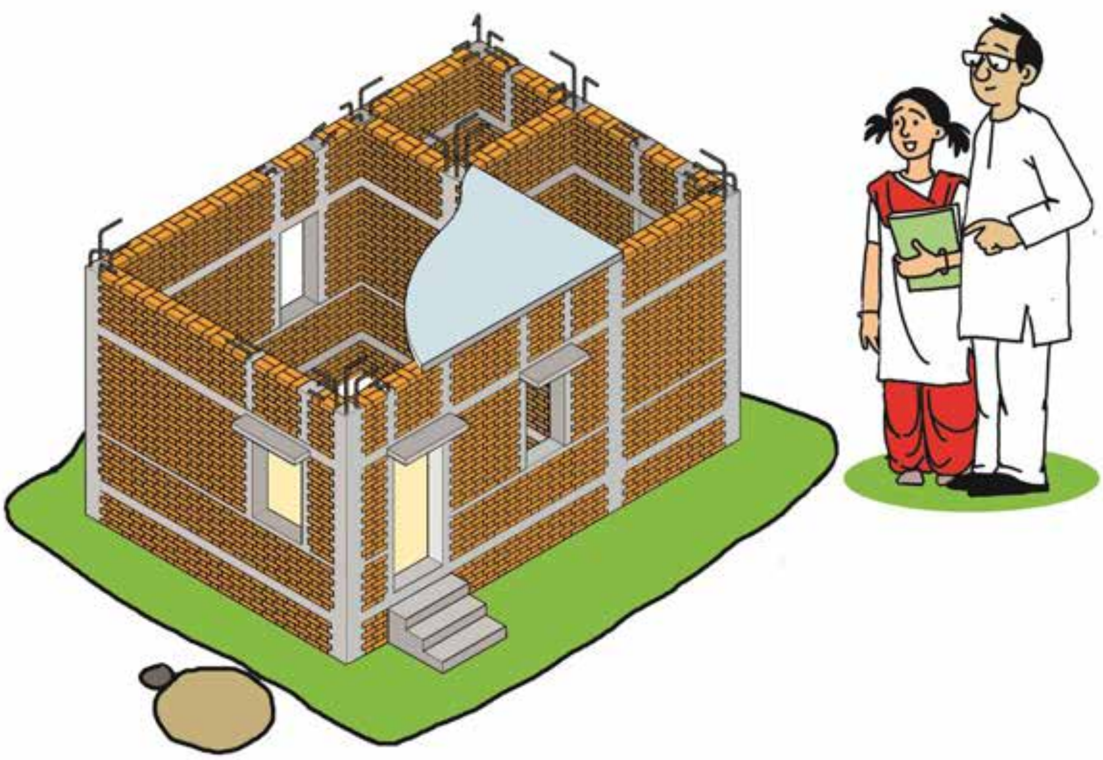
The *special features* of confined masonry buildings include:

(1) *Tie-Columns* are placed at all intersections of masonry walls and free tips of masonry walls, such that the length of masonry wall panel in between two Tie-Columns is in the range 3.0 m – 4.0 m. The width of the Tie-Column should be the same as the thickness of masonry wall; minimum thickness is 230 mm of walls and hence the width of the Tie-Columns.

(2) *Tie-Beams* are placed at plinth, sill, lintel and roof levels, such that they rest on the masonry walls and their reinforcement is passed through the inside of the vertical steel reinforcement bars of the Tie-Columns.

The appearance of finished *Confined Masonry Buildings* and *RC Frame Building with masonry infill walls* may look the same. But, the way the gravity and earthquake loads are resisted, carried and transferred is different in the two types of buildings.

Confined Masonry construction requires **Masonry Walls to be built first** and then vertical RC Tie Columns are cast snugly between these walls.



4.10 What is the maximum number of storeys that can be built using reinforced masonry in earthquake prone areas?

When such buildings are constructed as per the Indian Standards, the maximum number of stories that can be built depends upon type of masonry units, mortar strength and severity of the earthquake ground shaking. Considering the materials available across the country, the maximum number of storeys of masonry construction should be limited to *4*.

This can be achieved with *reinforced masonry* or *confined masonry* strategies. Confined masonry is one of the best techniques for earthquake resistant residential buildings, in earthquake prone areas.

National Building Code of India 2016
Part 6: Structural Design

Unless detailed engineering is done,
it is prudent to **limit the number of storeys**
of a Masonry Building.

4.11 Which types of RC buildings are suitable in earthquake prone areas?

Multi-storeyed RC frame buildings consist of horizontal members (*beams* and *slabs*), vertical members (*Columns* and *Structural Walls*), and masonry infill walls. During major earthquakes worldwide in the last four decades, it is observed that *RC Buildings with Moment Frames* (made of beams, columns and slabs) *collapsed* during strong earthquake ground shaking. On the other hand, *RC Buildings with Moment Frames together with RC Structural Walls* have performed well with *no collapse*.

The salient desirable features of RC Buildings with Moment Frames and RC Structural Walls to be built in earthquake prone areas are:

(1) The structural system should be symmetrical in both plan directions.

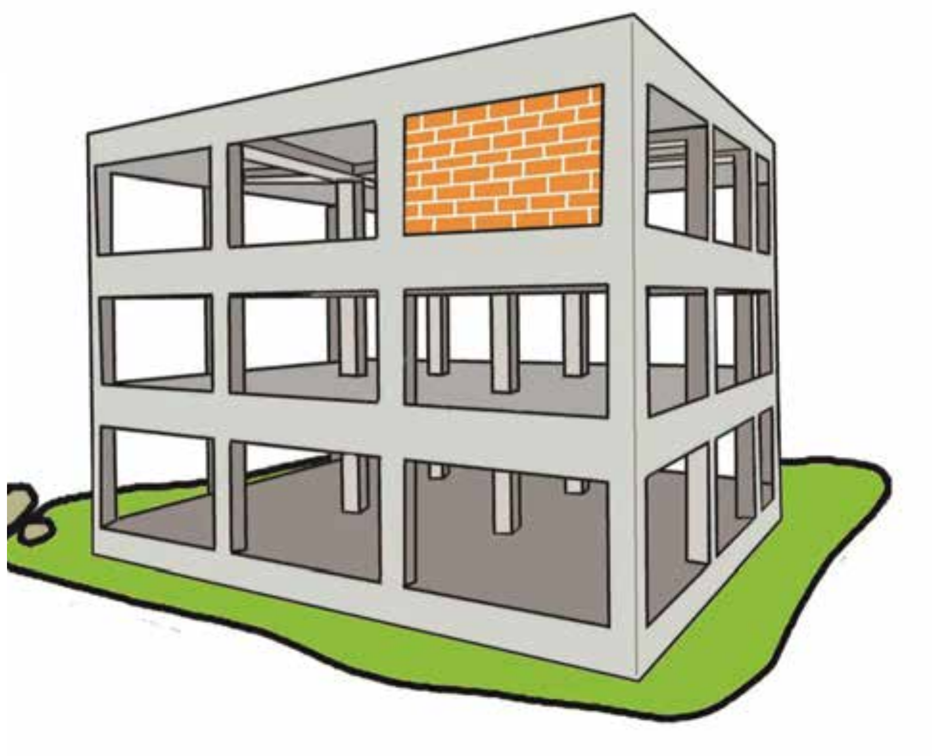
(2) Buildings should be regular in plan and elevation.

(3) The overall geometry of the building should be rectangular in plan, with plan aspect ratio less than 3 and elevation aspect ratio less than 12.

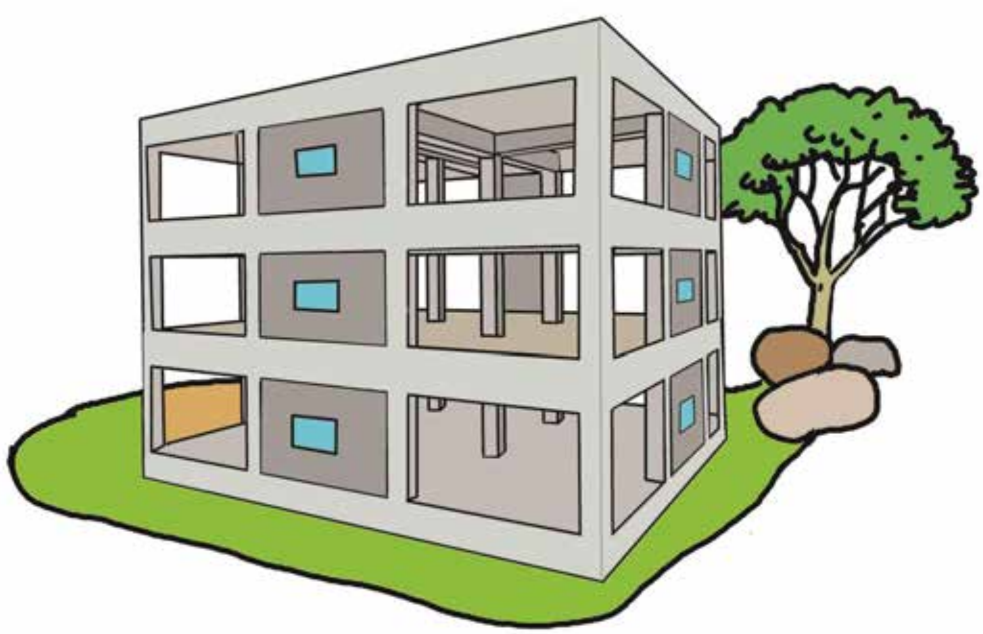
(4) RC beams, columns and structural walls should be proportioned such that the vertical members (*i.e.,* columns and walls) are stronger than the beams, even when the beams form the ductile plastic hinges at their ends.

(5) Each RC beam, column and structural wall should be designed by the concepts of *Capacity Design*, with shear failure precluded, and ductile under-reinforced failure as the basis of design.

(6) These joints at the intersection of *beams* and *columns*, *beams* and *structural walls*, *columns* and their *foundations*, and *structural walls* and their *foundations*, do not suffer any damage.



Moment Frames alone cannot help RC Buildings withstand strong earthquake shaking. RC **Structural Walls also should be provided** in RC Buildings.



4.12 What are the minimum sizes of the structural members of an earthquake resistant RC building?

The minimum sizes of concrete beam and column are prescribed to:

(a) Meet structural safety requirements to provide sufficient stiffness, strength and ductility,

(b) Ensure good durability and resistance to fire, which is ensured through the sufficient concrete cover to reinforcement, and

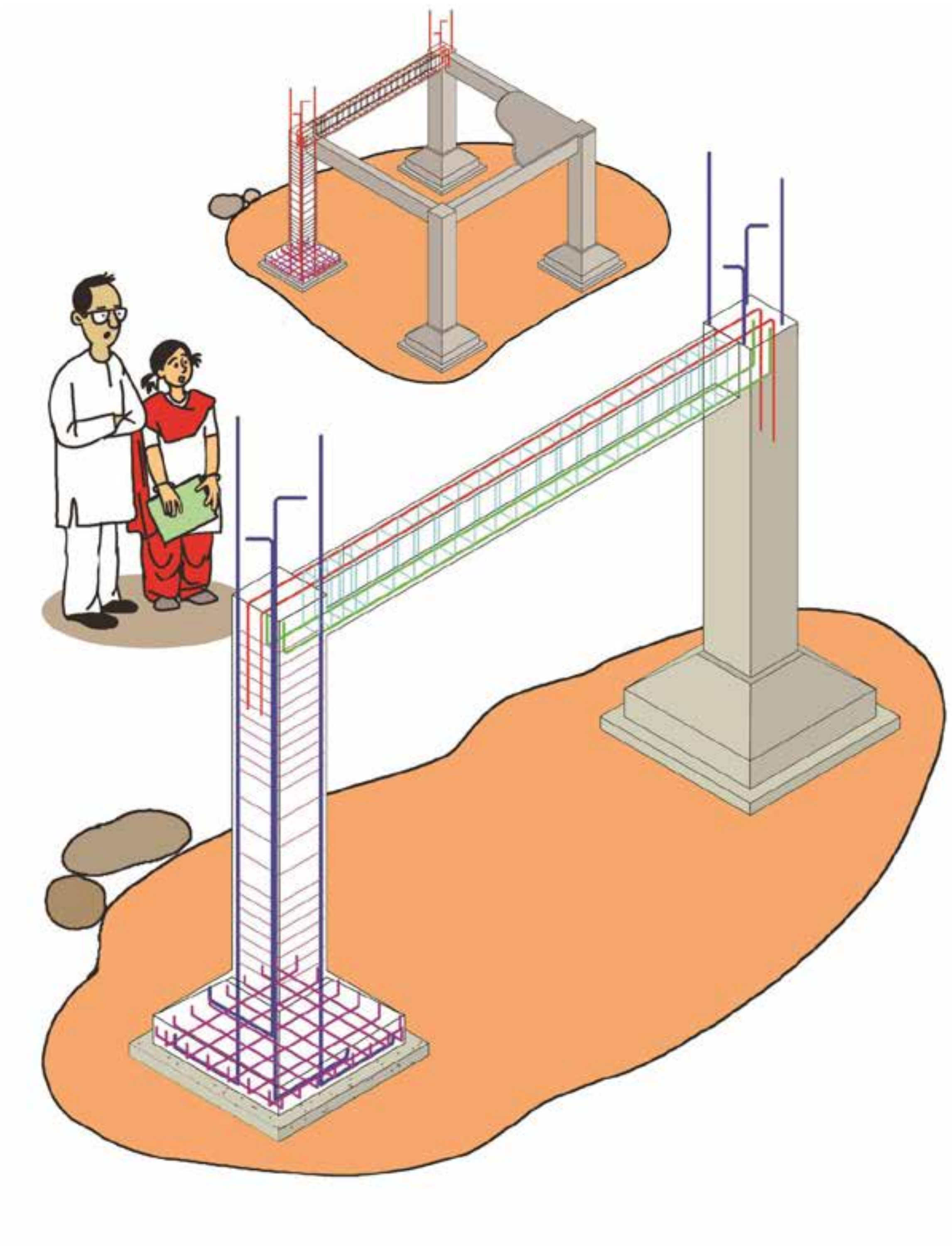
(c) Permit ease of construction.

The minimum sizes of structural members in earthquake resistant RC buildings as prescribed by **NBC 2016** are:

(1) Minimum width of beam shall be 200 mm;

(2) Minimum width of column (that is part of the *lateral load resisting system*) shall be larger of 300 mm or 20 times the diameter of longitudinal reinforcement.

National Building Code of India 2016
Part 4: Fire and Life Safety
Part 6: Structural Design



The minimum sizes prescribed provide **space to place reinforcement bars** without much difficulty. They are based on experiments and experience.

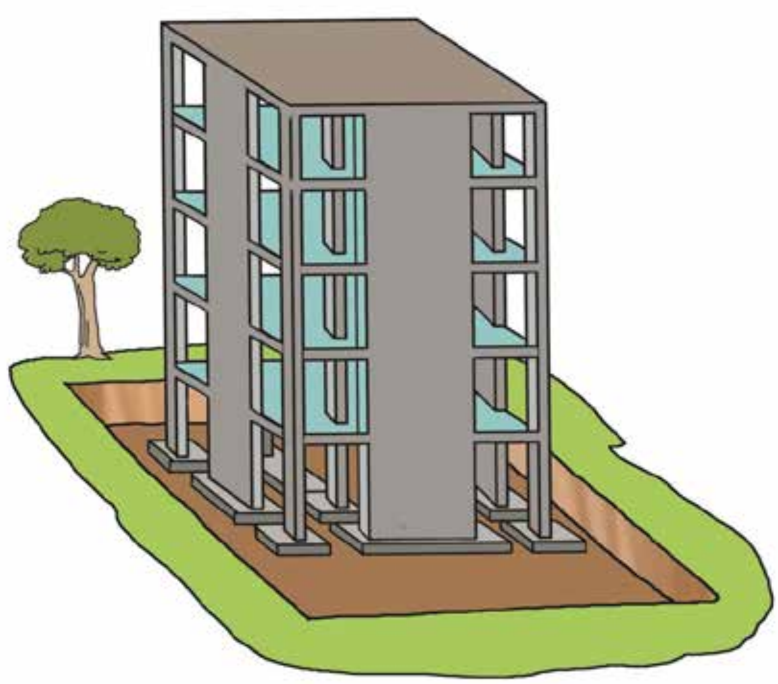
4.13 Are buildings on stilts safe to construct in earthquake prone areas? Are open storeys with little or no walls in any upper storey acceptable in buildings in earthquake prone areas?

NO. Buildings on stilts are *unsafe* in earthquake prone areas. Also, any building with little or no walls in any upper storey is *not acceptable* in buildings built in earthquake prone areas. Clearly, an open storey with significantly reduced lateral stiffness and lateral strength is *not acceptable* in a building to be built in earthquake prone areas, irrespective of whether such a storey is located in the basement storeys, ground storey or any other storey above. Such buildings have shown consistently poor performance during past earthquakes across the world; a significant number of them have collapsed.

Ideally, the lateral stiffness and lateral strength of any storey should not fall below those of storey above. **NBC 2016** provides guideline for addressing this critical aspect. For this reason, it is mandatory to provide structural walls in RC Frame Buildings located in *Seismic Zones III, IV* and *V*. Also, these structural walls should be placed in select bays along each of the principal plan directions and away from centre of the building, such that the building storeys do not twist during earthquake shaking.

National Building Code of India 2016
Part 3: Development Control Rules and General Building Requirements
Part 6: Structural Design

DO NOT build RC buildings on just stilts. **RC Structural Walls should be provided** in RC buildings throughout their height in both principal directions.



4.14 How to protect Non-Structural Elements in buildings against earthquake shaking?

Non-Structural Elements (NSEs) are those elements of buildings, which are not part of the lateral load resisting system, but are rested on or connected on *Structural Elements*. If not secured formally to the Structural Elements, they can be damaged themselves, and cause additional damage to the Structural Elements (SEs) or loss to the life and property during earthquake ground shaking. Typical NSEs of buildings can be grouped into three sets, namely:

(a) *Contents of buildings*: Items required for functionally enabling the use of spaces;

(b) *Appendages to buildings*: Items projecting out from buildings, either horizontally or vertically; and

(c) *Services and utilities of buildings*: Items required for facilitating essential activities in the buildings.

Some examples of NSEs are furniture, almirahs, closets, interior partition walls, false ceilings, hanging lights and chandeliers, fans, exterior wall claddings, cables, gas and water pipes, water heaters, gas appliances, water tanks, masonry chimneys, masonry parapet walls, HVAC duct systems, large mirrors, and large picture frames. Today, the cost of NSEs is much more than that of the SEs up to 5 times in hospitals, 4 times in high-end offices and up to 2 times in normal residential buildings.

NSEs should be secured to Structural Elements of buildings as per specifications of NBC 2016.

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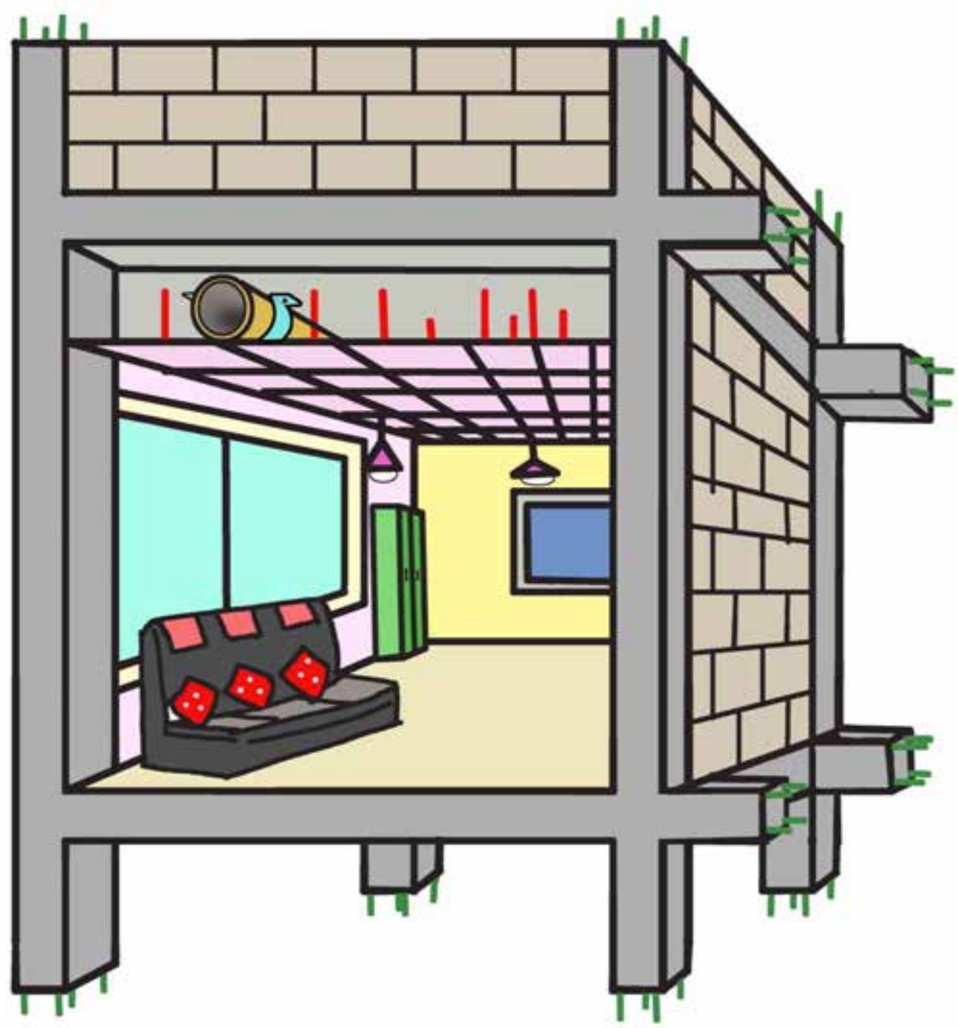
Part 6: Structural Design
Part 8: Building Services
Part 9: Plumbing Services



Structural Safety is pre-requisite. But, safety of Non-Structural Elements also is vital to **save peoples lives**.

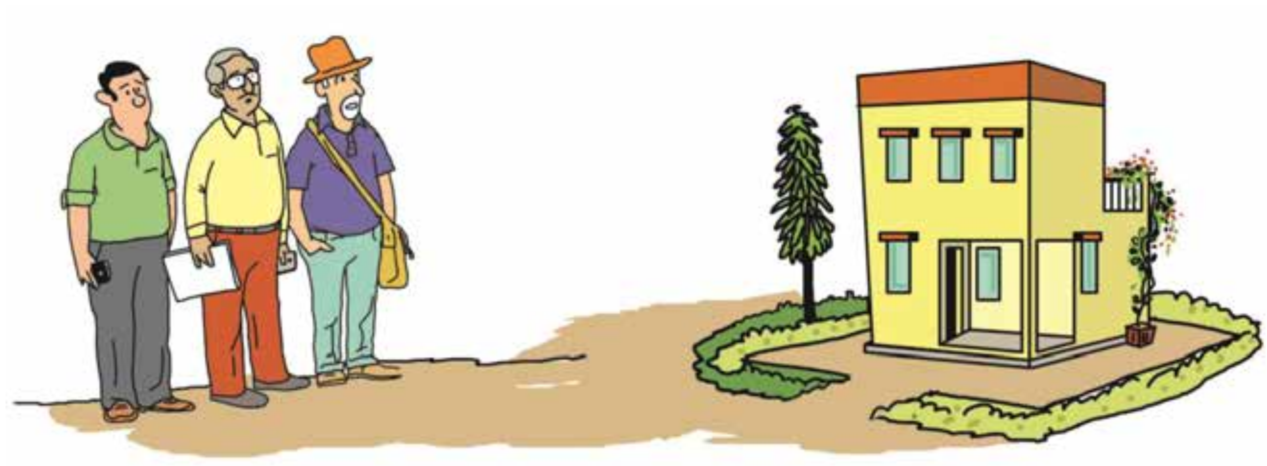
5

Regulatory Mechanism

5.1 Should a Structural Engineer be appointed for designing a building, or can an Architect do it?

The role of an *Architect* is distinctly different from that of an *Engineer*. A *Civil Engineer* or a *Structural Engineer* (depending on size and height of the building) should be engaged to ensure that the structural design and related calculations are prepared and duly signed for submission to *Statutory Authority*.

National Building Code of India 2016
Part 2: Administration



A **Civil Engineer** may be sufficient for structural design of a small building. But, when a **large building** is to be made, a **Structural Engineer also is required**.

5.2 How to know if the Architect or the Structural Engineer has used the latest design codes?

Generally, the local building bye-laws insist on use of latest Indian Standards, and the *Architects* and *Engineers* are required to prepare the *plans*, *designs* and *drawings* accordingly. The bye-laws cross refer to NBC 2016. When the Civil Engineer submits the structural design calculations and drawings to the local statutory authority, the same needs to be examined for compliance of the safety standards (including those related to earthquake resistant design, detailing and construction) by the statutory authority.

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Part 2: Administration

The **Municipal Authority** will examine the structural design calculations and drawings to check if the latest standards have been followed.

5.3 Who should be contacted to know the status of earthquake safety of an existing house?

The services should be sought of a competent *Structural Engineer*, who has vast practical experience in earthquake resistant *design*, *detailing*, *construction* of new buildings and structures and *retrofit* of existing ones.

A **Structural Engineer** will be required to assess the structural safety of a house.

5.4 If a building is found to be structurally deficient, what are the steps to be followed?

If a building is found to be structurally deficient, the following steps need to be followed:

(1) A competent *Structural Engineer* should evaluate the extent of structural deficiency.

(2) The *Structural Engineer* should suggest a couple of distinctly viable structural options for earthquake retrofitting, remedial measures as per **NBC 2016** and the relevant Indian Standards, appropriate for the type of construction.

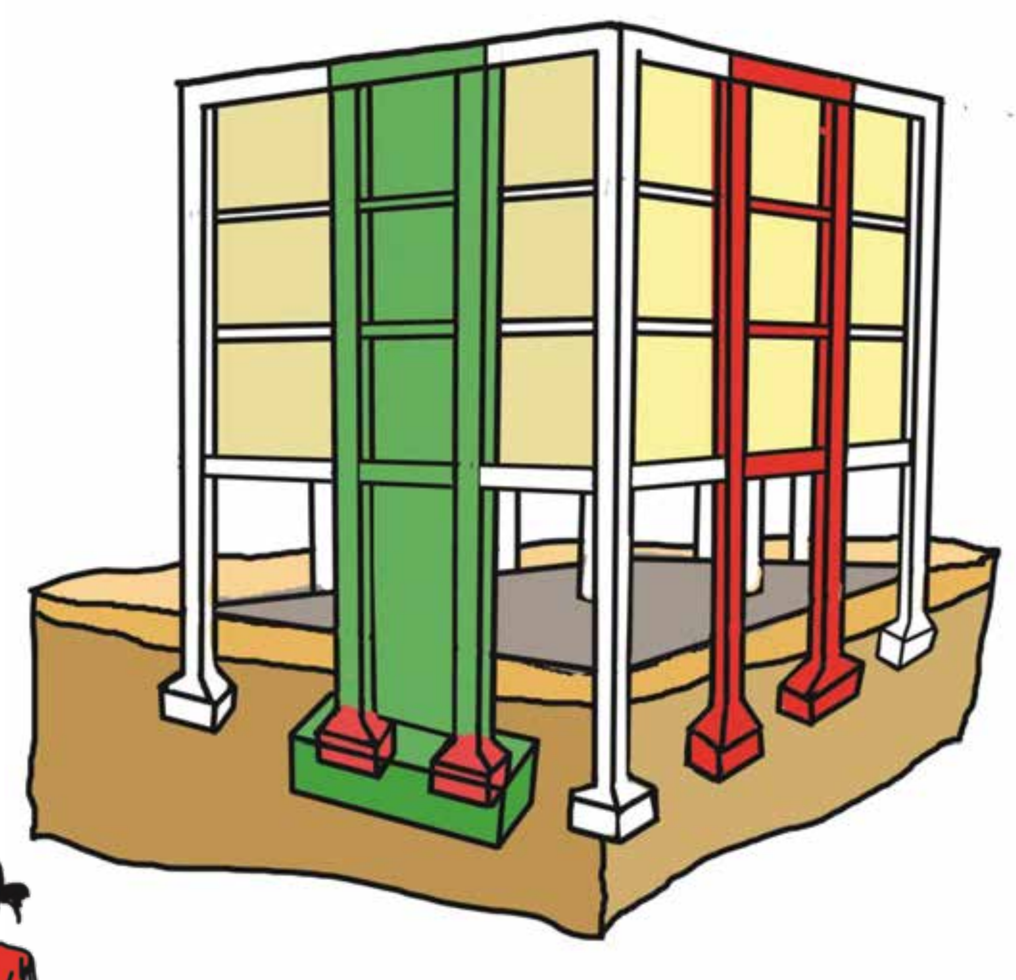
(3) The retrofit options proposed by the *Structural Engineer* should be compared to identify the one that is acceptable from the standpoint of *available resources* (*i.e.*, material, money, skills and time for retrofit) and *downtime* of the structure.

(4) Approval should be sought from the *Local Statutory Authority* to undertake modifications to the existing building/structure.

(5) Identify and commission a *Contractor* who can implement the chosen retrofit option within the available budget and within an acceptable timeframe.

(6) Upon completion of the work, apply for an *Occupancy Certificate* from the Local Statutory Authority.

National Building Code of India 2016
Part 2: Administration



Appointing a competent
Structural Engineer
is the first step.

5.5 What steps should be taken to construct a Communication Tower, a Billboard, a Generator and Solar Panel Array atop an existing building?

As in the construction of a new building, the following steps need to be followed by the *Owner* for installing a *communication tower*, a *billboard*, a *generator* and *solar panel array* atop an existing building:

(1) A competent *Structural Engineer* should evaluate the structural safety and adequacy of the existing building considering the condition of existing strength of building, loads expected to be imposed due to additional objects, and siting, design and erection of the same.

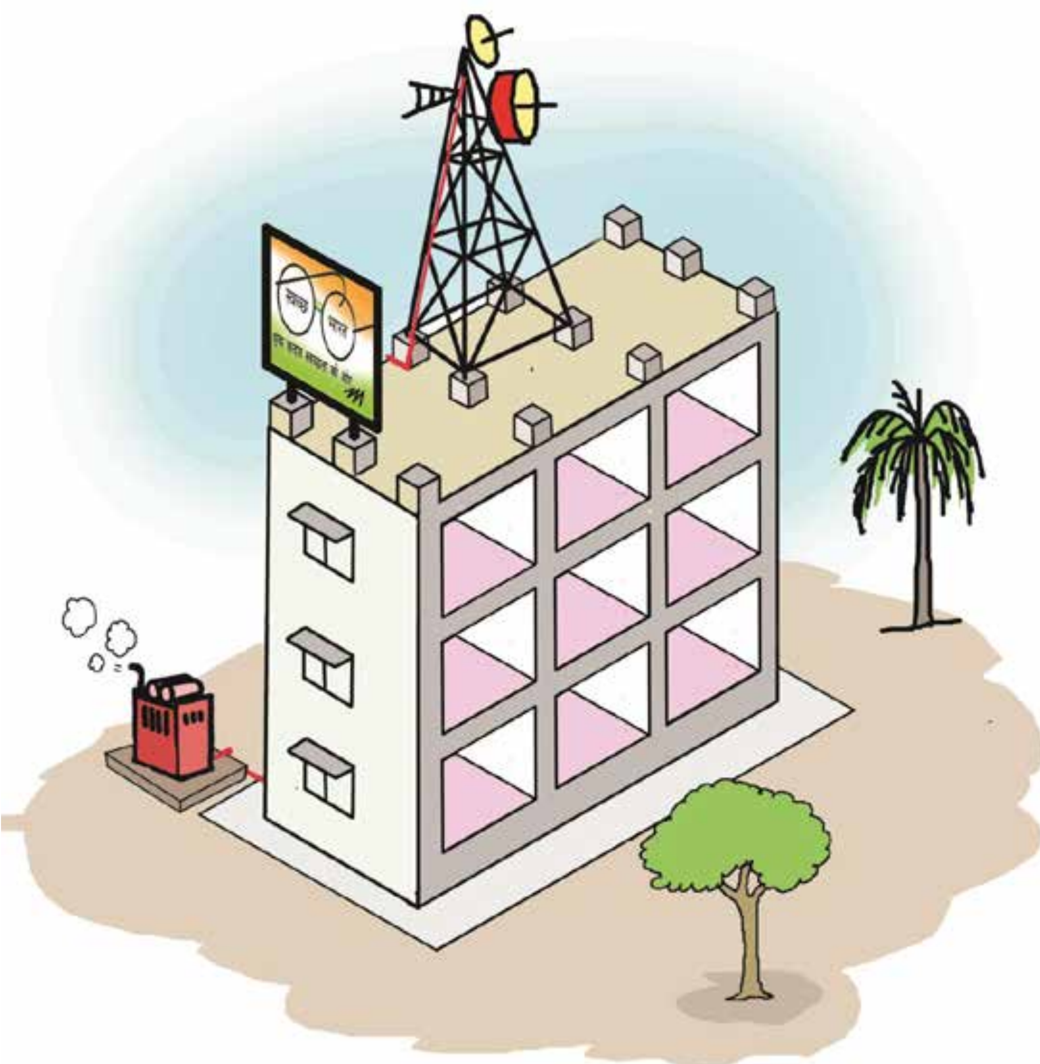
(2) The *Structural Engineer* should suggest a structural solution for appending the said objects as per **NBC 2016** and the relevant Indian Standards, including the structural requirements for retrofit of the existing building, if required.

(3) Approval should be sought from the *Local Statutory Authority* on the addition of the new object to the existing building. Such additions can be made only *after* the approval is accorded.

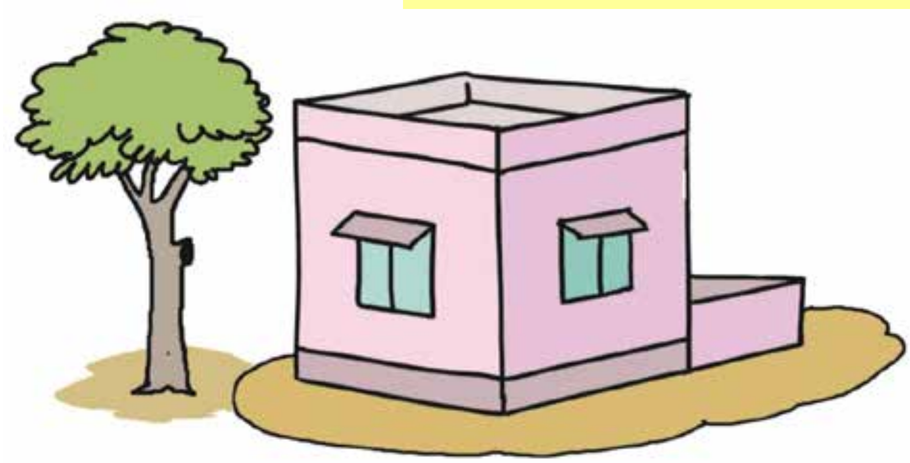
(4) Identify and commission a *Contractor* who can implement the chosen appendage.

(5) Upon completion of the work, apply for a *Completion Certificate* from the Local Statutory Authority.

National Building Code of India 2016
Part 2: Administration
Part 8: Building Services



Such items can be installed only on top of **engineered buildings** and that too after detailed design and calculations of safety. They should not be placed atop small ones.



5.6 What is the role of an Architect in the making of a building?

A good conceptualization and planning is important for functionality and well-being of the residents of a building. A competent *Architect* can provide the following services in the making of a building:

(1) Prepare *architectural plans* and other plans (based on norms laid down in the prevalent *bye-laws* and *NBC 2016*) and give specifications of architectural finishes,

(2) Provide information related to building permits,

(3) Provide engineering services of *ONLY* of low-rise buildings and non-special buildings,

(4) Supervise the construction with respect to architectural aspects of buildings, and

(5) Issue a *Completion Certificate* with respect to Item (4) above.

An Architect plays **a central role**
in the making of a Building, e.g., planning functional spaces.

5.7 What is the role of a Structural Engineer in the making of a building?

A competent *Structural Engineer* can provide the following services in the making of a building:

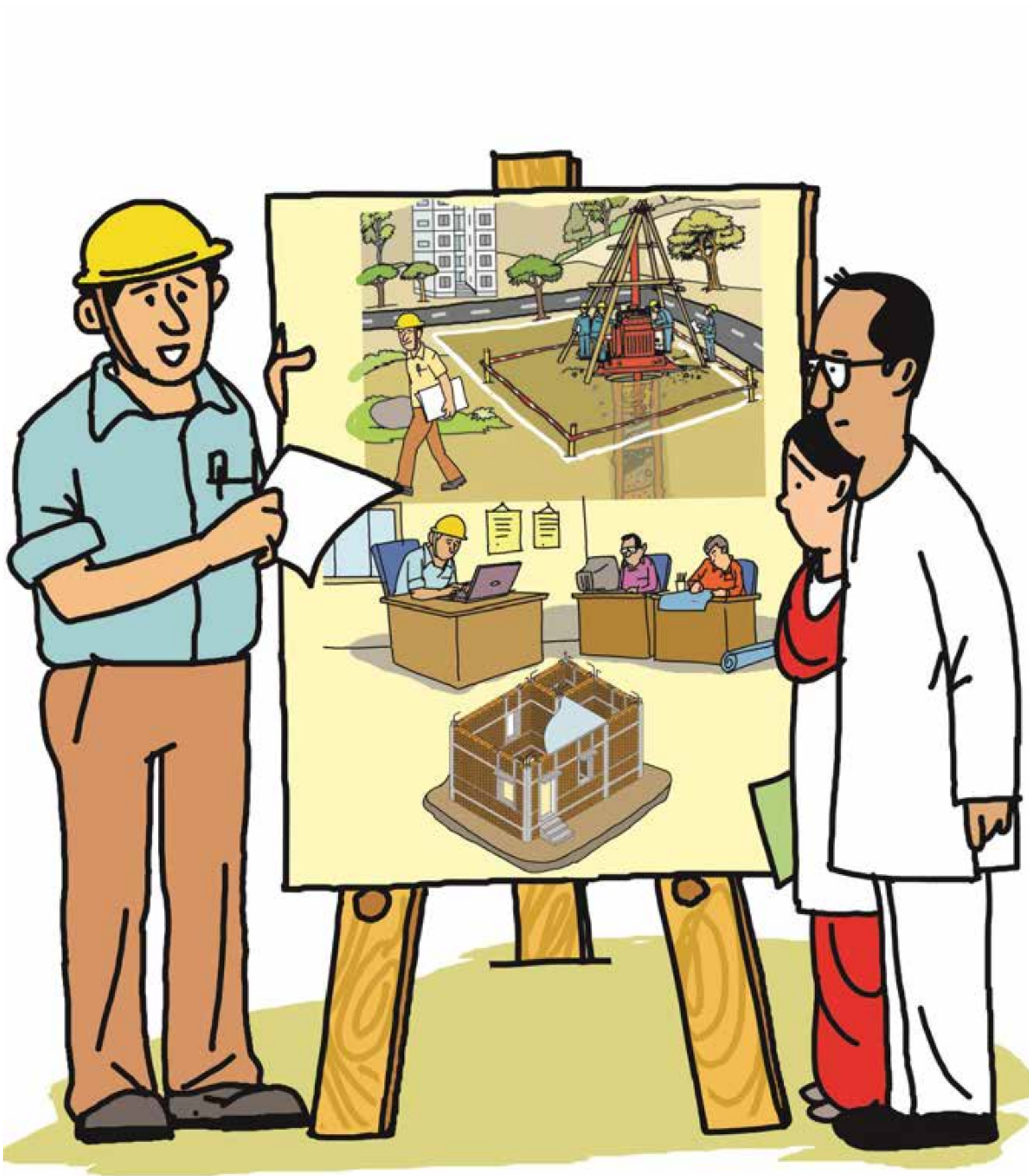
(1) Provide to a Geotechnical Engineer the *proposed structural system and loads appearing because of the building on the soil stratum*, to obtain soil investigation report, recommendation on type of foundation, bearing capacity, likely deflection of the soil under short-term and long-term actions, and depth at which the foundations should be rested,

(2) Prepare the *structural design,* and provide *structural design calculations and drawings* (with structural detailing),

(3) Supervise the construction with respect to structural detailing of the building, and

(4) Issue a *Completion Certificate* with respect to Item (3) above.

National Building Code of India 2016
Part 2: Administration – Annex A



A Structural Engineer plays **a critical role** in the making of a Building, e.g., ensuring safety.

5.8 What are the roles and required competence of a Contractor in the making or retrofitting of a building?

A competent *Contractor* (technically called *Builder* OR *Constructor*), if technically qualified **OR** through his technically qualified representative, can provide the following services:

(1) Construct a new building,

(2) Retrofit an existing building, and

(3) Issue a *Completion Certificate* with respect to Item (1) or (2) above.

A Contractor plays **a primary role** of constructing the Building.

5.9 What is the role of Quality Assurance personnel in the making of a building?

The services rendered by Architects, Engineers and Contractors related to structural safety, based on the good practices learnt by them during their education and their past experience. Notwithstanding them offering their best services related to structural safety, it is necessary to examine the quality of these services by an independent set of competent personnel.

In small building projects, an individual professional (Civil Engineer) is made responsible for supervision of the following to be as per the structural drawings and specification mentioned therein:

(a) Materials used,

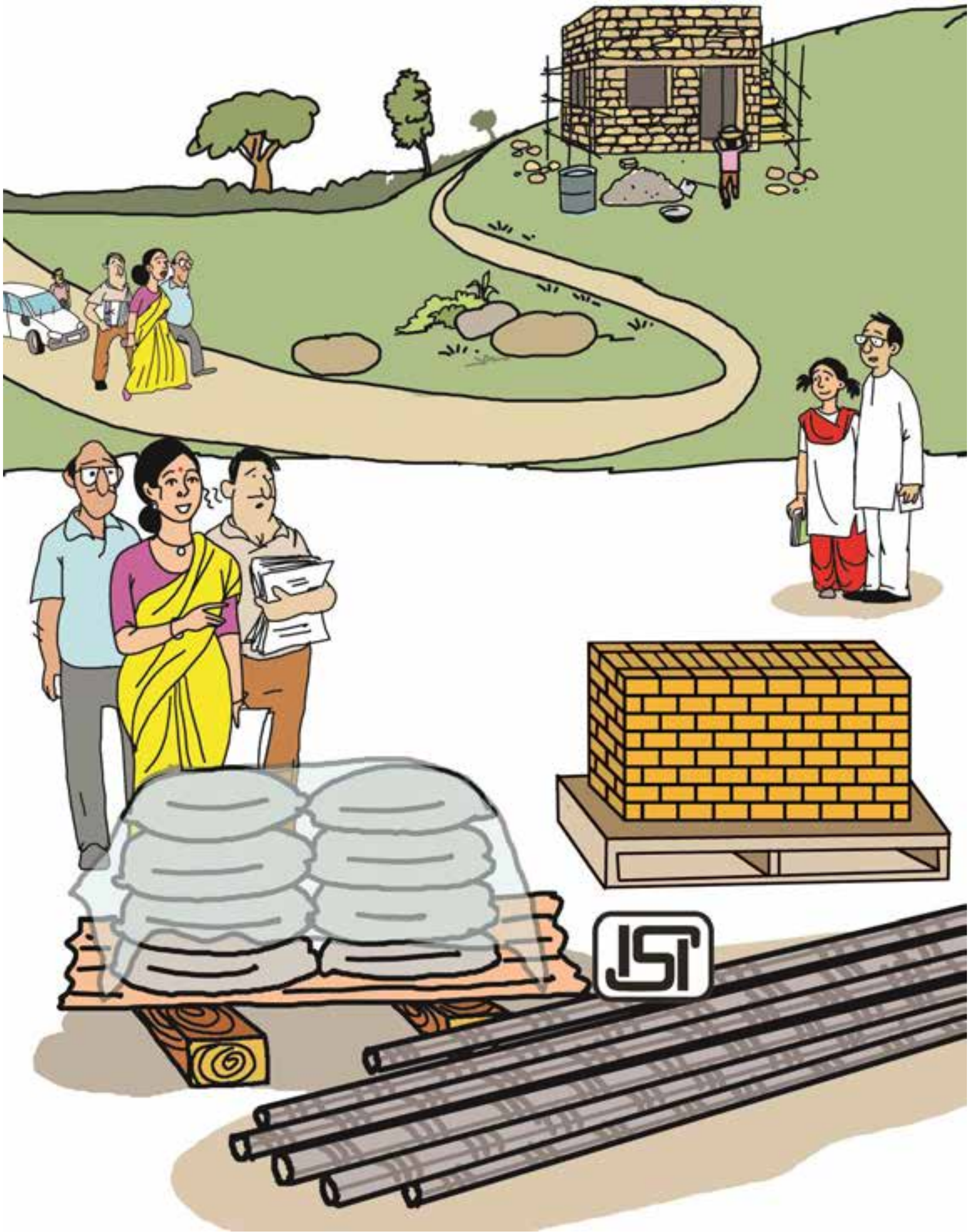
(b) Proportioning and mixing employed of concrete, mortar and plaster,

(c) Formwork (shuttering and shoring), and

(d) Detailing (bar bending, spacing, hooks, laps, *etc.* of reinforcing steel in RC buildings; and sections, welding, bolting, joints, connections, *etc*. in Steel buildings).

But, in large building projects, a separate *Project Management Consultant (PMC)* or *Quality Assurance Agency* is appointed to independently monitor and report directly to the Client (or to the representative of the client). The objective is to avoid any breach in *quality* at every aspect in every stage of the construction.

National Building Code of India 2016
Part 2: Administration
Part 7: Construction Management, Practices and Safety



A Quality Assurance Personnel play **a special role** of examining the quality of building materials and supervision of construction.

5.10 What is the role of a Regulatory Authority in the making of a building?

A Building Official(s) of a *Regulatory Authority* are required to provide the following services:

(1) Inspect the Plans, Drawings and Forms submitted by the Owner,

(2) Grant or decline (by listing valid grounds) the issue of building permit for construction,

(3) Visit periodically the construction site, or accept reports of authorized inspectors,

(4) Issue necessary notices OR orders, even notify **STAY** on the construction, if the same is not as per plan and demand corrections to be effected, and

(5) Issue occupancy permits after satisfying themselves of requisite compliances, and

(6) Examine existing and unsafe buildings, and issue notices and take necessary steps thereon, including activities related to retrofitting or demolition of a building.

National Building Code of India 2016
Part 2: Administration
Part 3: Development Control Rules and General Building Requirements

A Regulatory Authority plays
an important role
of examining compliance with
the prevalent laws, bye-laws and
norms for the built environment.

DOs and DON'Ts

Earthquake Safety

The following is a summary of the main points presented in this *Guide*, which need the attention of a *Home Owner* towards ensuring *Earthquake Safety*:

S.No.	DO's
1.	Ensure that the ground on which the house is being built is *competent*, either on *hill slopes* or in *plains*.
2.	Ensure that the building is: (a) neither *too long* nor *too tall*, (b) *simple* without any bend in plan, and (c) *uniformly wide* along the height, if not, wider at the base.
3.	Ensure that masonry houses have walls with: (a) *regularly shaped* masonry units, (b) *bands*, (c) proper *masonry courses*, (d) relatively *small door and window openings*, which are away from wall corners, and (e) *buttresses* supporting long walls.
4.	Ensure that RC Frame buildings have: (a) *structural walls* along the full building height, (b) *135° hook ends* in transverse ties, and (c) additional *horizontal RC elements* to break slender masonry infill walls into smaller panels.
5.	Ensure that *good quality materials* are used in construction of the house. In houses built of stone masonry, only *dressed* stones should be used.
6.	Ensure that masonry and RC works are *cured* for the prescribed duration using potable water.
7.	Secure properly the following *to RC members* and never to masonry walls: (a) heavy objects (like *water tanks*), and (b) utilities (like *electric*, *gas* and *water* lines).
8.	Ensure regular maintenance of buildings, and repair of: (a) Minor *structural* and *non-structural damages*, (b) Plumbing items and *water* leakages from joints, (c) *Electrical* items, (d) Aesthetics and *painting*, and (e) General *cleaning* of roofs, balconies and ledges.
9.	Seek services of competent *Professionals* for design and construction of the house, and skilled *Artisans* for construction.

S.No.	*DON'Ts*
1.	Do not purchase any land for constructing the house, if *it is under dispute*.
2.	Do not start construction until the plot of land is *marked by the Surveyor* from the Municipal Office, and *approvals are provided* for construction by the Municipal Office.
3.	Do not use false ceilings excessively in the house.
4.	Do not use *excessive appendages* (like façade, stone cladding) or *large sized glass windows/walls* in the house.
5.	Do not buy a house that is not certified to be *earthquake-resistant* by a competent Structural Engineer.

❖ ❖ ❖

National Building Code of India 2016

Part 0: Integrated Approach – Prerequisite for Applying Provisions of the Code
Part 1: Definitions
Part 2: Administration
Part 3: Development Control Rules and General Building Requirements
Part 4: Fire and Life Safety
Part 5: Building Materials
Part 6: Structural Design
Part 7: Construction Management, Practices and Safety
Part 8: Building Services
Part 9: Plumbing Services (including Solid Waste Management)
Part 10: Landscape Development, Signs and Outdoor Display Structures
Part 11: Approach to Sustainability
Part 12: Asset and Facility Management

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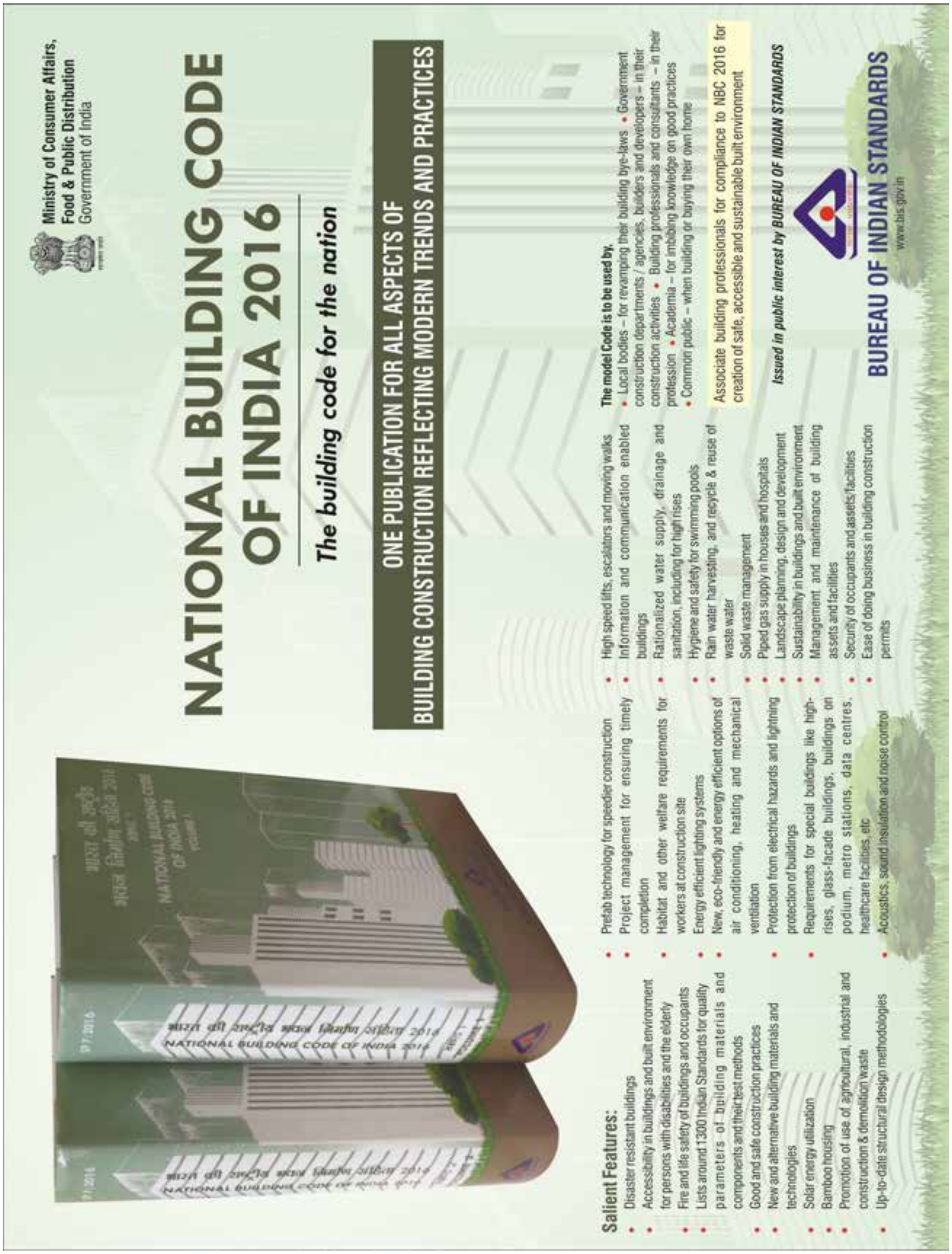
https://bis.gov.in/index.php/standards/technical-department/national-building-code/
https://manakonline.in


Ministry of Consumer Affairs, Food & Public Distribution
Government of India
NATIONAL BUILDING CODE OF INDIA 2016
The building code for the nation
ONE PUBLICATION FOR ALL ASPECTS OF BUILDING CONSTRUCTION REFLECTING MODERN TRENDS AND PRACTICES
Salient Features:
Disaster resistant buildings
Accessibility in buildings and built environment for persons with disabilities and the elderly
Fire and life safety of buildings and occupants
Lists around 1300 Indian Standards for quality parameters of building materials and components and their test methods
Good and safe construction practices
New and alternative building materials and technologies
Solar energy utilization
Bamboo housing
Promotion of use of agricultural, industrial and construction & demolition waste
Up-to-date structural design methodologies
Prefab technology for speedier construction
Project management for ensuring timely completion
Habitat and other welfare requirements for workers at construction site
Energy efficient lighting systems
New, eco-friendly and energy efficient options of air conditioning, heating and mechanical ventilation
Protection from electrical hazards and lightning protection of buildings
Requirements for special buildings like high-rises, glass-facade buildings, buildings on podium, metro stations, data centres, healthcare facilities, etc
Acoustics, sound insulation and noise control
High speed lifts, escalators and moving walks
Information and communication enabled buildings
Rationalized water supply, drainage and sanitation, including for high rises
Hygiene and safety for swimming pools
Rain water harvesting, and recycle & reuse of waste water
Solid waste management
Piped gas supply in houses and hospitals
Landscape planning, design and development
Sustainability in buildings and built environment
Management and maintenance of building assets and facilities
Security of occupants and assets/facilities
Ease of doing business in building construction permits
The model Code is to be used by,
Local bodies – for revamping their building bye-laws • Government construction departments / agencies, builders and developers – in their construction activities • Building professionals and consultants – in their profession • Academia – for imbibing knowledge on good practices • Common public – when building or buying their own home
Associate building professionals for compliance to NBC 2016 for creation of safe, accessible and sustainable built environment
Issued in public interest by BUREAU OF INDIAN STANDARDS
BUREAU OF INDIAN STANDARDS
www.bis.gov.in


उपभोक्ता मामले, खाद्य और
सार्वजनिक वितरण मंत्रालय
भारत सरकार
भारत की राष्ट्रीय
भवन निर्माण संहिता 2016
राष्ट्र निर्माण के लिए समर्पित
भवन निर्माण के सभी पक्षों के लिए एक प्रकाशन जिसमें शामिल हैं
सभी आधुनिक प्रवृत्तियाँ और रीतियाँ
NATIONAL BUILDING CODE OF INDIA 2016
प्रमुख विशेषताएँ:
आपदा प्रतिरोधी भवन
दिव्यांग और वरिष्ठ व्यक्तियों हेतु भवनों और निर्मित परिवेश में पहुँच
भवनों और निवासियों के लिए अग्नि एवं जीवन सुरक्षा
भवन सामग्री और घटकों तथा उनकी परीक्षण पद्धतियों के मापदंडों के लिए लगभग 1300 भारतीय मानक दर्ज
अच्छी और सुरक्षित निर्माण रीतियाँ
सौर ऊर्जा उपयोगिता
बांस से घर निर्माण
कृषि और औद्योगिक अपशिष्ट, और मलबे के उपयोग को प्रोत्साहन
नवीनतम संरचनागत डिजाइन कार्य-प्रणाली
शीघ्र निर्माण के लिए प्रीफैब प्रौद्योगिकी
समयबद्ध कार्य समाप्ति के लिए परियोजना प्रबंधन
निर्माण स्थल पर श्रमिकों के रहने की और अन्य कल्याण अपेक्षाएँ
ऊर्जा-दक्ष प्रकाश व्यवस्थाएँ
एयर कंडीशनिंग, गर्म और यांत्रिक संवातन के नए, पर्यावरण अनुकूल तथा ऊर्जा-दक्ष विकल्प
बिजली के जोखिमों और आकाशीय बिजली से सुरक्षा
विशेष भवनों जैसे ऊँची इमारतें, कांच के अग्रभाग वाली इमारतें, मंच पर इमारतें, मेट्रो स्टेशनों, डाटा केन्द्रों, हेल्थकेयर सुविधाओं इत्यादि की अपेक्षाएँ
ध्वनिरोधन और शोर नियंत्रण
तेज गति वाली लिफ्ट, स्वचालित सीढ़ियाँ और चलपथ
सूचना एवं संप्रेषण समर्थ भवन
ऊँची इमारतों के लिए पानी की युक्तियुक्त आपूर्ति, निकासी और सेनीटेशन
स्विमिंग पूलों में साफ-सफाई एवं सुरक्षा
वर्षा जल संरक्षण और व्यर्थ पानी का पुनर्प्रयोग
ठोस कचरा प्रबंधन
घरों एवं अस्पतालों में पाइप से गैस आपूर्ति
लैंडस्केप आयोजना, डिजाइन एवं विकास
भवनों और परिवेश में संवहनीयता
भवन सम्पदा एवं सुविधाओं का प्रबंधन एवं रखरखाव
निवासियों एवं परिसम्पत्ति / सुविधाओं की सुरक्षा
मॉडल संहिता निम्नलिखित द्वारा प्रयोग की जाए:
• स्थानीय निकाय – भवनों के उपनियमों के पुनरीक्षण के लिए • सरकारी निर्माण विभाग / एजेंसियाँ, बिल्डर्स एवं डेवेलपर्स – अपनी निर्माण गतिविधियों में • भवन निर्माण व्यवसायिक और परामर्शदाता • शिक्षा क्षेत्र – भवन निर्माण संबंधी सुरीतियाँ आत्मसात करने हेतु • आमजन – अपना घर बनाते अथवा खरीदते समय
एनबीसी 2016 के अनुरूप सुरक्षित, गम्य व संवहनीय परिवेश निर्माण को सुनिश्चित करने के लिए संबद्ध भवन व्यवसायिकों से परामर्श लें ।
भारतीय मानक ब्यूरो द्वारा जनहित में जारी
भारतीय मानक ब्यूरो
www.bis.gov.in

Simplified Guidelines

for Earthquake Safety of Buildings
from National Building Code of India 2016

September 2021

National Disaster Management Authority
Government of India

Bureau of Indian Standards
Government of India

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