VULNERABILITY ATLAS OF INDIA

NATURAL HAZARD MAPS AND DAMAGE RISK TO HOUSING

1. BACKGROUND

As per prevalent geo-climatic conditions, Indian sub-continent is prone to natural hazards such as earthquakes, wind storms & cyclones, landslides, floods, thunderstorms. India has witnessed several disasters leading trail of destruction, irreparable loss of lives and properties. Recognizing the vulnerability of Indian sub-continent, Disaster Management Act was enacted in 2005 followed up by National Policy for Disaster Management in 2009 and National Disaster Management Plan in 2016. Internationally also, 1990-2000 was declared as International Decade for Natural Disaster Reduction (IDNDR) by UN General Assembly, which was subsequently supported by Yokohama Strategy for Safer World in 1994, Hygo Framework for Action (2005-2015) and Sendai Framework for Disaster Risk Reduction in 2015-2030. All these policy frameworks brought paradigm shift in disaster risk management from post disaster relief centric measures to pro-active pre-disaster preventive measures.

Vulnerability Atlas of India, 1997

BMTPC since its inception in 1990 was committed towards promoting disaster mitigation measures through preparedness and brought out its first Vulnerability Atlas of India in 1997 under the auspices of Expert Group set up by the Ministry of Housing & Urban Affairs (erstwhile Ministry of Urban Development) *(Annex-1)*. It was first of its kind tool for the Disaster Management authorities, agencies, related stake holders and citizens of India for identifying the level of damage risk (degree of vulnerability) of housing stock with respect to earthquakes, floods and cyclones, in any part of the country. The data from Government nodal agencies such as Indian Meteorological Department (IMD), Survey of India (SOI), Geological Survey of India (GSI), Census of India, Bureau of Indian Standards (BIS), Central Water Commission (CWC) was assimilated and natural hazards maps were prepared upto district level in each State of India.

The expected loss from a given hazard and related depends upon the hazard intensity, population exposed and vulnerability of housing stocks. A simplified way of projecting the inter-dependencies of these factors and risk at a place is :

Risk at any place = [(Hazard x Vulnerability) x exposure] / Capacity,

where various terms are defined as
Risk is combination of probability of an event and its negative consequences
Hazard is a threatening event i.e. Earthquakes/Wind storm/ Cyclones/Floods/Landslides
Vulnerability is Characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard
Exposure is in terms of People, buildings, businesses, infrastructure
Capacity is combination of all the strengths, attributes and resources available within a community, society or organization

Accordingly, the housing risk tables enumerating level of damage risk with reference to earthquakes, cyclones and floods having potential of damaging the housing stocks were also incorporated in the Vulnerability Atlas of India. The Atlas with the help of State and Union Territory wise hazard maps as well as housing risk tables for each districts, indicate overall vulnerability of different regions. The macro level information on hazard risk of housing stock has proved to be an innovative tool for assessing district wise vulnerability and risk level of housing stock. It is being utilized by state governments and their agencies.

The Vulnerability Atlas of India published by BMTPC was commended as *"useful tool for policy planning* *on natural disaster prevention and preparedness, specially for housing and related infrastructures"* by the United Nation Centre for Human Settlement, Nairobi, Secretariat for International Decade for Natural Disaster Reduction (IDNDR). The IDNDR also adjudged the project with high demonstrative value.

Vulnerability Atlas of India, 2006

Ever since its first publication in 1997, it was felt that the publication of the Atlas ought to be periodically revised based on the new data and information collated by various nodal agencies. One of the most important data is on housing statistics which is released by Census of India after every 10 years and therefore, it was prudent to upgrade the Atlas after every Census data with the incorporation of newer data, demographic changes and supplementary scientific and engineering information observed during the period.

Accordingly, the second edition Vulnerability of India was brought out by BMTPC in 2006 based on Census 2001 data using GIS tools and digitized maps were developed for the first time providing hazard and seismo-tectonic information upto district level. Based on Census Housing Stock data, housing risk tables upto districts were also published based on distribution of houses by predominant material of roof and wall. The Vulnerability Atlas of India 2006 was brought out under the guidance of Peer Group set up by the then Ministry of Housing & Urban Poverty Alleviation *(Annex-2)*.

In the second edition (first revision) of the Atlas, to project earthquake hazard, new earthquake hazard map of India, (IS 1893:2002 -Part 1) brought out by Bureau of Indian Standards by merging Seismic zoning I and II and extending zone III in the States of Maharashtra, Karnataka and Tamil Nadu, was used. All the datasets in the various maps including boundaries of the States and Districts in digitized form taken from the Survey of India maps and the boundaries of the various Hazard zones and Seismo tectonic details were digitized to bring more accuracy in the maps. Other important modifications were inclusion of landslide map based on Landslide Atlas (2003) brought out by BMTPC and revision of risk tables on the basis of 2001 Census data, with district names according to 2001 Census.

Vulnerability Atlas of India, 2019

While the second edition was being finalized, Disaster Management Act 2005 was enacted by the Government on 26 December 2005, making Disaster Risk Reduction a continuous and integrated process involving individuals, communities, government, non government bodies, civil societies and other stakeholders in the entire cycle of Disaster Risk Management. This also led the creation of National Disaster Management Authority (NDMA) headed by Prime Minister and initiation of formation of State Disaster Management Authorities headed by Chief Ministers and Districts Disaster Management Authorities headed by District Collector/District Magistrate/Deputy Commissioner, as the case may be, to spearhead and adopt a holistic and integrated approach towards Disaster Management and create the needed techno-legal framework for paradigm shift from post-disaster relief-centric response to a pro-active preventions, mitigation and preparedness.

Subsequently, National Policy for Disaster Management was brought out by NDMA in 2009. The hazard maps prepared for the Vulnerability Atlas of India (2006) was referred in National Policy for describing the extent of earthquakes, flood and cyclone hazards in the country. The objectives of the policy, inter alia, include promoting a culture of prevention, preparedness and resilience at all levels through knowledge, innovation and education, besides mainstreaming disaster management into development planning process.

Given the increasing concern about the impact of disasters, the broader global awareness of the social and economic consequences of disasters caused by natural hazards developed as the decades progressed. The Hygo Framework for Action (2005-2015) Building the Resilience of Nations and Communities to Disasters was an outcome of the 2005 Conference. The present Sendai Framework for Disaster Risk Reduction 2015-2030, which was adopted at the Third UN World Conference on Disaster Risk Reduction (WCDRR) is built on the basis of the experience matured in the implementation of the Hygo Framework for Action and other relevant international frameworks.

India is also committed to make all efforts to contribute to realization of the global targets by improving the entire disaster management cycle in India by following the recommendations in the Sendai Framework and by adopting globally accepted best practices. The four priorities of Sendai Framework are (i) Understanding disaster Risk, (ii) Strengthening disaster risk governance to manage disaster risk, (iii) Investing in disaster risk reduction for resilience, and (iv) Enhancing disaster preparedness for effective response and to *Build Back Better* in recovery, rehabilitation and reconstruction.

A mile stone in the history of disaster management in India is the National Disaster Management Plan which has been drawn by NDMA in 2016, with the vision "*Make India disaster resilient, achieve substantial disaster risk reduction, and significantly decrease the losses of life, livelihoods and assts-economic, physical, social, cultural, and environmental – by maximizing the ability to cope with disasters at all levels of administration as well as among communities*".

Since the publication of Vulnerability Atlas of India (2006), there has been invaluable feedback from users on the Atlas. Also, Vulnerability Atlas of India was brought out in digitized CD form in 2008 and was also uploaded on National Informatics Centre (NIC) platform. National Institute of Disaster Management (NIDM), Government of India also used the Atlas for training SAARC countries so as to prepare the region towards disaster risk reduction.

There have been subtle changes in the available knowledge and information in the area of disaster mitigation and management. New datasets with respect to earthquake occurrence, cyclones, wind storms, landslides, thunderstorm etc. have been brought out by nodal government agencies. There are demographic changes also on account of formation of new States and new districts. During this period, the country has also experienced some damaging earthquakes, cyclones, floods and landslides. Thunderstorms, urban flooding, flash floods have also caused significant damages to lives and properties. The major changes are given below:

i) Major earthquakes affecting the country

Year	Place of Occurrence	Magnitude	Maximum Intensity	Other features
2006	Sikkim	5.7	VII	Structural damage was observed in and around state capital of Sikkim
2009	Andaman Islands	6.9	-	Minor damage to buildings
2011	Sikkim	6.9	Vii	Significant building collapse and mud slides
2015	Nepal	7.9	IX	States of Bihar, West Bengal, Sikkim, Assam, Rajasthan and Uttar Pradesh experienced damage,79 deaths and 627 injured,477 houses collapsed fully and 9673 got partially damaged.
2016	Manipur	6.7	VII	Loss of damage to life and property,08 deaths and 78 injured in Manipur and Assam. 1825 buildings damaged in Manipur

Source : NDMA

i) Major Flood, Cyclone, Landslides and Flashflood Disasters in India

S. No.	Name of Event	Year	State & Area	Fatalities
1.	Floods	October 2014	Jammu & Kashmir	---
2.	Cyclone Hud Hud	September 2014	Andhra Pradesh & Odisha	---
3.	Odisha Floods	October 2013	Odisha	21
4.	Andhra Floods	October 2013	Andhra Pradesh	53
5.	Cyclone Phailin	October 2013	Odisha and Andhra Pradesh	23
6.	Floods/Landslides	June 2013	Uttarakhand and Himachal Pradesh	4,094
7.	Cyclone Mahasen	May 2013	Tamil Nadu	08
8.	Cyclone Nilam	October 2012	Tamil Nadu	65
9.	Uttarakhand Floods	Aug – Sep 2012	Uttarkashi, Rudraprayag and Bageshwar	52
10.	Assam Floods	July – Aug 2012	Assam	---
11.	Cyclone Thane	December 2011	Tamil Nadu, Puducherry	47
13.	Odisha Floods	September 2011	19 Districts of Odisha	45
14.	Sikkim Earthquake	2011	North Eastern India with epicenter near Nepal Border and Sikkim	97 people died (75 in Sikkim)
15.	Cloudburst	2010	Leh, Ladakh in J&K	257 people died
16.	Drought	2009	252 Districts in 10 States	-----
17.	Krishna Floods	2009	Andhra Pradesh, Karnataka	300 people died
18.	Kosi Floods	2008	North Bihar	527 deaths, 19,323 livestock perished, 2,23,000 houses damaged, 3.3 million persons affected
19.	Cyclone Nisha	2008	Tamil Nadu	204 deaths

Source : NDMA

ii) Revision of Indian Standards Codes and National Building Code

a) IS 875 : PART 3 : 2015 Design Loads (Other than Earthquake) for Buildings and Structures - Code of Practice - Part 3 Wind Loads

b) IS 1893 : PART 1 : 2016 Criteria for Earthquake Resistant Design of Structures - Part 1 : General Provisions and Buildings

c) IS 1893 : PART 2 : 2014 Criteria for Earthquake Resistant Design of Structures Part 2 Liquid Retaining Tanks

d) IS 1893 : PART 3 : 2014 Criteria for Earthquake Resistant Design of Structures Part 3 Bridges and Retaining Walls

e) IS 1893 : PART 4 : 2015 Criteria for Earthquake Resistant Design of Structures Part 4 Industrial Structures Including Stack - Like Structures (First Revision)

f) IS 4326 : 2013 Earthquake resistant design and construction of buildings - Code of practice

g) IS 13920 : 2016 Ductile Detailing of Reinforced Concrete Structures subjected 6to Seismic Forces - Code Of Practice

h) IS 13935 : 2009 Seismic Evaluation, Repair and Strengthening of Masonry Buildings – Guidelines

a) (Reaffirmed 2014)
b) IS 15988 : 2013 Seismic Evaluation and Strengthening of Existing Reinforced Concrete Building – Guidelines
c) National Building Code 2016.

i) Development of basin wise Atlases for Probable Maximum Precipitation (PMP) by Central Water Commission and India Metrological Department i.e. (a) Ganga river basin, (b) Brahmaputra river basin, (c) Godavari river basin, (d) Mahanadi and other adjoining river basins, (e) Cauvery and other east flowing river basins; (f) Narmada Tapi, Sabarmati and Luni river basins, rivers of Saurashtra & Kutch regions including Mahi, West flowing rivers of western ghats and (g) Krishna river basins.

ii) Availability of more than 9000 field verified landslide incidence data from Geological Survey of India – the nodal agency of Government of India for study of landslides in the country.

iii) Availability of climatological data for thunderstorms from IMD in terms of number of thunderstorms at a station from 1981 to 2010.

iv) The political map of the country has undergone change in terms of bifurcation of Andhra Pradesh into two States, namely Andhra Pradesh and Telangana and creation of 47 new districts across different states.

v) The housing data of Census 2011 are made available on various relevant factors relating the population growth and the changed building typologies (roof-wall types). The number of houses have increased from 249,095,869 to 330,835,767. The percentage of mud/un-burnt bricks walls in rural areas has reduced from Census 2001 i.e. 26.4% to 19.1% and in urban areas from 3.2% to 2.7%. In so far as houses with burnt brick walls & stone packed with mortar walls are concerned, there is increase in both urban area and rural areas. In urban areas from 19.7%, it has gone to 24.6% while in rural areas it has increased from 25.2% to 34.3%. Percentage of heavy weight sloping roofs in both rural and urban combined has decreased from 31.4% to 30.7%. There is increase in flat roof also, which has gone from 33.7% to 36.2%.

vi) Availability of digitized Earthquake Hazard Zoning Atlas of India, States and Union territories and Districts with Subdistrict boundaries for NDMA prepared by BMTPC in 2016.

vii) As regards latest data on flood prone areas is concerned, the nodal agency, Central Water Commission, has informed that the work of scientific assessment of flood prone area in India is under progress and it would take time to come out with the final report of scientific assessment of flood prone area in India. Therefore, the existing flood maps of 2006 Atlas are used for presenting Flood Hazard Maps and flood prone areas. Once the final report is made available by CWC, the flood maps will be updated accordingly as a supplementary to new Atlas.

With the advancement of scientific & technical knowledge, addition of new datasets, experience of disasters caused due to earthquakes, cyclones, damages potential of landslides/mass movements, floods, frequent thunderstorms, failures of roadways and railways during disasters, changes in the political map of the country, new data statistics of walling and roofing data of houses; the revision of the Atlas was initiated by the Peer Group set up by the Ministry vide OM No.I-21011/1/2015-HFA/FTS-13218 dated 18th June 2015 (Annex-3). A number of meetings of the Peer Group and interaction with nodal agencies were held to arrive at consensus for various modifications and additions. The revised Atlas contains following new special features :

❖ State and district boundaries as per Survey of India's digitized data.

❖ Inclusion of railways, national highways, expressways and water bodies in hazard maps.

❖ Inclusion of Housing/Population data as per Census 2011 in hazard maps.

❖ Inclusion of landslide Incidence Maps with detailed note on landslide occurrences and effects.

❖ Inclusion of Map showing frequencies of Thunderstorms at different stations in the country and corresponding note on causes and effect of thunderstorms.

- ❖ Digitisation of all data sets in the various maps including boundaries of the States and Districts according to the Survey of India Maps as well as the boundaries of the various hazard zones, thus improving their accuracy.
- ❖ The Vulnerability and Risk Tables of Housing Data in each district is now based on wall types and roof types as per 2011 Census data. The district names and reference numbers are taken according to 2011 Census for ease of cross reference.

In order to incorporate the special features, the following methodology has been adopted in the revised Atlas:

i) **Earthquake Hazard Maps :** Modifications of Earthquake Hazard maps both India and State/UT levels based on latest Seismic hazard zoning map of India as per IS 1893 (Part 1) 2002. Addition of railway lines, national and state highways, rivers and water bodies, housing/population data as per Census 2011, faults, thrust & other seismo-techtonic details as per GSI. Earthquake epicenter data of magnitude $\geq$5 up to 2016 from IMD. Earthquake epicenter of magnitude 7.1 shown earlier in Rajasthan was deleted with the confirmation from IMD that it occurred in Baluchistan and not in Rajasthan.

While developing the Earthquake Hazard Maps, the base maps were initially developed by taking Seismic Zoning Map from IS 1893 (Part-1): 2016 and National Building Code 2016. While digitizing, it was found that there is variation in seismic zones boundaries in the Seismic Zones of India Map given in IS 1893(Part-1):2016 / NBC 2016 while comparing with Seismic Zones of India Map as given in the IS 1893 (Part-1):2002. The issue was discussed with various members of the relevant Sectional Committee and BIS. It was responded by the Members that there are no changes in the seismic zoning and the base map used by BMTPC in its earlier map as presented in 2006 Atlas is in order. Therefore, Earthquake Hazard Maps of India and States/UTs for the revision of the Atlas has been prepared based on Seismic Zones of India Map as given in the IS 1893 (Part-1): 2002.

ii) **Wind Hazard Maps :** Revision of Wind Hazard map both India and State/UT levels based on the latest wind speed map given in National Building Code 2016 with updated cyclone and super cyclone data in terms of number of cyclonic storms (C.S.) and number of severe cyclonic storms (S.C.S.) passing 1° latitude for a period 1891 to 2017, as provided by IMD.

While developing the Wind Hazard Map, it has been noted that the revised Basic Wind Speed map has been included in the National Building Code of India 2016 whereas the same has not been included in the IS 875 (Part-3): 2015 which is still using the old wind map. The Chairman, Peer Group desired that this anomaly in the Basic Wind Map in the IS 875 (Part-3): 2015 may be brought to the notice of BIS and related Sectional Committee. However, it was noted from the SERC representative (part of Peer Group) who is responsible for bringing changes in the Basic Wind Speed map that the Basic Wind Map given in NBC 2016 is being included in IS 875 shortly through amendment.

iii) **Cyclone Occurrence Map :** On the suggestions of the Director General, IMD, two maps, namely, (a) Wind Hazard Maps both India and State/UT levels, and (b) Cyclone Occurrence Map for Coastal India have been developed. The Cyclone Occurrence Map of India has been developed based on maximum/ estimated 3-minute average Maximum Sustained Wind (MSW) in knots (1 knot = 0.5144 m/s) that affected coastal districts of India during 1891-2008, as per data provided by IMD.

It was earlier decided to include Cyclone track maps showing depression, severe and very severe cyclones from sea to land and land to sea. However, since these are available on the website of the IMD

(Cyclone Track E-Atlas – http://www.rmcchennaieatlas.tn.nic.in), the same is not part of this Atlas.

i) **Flood Hazard Maps :** Flood hazard maps, both India and State/UT levels, are based on the existing flood hazard map given in 2006 version of the Atlas. The Peer Group also considered using Flood hazard maps of Assam and Bihar brought out by National Remote Sensing Centre (NRSC), Hyderabad. However, considering the fact that NRSC Atlases are based on limited satellite imagery data of 13 years only and also that the data itself has got lots of limitation, the same has not been included.

ii) **Landslide Incidence Maps :** New Landslide Incidence Maps both India and State/UT levels based on the field verified data (about 9000) given by GSI has been included. The Landslide Incidence Maps also provides Annual State Rainfall Normals (mm) in the base layer, as provided by IMD.

iii) **Thunderstorm Incidence Map :** A new Thunderstorm Incidence Map of India showing frequency of thunderstorms at different locations has been included.

iv) **Vulnerability and Risk Tables :** The Vulnerability and Risk Tables of Housing Data in each district is now based on wall types and roof types as per 2011 Census data. The district names and reference numbers are taken according to 2011 Census for ease of cross reference. As per 2011 Census housing data, the houses with stone walls not packed with mortar and houses stone walls packed with mortar are categorized in two different categories.

Probable Maximum Precipitation : Probable Maximum Precipitation (PMP) for each districts are now based on the PMP Atlases of Probable Maximum Precipitation developed by Central Water Commission and India Meteorological Department. The values have been derived from the 1 day areal PMP (mm) for 1000 sq km given at 1 degree grid point of different river basins. For the values in the districts tables, nearest grid point value or average have been taken depending upon the location of the district HQ. Users of the Atlas are suggested that for more accurate values, PMP Atlas of Central Water Commission and India Meteorological Department may be referred. A number of States/Districts have not been covered in PMP Atlases of different basins. Therefore, for these States/Districts, PMP values in District tables have not been changed and they continue as given in earlier Atlas as "*Probable Maximum Precipitation at a Station of the district in 24 h*."

2. DESCRIPTION OF THE VULNERABILITY ATLAS

The Vulnerability Atlas contains the following maps and tables for each State and Union Territory of India:

a) Earthquake hazard maps both India and State/UT levels

b) Wind hazard maps both India and State/UT levels

c) Flood hazard maps both India and 14 States/UTs

d) The Landslide Hazard Incidence Maps for India and States/UTs of Jammu and Kashmir, Uttarakhand, Himachal Pradesh, Maharashtra, Kerala, Karnataka, Tamil Nadu, Tripura, West Bengal, Goa and North Eastern States including Sikkim

e) Cyclone Occurrence Map of Coastal India based on maximum/estimated 3-minute average Maximum Sustained Wind (MSW)

f) India Map showing frequency of thunderstorms at different stations of the country

g) Housing stock vulnerability table for each State and districts, indicating for each house by wall and roof type, the level of damage risk with regard to earthquake, wind and floods.

\

All hazard maps of the States and UTs, in digitized form have been reproduced on larger scale of 1:2 million based on Survey of India map. The State maps show the state & district boundaries and names of districts for ease of identifying the hazard zone boundaries in the districts. While printing, some maps of the larger States have been reduced so as to accommodate them in A3 size. Maps of the Union Territories are drawn to different scales to suit A3 or A4 size. The accuracy of the enlarged maps is limited to the accuracy of the small-scale map.

The various parameters involved, the sources of information used and the limitations of the present maps and tables are described in the following paras:

3. THE GEOLOGIC HAZARDS

The predominant geologic hazards in India consist of earthquake and landslides. An isolated case of active volcano occurs at the Barren Island in the Andaman and Nicobar Islands. These are briefly described below:

3.1 Earthquake and Seismic Zones

The entire Indian landmass, susceptible to different levels of earthquake hazard, has broadly been classified into four distinct seismic Zones, referred to as Zones II to IV as per the Seismic Zoning Map of India contained in IS 1893:2002 (Part-1). As per the Foreword to the Seismic Code IS 1893:2002, the general basis of the zones is as follows:

Zone V: Covers the areas liable to seismic intensity IX *and above* on MSK (1964) Intensity Scale. This is the most severe seismic zone and is referred here as Very High Damage Risk Zone.

Zone IV: Gives the area liable to MSK VIII. This zone is second in severity to zone V. This is referred here as High Damage Risk Zone.

Zone III: The associated intensity is MSK VII. This is termed here as Moderate Damage Risk Zone.

Zone II: The probable intensity is MSK VI *or less*. This zone is referred to as Low Damage Risk Zone.

Note 1: In reproducing the map from IS 1893:2016 and National Building Code 2016, it was observed that there are variations in boundaries of zones. Noting that BIS Technical Committee CED 39 has not changed the seismic zoning, the map used in this Atlas has utilized seismic zoning map of IS 1893 (Part-1): 2002.

Note 2: In reproducing the map from IS 1893:2002, it was observed that some important differences have crept in the map given in IS 1893:1984. Noting that BIS Technical Committee had not changed the seismic zoning in the North of Peninsular India, the map used in this Atlas has utilized seismic zoning map of 1984 for North India and 2002 map for Peninsular India, where revision of the map was introduced by the BIS Committee CED 39.

Note 3: In the Seismic Zone Map of 2002, the seismic zone I as given in 1984 has been merged into Seismic Zone II and renamed as Zone II. Zone III has been extended to cover more areas in Maharashtra, Andhra Pradesh, Telangana and Tamil Nadu. Zones IV and V have remained unchanged.

It may be mentioned here that the new Intensity scale, called as MSK Intensity Scale 1964, is much more detailed and quantitative in nature as compared to the Modified Mercalli (MM) though almost similar in intensity.

Hence MSK could be used in place of MM in the classification of the seismic zones given above. The two intensity scales are reproduced in Annex-4 and 5.

The following important comments, from the Foreword to the IS 1893:2002, are very relevant for clearer understanding of the seismic zoning:

(a) "The Sectional Committee responsible for the formulation of this standard (IS 1893:2002 Part I) has attempted to include a seismic zoning map. The object of this map is to classify the area of the country into a number of zones in which one may reasonably expect earthquake shaking of more or less same maximum intensity in future. The Intensity as per Comprehensive Intensity Scale (MSK 64) broadly associated with the various zones is VI (or less), VII, VIII and IX (and above) for Zones II, III, IV and V, respectively. The maximum seismic ground acceleration in each zone cannot be presently predicted with accuracy either on a deterministic or on a probabilistic basis. The basic zone factors included herein are reasonable estimates of effective peak ground accelerations for the design of various structures covered in this standard."

(b) "The Sectional Committee has appreciated that there cannot be an entirely scientific basis for zoning in view of the scanty data available. Though the magnitudes of different earthquakes which have occurred in the past are known to reasonable degree of accuracy, the intensities of the shocks caused by these earthquakes have so far been mostly estimated by damage surveys and there is little instrumental evidence to corroborate the conclusions arrived at. Maximum intensity at different places can be fixed on a scale only on the basis of the observations made and recorded after the earthquake and thus a zoning map which is based on the maximum intensities arrived at, is likely to lead in some cases to an incorrect conclusion in view of (a) incorrectness in the assessment of intensities, (b) human error in judgment during the damage survey, and (c) variation in quality and design of structures causing variation in type and extent of damage to the structures for the same intensity of shock. The Sectional Committee has therefore, considered that a rational approach to the problem would be to arrive at a zoning map based on known magnitudes and the known epicenters assuming all other conditions as being average and to modify such an idealized iso-seismal map in the light of tectonics, lithology and the maximum intensities as recorded from damage surveys. The Committee has also reviewed such a map in the light of the past history and future possibilities and also attempted to draw the lines demarcating the different zones so as to be clear of important towns, cities and industrial areas, after making special examination of such cases, as a little modification in the zonal demarcations may mean considerable difference to the economics of a project in the area."

(c) "In the seismic zoning map, Zones I and II of the contemporary map have been merged and assigned the level of Zone II. The Killari area has been included in Zone III and necessary modifications made, keeping in view the probabilistic hazard evaluation. The Bellary isolated zone has been removed. The parts of eastern coast areas have shown similar hazard to that of the Killari area, the level of Zone II has been enhanced to Zone III and connected with Zone III of Godawari Graben area."

Epicentres of Earthquakes of M $\geq$5.0

All earthquakes of M $\geq$ 5.0 on Richter open ended logarithmic scale have been plotted along with the seismic-intensity zones. The catalogue of earthquakes prepared by India Meteorological Department (IMD), Government of India has been utilized for the purpose. The Magnitude of the earthquake as well as the year of occurrence are shown along with the location on the maps. With regard to earthquakes of lower magnitudes, it is known that their frequency of occurrence is much higher than the larger earthquakes. Also lower the magnitude, the closer must be the installations of seismological instruments and better should be their installation to permit higher gain, so as to be able to record the shocks and find their location. The present seismological network in India is not so capable and is non-uniform in its capability as well. No doubt, small magnitude earthquakes have been recorded in several parts of the country through local, small aperture networks of high gain instruments by some organizations and institutions, but the non-uniformity of the data and time gaps as well, may convey an unrealistic picture of relative seismic activity in different areas, that is, areas having dense local instrument network showing more activity than those where such networks do not exist. No attempt was therefore made to present this available information on the general purpose hazard maps which are meant here specifically for prevention, mitigation and preparedness concerning housing and related infrastructure. As recommended in the Code itself, in the case of special structures, detailed investigations (site related geologic, seismotectonic, geotechnical) should be undertaken. Such special structures will include very tall buildings, say more than 90 m in height; very long span, special type and important bridges, major dams, major power plants, hazardous/risky structures, etc. The seismic risk to such structures can not be worked out from the data presented in this Atlas.

Earthquake Magnitude and Intensity

The magnitude M of an earthquake is denoted by a number which is a measure of energy released during the earthquake occurrence. It is now measured in different ways, the most commonly used is the Richter Scale according to which "the magnitude of an earthquake is the logarithm to the base 10 of the maximum trace amplitude, expressed in microns, with which the standard short period torsion seismometer (with a period of 0.8 second, magnification of 2800 and damping nearly critical) would register the earthquake at an epicentral distance of 100 km". The scale being logarithmic, the energy of earthquake magnitude 'm+1' is about 31 times the energy released in earthquake of magnitude 'm'. Magnitude scale is open ended, denoted numerically to one place of decimal (5.6, 8.3, etc.).

"The intensity of an earthquake at a place is a measure of the effects of the earthquake". A number of intensity scales have been in vogue in different times, namely Rossi-Forel (RF), Modified Mercalli (MM), MSK 1964 and Japan Meteorological Agency (JMA) scales. All the scales are close-ended stepped scales, RF having 10 points (I to X), MM and MSK with 12 points (I to XII) and JMA with 7 points (I to VII). Presently MSK 12 point scale is the most used, JMA being used in Japan. In historical earthquakes in India such as 1905 Kangra earthquake and 1934 Bihar- Nepal earthquake, RF intensity scale was used for drawing the isoseismal.

While for a given earthquake, the magnitude has one unique value and epicentral location, the intensity varies from the maximum in the epicentral area to smaller values at increasing distances from the epicentre. Isoseismals derived from the observed damages in an earthquake as per the intensity scale show the intensity distribution caused in the earthquake.

The relationship between the earthquake magnitude and the maximum intensity caused is not precise. Approximate relationship between them is shown in Table-1 as a general guide.

MSK Intensity Scale

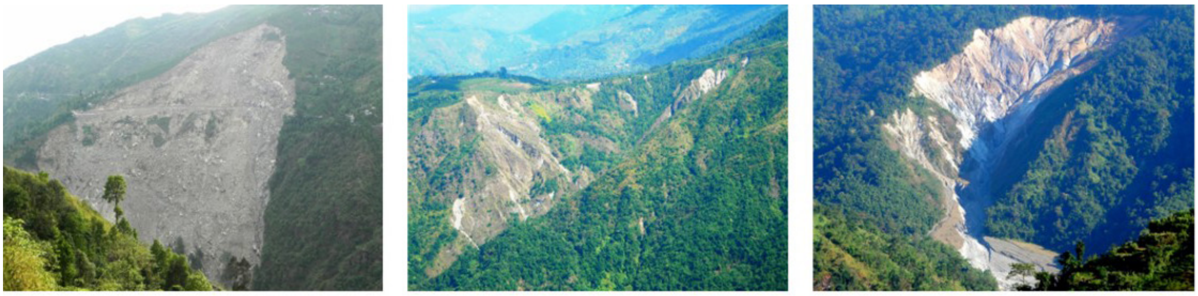
The MSK intensity scale (Annex-5) describes the generally observed grades of damage to buildings and structures in various intensity levels. For convenience of reference, the damage vulnerability of the various building types in MSK seismic intensities VI, VII, VIII and IX is presented in Table-2.

3.2 Landslides

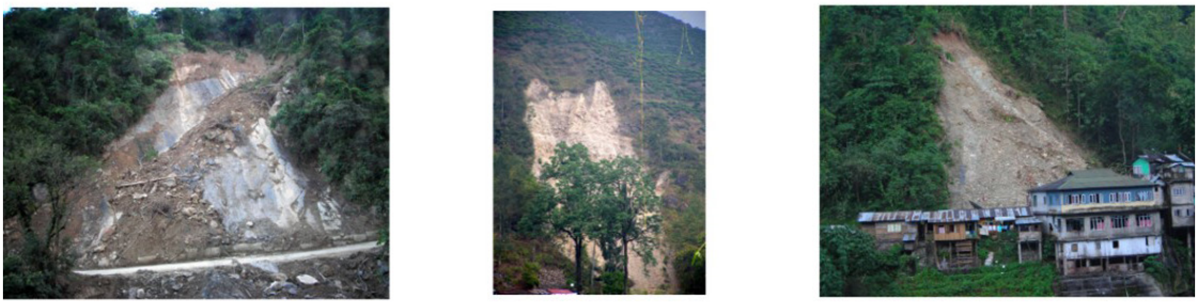
In India, landslides are perennial hazards in the hilly/mountainous terrains that directly inflicts irreparable losses of precious human lives and properties, including un-ending indirect miseries to the society at large.

Landslides are caused mainly by two factors – pre-disposing causal geofactors and the triggering factors (e.g., rainfall, earthquake, sudden slope cutting etc.). The pre-disposing causal geo factors such as variation in topographic gradient, topographic shape, aspect (direction of slope), geomorphology and its prevalent processes, geology, structure, lithology of the overburden material, changes in land use, and land cover are the main controlling geofactors which are instrumental in causing the landslides, including its varying types of movements, material and magnitudes. In India, the landslide prone areas represent a wide spectrum of topography, geology and geomorphic set up and thus cause landslides of varying types, magnitudes and failure mechanisms. All sorts of landslide failure mechanisms – deep-seated, shallow translational slides, flows involving varying material, movement type and magnitudes are observed in India (Fig. 1) which are strongly influenced by prevalent topography, geology and geomorphology of the terrain.

The landslides can be rapid or slow and occur in a wide variety of geological environs including under water. The secondary or domino/ cascading effects of landslides can also be very disastrous. Waves generated by landslides entering rivers, lakes, reservoirs and other water bodies have caused substantial damage to engineering and civil infrastructures in many parts of the world. The artificial landslide debris-dammed lakes can flood upstream areas and also on breaching can generate Landslide Lake Outburst Flow (LLOF) having enormous amount of discharge and energy that can suddenly trigger flash flood or inundation in downstream, low-lying areas and can also trigger many new landslides due to toe cutting and excessive rate of erosion by the flowing debris-laden flood discharge downstream along the narrow mountainous rivers. The examples of such type of cascading hazards are plenty in Indian Himalayas (e.g. the deluge of 2013 in Uttarakhand).



Deep-seated large landslides



Shallow translational landslides

Slide and Flows

Fig. 1: Different types of landslides and failure mechanism that are prevalent in India

In India excepting the permafrost terrain in the Himalayas, 12.6 percent of landmass (~0.42 million km^2) in the mountainous/ hill regions are landslide prone spreading mainly over 18 States. The main landslide prone areas belong to the Himalayan States in the north occupying about 53% of landslide prone areas of India. In the Northeast, the Meghalaya plateau, the Tertiary hills of Assam, Mizoram, Manipur, Tripura and Nagaland occupies about 25% of the landslide prone landmass, and the rest 22% are occupied by the Western Ghats and Konkan Regions in States of Maharashtra, Tamil Nadu, Karnataka, Kerala, Goa respectively. In all the above 18 States, landslides with varying frequencies are reported. These landslides of varying magnitudes are mostly triggered by the high/ extreme rainfall events during monsoon (June-October in Northern and Northeastern States; July-August and November-March in the Western Ghats and Konkan Regions). However, many of the above landslide-prone areas in India, especially the Himalayas and Northeast India also belong to the maximum earthquake-prone areas (Zone-IV and V of Seismic Zoning Map given in IS 1893 (Part1):2002), where earthquakes of MSK VIII to IX or more can occur, and thus are also prone to earthquake-induced/ triggered landslides. Amongst these18 landslide prone States, landslides are quite frequent in the Himalayan States like Uttarakhand, Jammu & Kashmir, Himachal Pradesh, Sikkim, West Bengal, and Arunachal Pradesh, followed by fragile Tertiary Hills in the Northeastern States and The Nilgiris in the southwest within the Western Ghats.

In this revised version of Vulnerability Atlas of India, 9883 nos. historic landslide data, that have been mapped and field validated till 2016 by the Geological Survey of India (GSI) – the nodal department of landslide studies in India, are incorporated to depict the landslide vulnerability of the above mentioned States of India. The distribution of such historic landslide incidences indirectly shows the relative densities of landslides in different such landslide prone States in the map as well as also in the associated textural database, indicating their types of movement, material type and dimensions, and in some cases their initiation years and damage details, wherever such information are available. However, landslide incidences demonstrated in this Vulnerability Atlas are time-dependent and dynamic features, therefore, its signatures in cases of many smaller landslides cannot always be recognized on ground on present day because of rapid land use and vegetation changes in time. In addition, the dimensions shown in the textural databases are mostly based on field-based eye-estimation, where actual landslide sizes could not always be measured at site because of local inaccessibility and time constraints. Damage details available so far in the historic record are based on the reports that are made available to the visiting field geoscientists by the local authorities and the local residents and could not always been validated with the actual government records, because of its non-availability and lack of real witnesses of the events. The densities revealed by this historic data, collected so far by GSI are only based on the landslides that are field validated on ground only at the accessible locations, but there could be many more landslides which are available on remotely and inaccessibly-distributed natural slopes and also are not proximal to habitated areas. The latter group of landslides or the landslides that are mainly mapped using only the remote sensing data are not incorporated in the landslide database of this present Atlas, because the same could not be validated through fieldwork.

The available historic landslide data (9883 nos.) presented in this Atlas indicate that about 60 percent of the incidences are smaller having lengths 50 m or lesser and about 14 percent of landslides are bigger having lengths 100 m or larger. According to the prevalent movement types, maximum (~85%) are primarily slides, followed by complex and other movement types (~6%), flows (~5%) and falls (~4%) respectively. According to the material involved or moved, about 60 percent are debris and/ or earth, followed by about 30 percent rock and the rest 10 percent are of mixed type involving both debris/ earth and rock material. As per the density of the field-validated landslides of this Atlas is concerned, the Himalayan and Northeastern States surpass all other landslide-prone terrains in India. Within the Himalayan States, Uttarakhand represents about 34 percent of the incidences, followed by Darjeeling-Sikkim Himalayas (~24%), Northeastern States including Arunachal Pradesh (~16%), Himachal Pradesh and J&K (~14%), and States in the Western Ghats and Konkan areas (~12%) respectively. However, the above region-wise statistics may slightly vary if all the field-validated and non-field-validated landslides present in inaccessible natural slopes are considered together. According to GSI, the non-field validated landslides which are not presented in this atlas also primarily favour the fact that within the 12.6percent of landslide prone landmass of India, the Himalayan and Northeastern States contain maximum amount of landslides (about 80-90%) in India.

Since the growth of population and infrastructure in such Himalayan, Northeastern States and Western Ghats/ Konkan areas are enormous in post-independence era, risks to landslide hazards also increase manifold and the losses incurred so far due to landslide hazards are huge. Thus sustainable infrastructure development and practicing the relevant land use zoning regulations strictly by following the prevalent landslide hazard scenarios of these areas are essential to reduce the landslide risks and its cascading effects. Moreover, due to climate change, behaviour, role and frequencies of the main landslide triggering factor i.e. the monsoon and extreme rainfall events are becoming more erratic and unpredictable nowadays, and thus sustainable developmental planning and its execution on ground must honour strict implementation of land use zoning practices for safer construction of buildings, and infrastructure. The same will not only ensure reduction of landslide risk in the mountainous terrains but also will ameliorate the resilience of people living in such fragile landmass to cope up the ever increasing risks of landslide hazards in India.

Disclaimer - *While GSI endeavors to keep the landslide information up to date and correct, however, GSI make no representations or warranties of any kind, express or implied, about the completeness, accuracy, reliability, suitability or availability with respect to landslides for any purpose. The landslide inventories including its dimensions presented are based on field data and visual estimation and are often limited to the accessibility and approachability in the mountainous terrain*

3.3 Indian Volcanoes

The lone active volcano in India is the “Barren Island Volcano” falling in the Southeast Asia volcanic belt. It lies about 135 km ENE of Port Blair, the capital of Andaman and Nicobar Group of Islands (12.29°N: 93.85°E) and occupies only 10 sq km area. The Barren Island rises from a depth of about 2250 m from the sea floor and stands out 355 m above the sea level. From west side it looks like a truncated cone girdled by precipitous cliffs all around. Except in its central part, Barren Island is covered with thick vegetation similar to other parts of Andaman and Nicobar Group of islands and closely related to Myanmar, Indonesia and Malayan Flora. No human habitation is ever reported from this Island.

4. WIND HAZARD MAPS

The statewise wind hazard maps contain the following information:

4.1 Basic Wind Speed Zones

The macro-level wind speed zones of India have been formulated and published in IS 875 (Part 3):2015 - “Indian Standard Code of Practice for Design Loads (other than earthquakes) for Buildings and Structures, Part 3 Wind Loads”. There are six basic wind speeds ‘V_b’ considered for zoning, namely 55, 50, 47, 44, 39 and 33 m/s. From wind damage view point, these could be described as follows:

55 m/s (198 km/h) - Very High Damage Risk Zone - A
50 m/s (180 km/h) - Very High Damage Risk Zone – B
47 m/s (169.2 km/h) - High Damage Risk Zone
44 m/s (158.4 km/h) - Moderate Damage Risk Zone – A
39 m/s (140.4 km/h) - Moderate Damage Risk Zone – B
33 m/s (118.8 km/h) - Low Damage Risk Zone

Infact, the cyclone affected coastal areas of the country are classified in 50 and 55 m/s zones. Wind speeds are applicable to 10 m height above mean ground level in an open terrain. Recently, Bureau of Indian

Standards has brought out two guidelines IS 15498:2004 (Reaffirmed 2015) and IS 15499:2004 (Reaffirmed 2015) on improving cyclonic resistance of low rise houses and other buildings/structures, and survey of housing and building typology in cyclone prone areas, respectively. IS 15498:2004 gives guidelines for increased wind speeds based on importance of structures in cyclone prone areas.

The above basic maximum wind speeds in m/s represent the peak gust velocity averaged over a short time interval of about 3 seconds duration. The wind speeds have been worked out for 50 years return period with probability of exceedance of 63%, based on the upto-date wind data of 43 Dines Pressure Tube (DPT) anemograph stations and study of other related works available on the subject since 1964. The map and related recommendations have been provided in the Code with the active cooperation of India Meteorological Department (IMD).

In general, wind speed in the atmospheric boundary layer increases with height from zero at ground level to a maximum value at a height, called gradient height. The variation with height depends primarily on the terrain conditions. However, the wind speed at any height never remains constant and it has been found convenient to resolve its instantaneous magnitude into an average or mean value and a fluctuating component around this average value. The average value depends on the averaging time employed in analysing the meterological data and this averaging time varies from a few seconds to several minutes. The magnitude of fluctuating component of the wind speed which is called gust, depends on the averaging time. In general, smaller the averaging interval, greater is the magnitude of the gust speed.

The basic wind-speed zones are plotted here in statewise maps which show the district boundaries as well as the district towns for their easy identification.

4.2 Design Wind Speed and Pressures

The basic wind speed is reduced or enhanced for design of buildings and structures due to factors like (i) the risk level of the structure measured in terms of adopted return period and life of structures (5, 25, 50 or 100 years), (ii) terrain roughness determined by the surrounding buildings or trees and, height and size of the structure, (iii) local topography like hills, valleys, cliffs, or ridges, etc., and (iv) Importance factor for the cyclonic region. This basic wind speed shall be modified to include the above effects to get design wind speed, V_z as follows:

$$V_z = V_b k_1 k_2 k_3 k_4$$

where
V_z = design wind speed at height z, in m/s;
k_1 = probability factor (risk coefficient);
k_2 = terrain roughness and height factor;
k_3 = topography factor; and
k_4 = importance factor for the cyclonic region.

Thus basic wind speed being the same in a given zone, structures in different site conditions could have appreciable modification and must be considered in determining design wind velocity as per IS 875 (Part 3):2015.

The design wind pressure at height z above ground level on a surface normal to the wind stream is given by

$$P_z = 0.0006\, V_z^2$$

where

V_z = design wind velocity, m/s

P_z = design wind pressure, kN/m^2

This value of wind pressure gets very much modified when applied to a given house: the windward vertical faces being subjected to pressure, the leeward and lateral faces getting suction effects, and the inclined roofs getting pressures or suction effects depending on their inclination. The projecting window shades, roof projections at eave levels are subjected to uplift pressures several times the intensity of P_z. These factors play an important role in determining the vulnerability of given building types in given wind speed zones.

Over the Indian continent, the average wind speed is reported on the basis of 3 minutes average. Wind speed increases manifold in of a squall or low pressure systems over the region. The highest wind speed recoded at the station during the past due to any weather system may be considered as the maximum probable wind for that region or a station.

High wind speed over the Agartala and Leh area is due to the following reasons:

Agaratala

- Tropical cyclones after re-curving move across northeast India, hence Agartala region lies in the affected zone of cyclonic winds.
- Severe thunderstorm causes high wind speed over Agartala region.
- Agartala is located in such orographic region therefore experiences katabatic and anabatic wind affects.

Leh

- The height of Leh from mean sea level is about 5,753 M at this height generally, strong wind prevails. This is the general phenomena of the atmosphere over these latitudes as per climatology.
- When the upper air jet core passes over the region, the region experiences strong wind.
- When divergence area falls over the region in association with active western disturbance passing over western Himalayan region, the area experiences strong wind.

4.3 Coastal Areas

The coastal areas are subjected to severe wind storms, cyclonic storms and tsunamis. It is known that in certain events, the wind gusts could appreciably exceed the given basic wind speeds (by as much as 40 to 55%)[1]. But for design of normal structures and classification of vulnerability and risk to buildings, the above macro-level zoning is considered as sufficient. Higher wind velocity may be adopted for the 50-60 km wide cyclonic belt on the east and west coasts as per the provisions in IS 15498:2004.

The frequency of occurrence of cyclones on the different portions of the coast has been different. Even for the same design wind speed in some areas, the risk of damage per year will be higher in areas subjected to more frequent cyclones. Therefore, for the States having coastal areas, the number of cyclones having crossed

1 Probable Maximum wind speed in coastal districts is shown on the Wind Hazard Maps for East Coast. Similar data for West Coast need to be computed.

the coastline from the year 1891 to 2017 has also been shown as cyclonic storm (C.S.) with wind speed between 34 and 47 knots. Under the S.C.S. Category all cyclones with wind speeds greater than or equal to 48 knots have been included. It is to be noted that the cyclones crossing West Bengal coast shown on the map include those upto Longitude 90°E that is a part of Bangladesh coast.

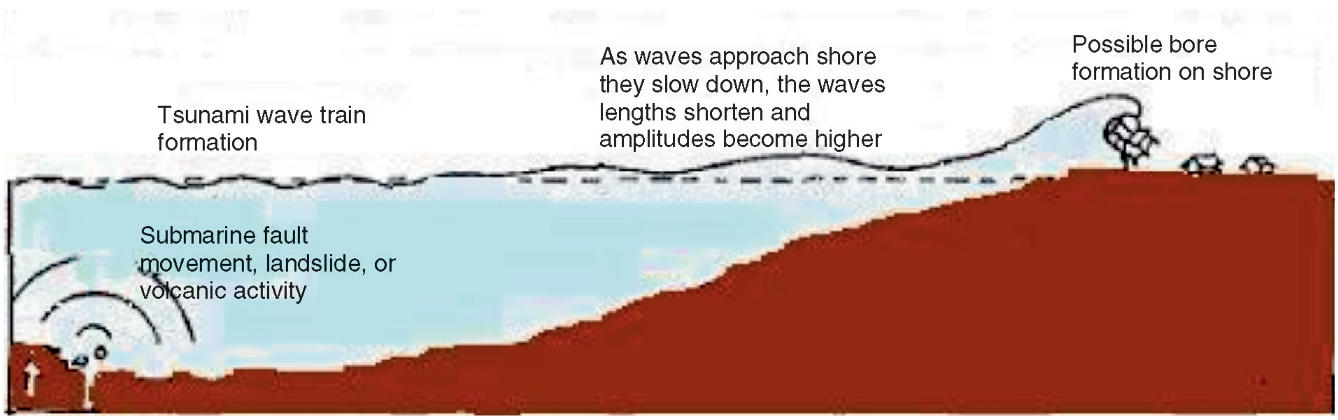
4.4 Storm Surge

Besides the very high velocity winds, the coastal areas suffer from the onslaught of sea water over the coast due to storm surge generated by cyclones. A storm surge is the sudden abnormal rise in sea level caused by cyclone. The surge is generated due to interaction of air, sea and land. The cyclone provides the driving force in the form of very high horizontal atmospheric pressure gradient that leads to very strong surface winds. The sea water flows across the coast as well as inland and then recedes back to the sea. Great loss of life and property takes place in the process. Scientists from India Meteorological Department have estimated the probable maximum heights of storm surge in various sections of the sea coast. These are shown in the relevant States' wind hazard maps. While calculating Probable Maximum Storm Surge (PMSS) the presumption has been made that there is a possibility of highest intensity storm generated in the adjacent sea/ area during past 100 years may strike any part of the coast touching that sea. The height of the storm surge is over and above the concurrent sea level, hence added to the normal astronomical tide level existing at the time of the cyclonic storm for calculating the maximum level to which the surge could strike under the storm.

4.5 Tsunami

A tsunami is a series of waves with a long wavelength and period (time between crests). Time between crests of the wave can vary from a few minutes to over an hour. They are often incorrectly called tidal waves; they have no relation to the daily ocean tides. Tsunami (soo-NAH-mee) is a Japanese word meaning harbour wave. They can occur at any time of day or night.

Tsunamis are generated by any large, impulsive displacement of the sea bed level (Fig.2). Earthquakes generate tsunamis by vertical movement of the sea floor. If the sea floor movement is horizontal, a tsunami is not generated. Earthquakes of Magnitude larger than M 6.5 are critical for tsunami generation. Tsunamis are also triggered by landslides into or under the water surface, and can be generated by volcanic activity and meteorite impacts.

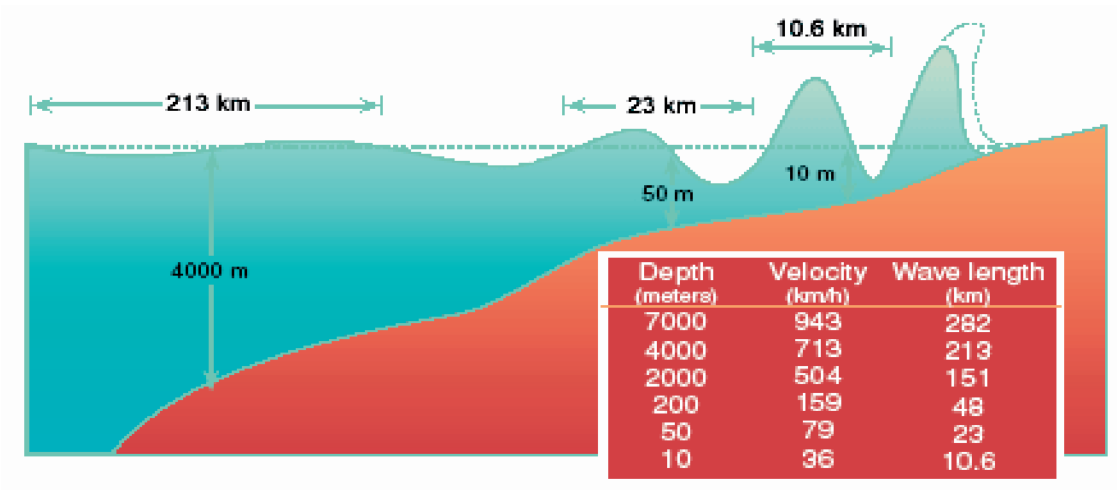


Source: International Tsunami Information Centre - Geologic Hazard

Fig.2 Wave train of Tsunami

On the average, there are two tsunamis per year in the Pacific Ocean somewhere, which cause damage near the source. Approximately every 15 years a destructive tsunami occurs in the Pacific. The destructive tsunami of Dec 26th, 2004 on the Indian Coast, in terms of its impact, seems to have occurred for the first time in the known history.

Tsunami velocity is dependent on the depth of water through which it travels (velocity equals the square root of water depth h times the gravitational acceleration g, that is V = g h). The tsunami will travel approximately at a velocity of 700 kmph in 4000 m depth of sea water. In 10 m, of water depth the velocity drops to about 36 kmph. See Fig.3. Even on shore tsunami speed is 35 to 40 km/h, hence much faster than a person can run.



Source: http://www.prh.noaa.gov/pr/itic/library/pubs/great_waves/tsunami_great_waves_4.html

Fig.3 Tsunami Velocities

Tsunamis range in size from centimeters to over 30 m height. Most tsunamis are *less than 3 m* in height. In deep water (greater than 200 m), tsunamis are rarely over 1m high and will not be noticed by ships due to their long period (time between crests). As tsunamis propagate into shallow water, the wave height can increase by over 10 times. Tsunami heights can vary greatly along a coast. The waves are amplified by certain shoreline and bathymetric (sea floor) features. A large tsunami can flood land up to1.5 km from the coast.

The force of some tsunamis is enormous. Large rocks weighing several tons along with boats and other debris can be moved inland tens of metres by tsunami wave activity. Houses and other buildings are destroyed. All this material and water move with great force and can kill or injure people.

Wind-generated waves usually have periods (time between crests) of 5 to 20 seconds. Tsunami periods are usually between 5 minutes and an hour. Wind-generated waves break as they shoal and lose energy offshore. Tsunamis act more like a flooding wave. A 6 m tsunami is a 6 m rise in sea level. This rise is of course temporary. Receding waters are also very destructive and take away to the sea whatever comes in the way.

There are two well recognized earthquake sources which are known to have generated tsunamis on the Indian coast. On the east, the west coast of Sumatra Islands and on the west, the Mekaran coast have generated tsunamis in the past. The entire coast line of India can be subjected to tsunamis and there is a need to take precautionary measures in about 1.5 km distance from the coast line particularly in the areas which are below 5 m elevation above the high tide line.

4.6 Thunderstorm

Thunderstorm is a severe weather phenomenon, the impact of which is felt by all the sectors of society including aviation service; it occurs all over the world. In general, the orographically dominant regions as well as the coastal areas are more prone to thunderstorm activities. In Indian scenario, most thunderstorm prone area is northeastern states and adjoining east India. Thunderstorm is popularly known as 'Nor'westers' over these regions because most of them move from northwest to southeast over these regions. Frequency of thunderstorms is the maximum during pre-monsoon season (April-May). It is accompanied with lightning, squalls and sometimes heavy rain and hailstorms.

Squalls in association with thunderstorm occurs when wind speed significantly increases and last for short duration of time (at least one minute) with wind speed reach 22 kts or more. As per IMD criteria, squalls with surface wind (in gusts) upto 80 kmph are known as "moderate squall", greater than 80 kmph as "severe squall" and greater than 100 kmph as "very severe squall" due to their appreciably more damaging effects.

5. FLOOD HAZARD MAPS

The statewise flood hazard maps cover the following information:

5.1 Areas Liable to Flooding

The "Flood Atlas of India" brought out by Central Water Commission (CWC), shows pictorially the areas liable to floods, expenditure made and the achievement of flood protection measures. The Atlas was first published in 1962 and again published in 1977 and updated upto March 1985. A further revision is in process now. As per the information collected from CWC, a total area of 14.37 million hectares are reported to have been protected in various states out of the total flood prone area of the country of about 40 million hectares as assessed by Rashtriya Barh Ayog (RBA) 1980. The protactable area has been considered to be of the order of 32 million hectares. The area liable to floods is the aggregate of different areas flooded in any year during the period of record. This, therefore, include the unprotected and protected areas. The protected area is also vulnerable to floods as the flood control structures, mainly embankments, may breach during a severe flood and the so called protected areas may also get flooded due to wrong alignment or breach of embankments. However, because of the protective measures adopted, vulnerability of houses, etc., in such areas, are considered to be comparatively less in usual circumstances.

The areas outside the flood prone areas are generally not vulnerable to flood. But experience shows that heavy rains in some of these areas can result in flood condition and at times flooding in such areas may be very severe and create more acute problem than in the identified flood prone areas. The economic loss and disruption to normal life in urban areas could be very high as seen in recent floods of Mumbai and Chennai (2006) which were unprecedented. These aspects may be kept in mind while using the vulnerability tables as mentioned in the note below the Risk Tables.

The State-wise flood hazard maps in this Vulnerability Atlas are based on the Flood Atlas of India (1987), and updated flood prone areas of Assam and other neighboring States including Bihar, West Bengal and Eastern Uttar Pradesh included in the Task Force Report (2004). These maps mark the areas which are liable to flooding. Since these maps given herein also show the district boundaries and the location of the district towns along with the rivers, districtwise identification of the vulnerable areas will be easy.

As regards latest data on flood prone areas is concerned, the scientific assessment of flood prone area in India is under progress by CWC. The existing flood maps presented here are of 2006 Atlas and will be updated as and when the data is made available by CWC.

5.2 Probable Maximum Precipitation

Besides the problem of flooding in the river plains, heavy intensity rains could cause local flooding in certain areas where the drainage is either naturally poor or the drains are choked due to various reasons such as careless dumping of refuse in the drains and lack of maintenance. Much of the flooding problems in towns and cities occur due to such causes. The Central Water Commission and India Meteorological Department have compiled statistics on Probable Maximum Precipitation (PMP) over the country considering one day rainfall data. The design of drainage should consider such PMP values, the catchment areas of the drain and the characteristics of the catchment area to avoid flooding.

5.3 Flooding in Coastal Areas

As stated earlier under cyclonic winds in coastal areas, the sea coast of India can be flooded due to heavy downpour on the one hand and the storm surge on the other. Whereas the PMP values give the probable intensity of raining, the probable maximum storm surge heights worked out by IMD and shown on the statewise maps will give an idea of height of water which could flow from the sea towards the coastal plains in extreme cases and the levels to which protection will be required. The depth of inland inundation could be worked out by taking the storm surge heights, where high resolution coastal maps with half metre contours are available.

6. HOUSING VULNERABILITY TABLES

6.1 House Types

The Census of Housing, 2011 Census of India, gives the following details of houses based on materials of construction for walls and roofs:

a) *Type of Roof:*
   - i) Pitched or sloping including tiles, stone/slate; corrugated iron, zinc or other metal sheets; asbestos cement sheets; plastic polythene, thatch, grass, leaves, bamboo, etc.
   - ii) Flat including brick, stone and lime; reinforced brick concrete/reinforced cement concrete.

b) *Type of Wall:*
   - i) Mud, unburnt bricks, stone packed and not packed with mortar
   - ii) Burnt bricks laid in cement, lime or mud mortar
   - iii) Cement concrete
   - iv) Wood or Ekra walling
   - v) Corrugated iron, zinc or other metal sheets
   - vi) Grass, leaves, reeds or bamboo or thatch, plastic polythene and others

c) *Type of Flooring:*
   Various types like mud, stone, concrete, wood or bamboo, mosaic floor tiles, etc.

The distribution of houses based on Predominant materials of roof and wall over whole of India according to 2011 Census is shown in Table-3. From the point of view of vulnerability to the earthquake, wind or flood hazards, it was seen that the type of flooring had hardly any significance, hence omitted from consideration, and that the roof types and wall types could not be grouped together. The appropriate grouping for the whole of India is shown in Table-4, wherein the wall and roofing groups are categorized as follows:

Wall Types

Category - A :	Buildings in field-stone, rural structures, unburnt brick houses, clay houses
Category - B:	Ordinary brick building; buildings of the large block and prefabricated type, half- timbered structures, building in natural hewn stone
Category - C:	Reinforced building, well built wooden structures
Category - X:	Other materials not covered in A, B and C. These are generally light structures.

Roof Types

Category - R1:	Light Weight (Grass, Thatch, Bamboo, Wood, Mud, Plastic, Polythene, GI Metal, Asbestos Sheets, Other Materials)
Category - R2:	Heavy Weight (Tiles, Stone/Slate)
Category - R3:	Flat Roof (Brick, Concrete)

With these groupings, the vulnerability of each subgroup could be defined separately for any given intensity of earthquake, wind or flood hazard. The risk levels of the various categories of houses for the three hazards are shown in Table-5, and explained in the following sections.

In the 1991 Census of Housing, roof and wall combinations were available for each house type. Therefore, the combined vulnerability of the complete house was indicated which is not possible for the data available in Census of Housing 2001 and 2011. For convenience of reference to those who may be studying existing houses taking wall and roof together Table 5A is reproduced from Vulnerability Atlas of India 1997.

6.2 Risk of Damage to House Types

The damage risk to various house types is based on their average performance observed during past occurrences of damaging events. In view of numerous variations in the architectural planning, structural detailing, quality of construction and care taken in maintenance, the performance of each category of houses in a given event could vary substantially from the average observed. The intensity scales as given in Annex -4 and 5 or Table-2 represent average observations. For example, under seismic occurrence, the following observations have been made in many cases:

(a) *All Masonry Houses (Categories A and B)*

- Quality of construction comes out as a major factor in the seismic performance particularly under intensities MSK VII to IX. Good quality constructions perform much better than poor quality constructions in any category. Appropriate maintenance increases durability and maintains original strength.
- Number of storeys in the house and the storey height are other factors. Higher the storey and more the number of storeys, greater is the observed damage.
- Size, location and number of door and window openings in the walls also determine seismic performance, since the openings have weakening effect on the walls. Smaller and fewer openings and located more centrally in the walls are better from seismic performance viewpoint.
- Architectural layout, particularly in large buildings, that is, shape of building in plan and elevation, presence of offsets and extended wings, also play important role in initiation of damage at certain points and its propagation as well. More symmetrical plans and elevations reduce damage and unsymmetrical ones lead to greater damage.

- Where clay/mud mortar is used in wall construction, its wetness at the time of earthquake is very important factor in the seismic performance since the strength of fully saturated mortar can become as low as 15% of its dry strength.

(b) *Wooden Houses*
- Quality of construction, that is, seasoning of wood and the joinery are important in seismic and cyclonic wind performance. Better the quality better the performance.
- Wood decays with time due to dry rot, insect and rodent attack, etc., therefore, the joints tend to become loose and weak. The state of maintenance of the wooden building will determine its performance during earthquake, high wind, as well as flooding.
- In houses with sloped roofs, a shallow angle for the roof, extended eaves projection, and reentrant corners lead to higher damage.
- In light roofs, pressures often exceed the dead weight leading to blowing-off of roofs.

(c) *Reinforced Concrete Houses*
- Mutltistorey RC frame buildings resting on soft soils and having soft first storey unconnected wall panels and floating columns in the superstructure collapsed even in Seismic Zone III.
- Besides bad quality of configuration planning and structural design, poor quality of construction lead to total collapses of 5 to 10 storeyed RC frame buildings.
- In reinforced concrete construction, good structural design and detailing and good quality construction only would ensure excellent performance. Carelessness in any of these can lead to poor behaviour both under earthquakes and cyclones.

Now the average risk levels to various categories of houses for various hazards and their intensities are defined here below for use in the house vulnerability tables.

6.3 Damage Risk Levels for Earthquakes

The damage risk to various house types is defined under various seismic intensities on MSK scale (see Annex-5). The following damage risks are defined based on this Intensity Scale.

Very High Damage Risk (VH)

Total collapse of buildings

High Damage Risk (H)

Gaps in walls; parts of buildings may collapse; separate parts of the building lose their cohesion; and inner walls collapse.

Moderate Damage Risk (M)

Large and deep cracks in walls fall of chimneys on roofs.

Low Damage Risk (L)

Small cracks in walls; fall of fairly large pieces of plaster, pantiles slip off; cracks in chimneys, part may fall down.

Very Low Damage Risk (VL)

Fine cracks in plaster; fall of small pieces of plaster.

6.4 Damage Risk Levels for Wind Storms

For damage risk to buildings from wind storms, there appears no universally accepted scale like the seismic intensity scale. The following damage risk scale has been adopted as per 2006 Atlas, for developing the house vulnerability tables.

Very High Damage Risk (VH)

Generally similar to “High Risk” but damage is expected to be more widespread as in the case of cyclonic storms.

High Damage Risk (H)

Boundary walls overturn, walls in houses and industrial structures fail; roofing sheets, and tiles or whole roofs fly; large scale destruction of life-line structures such as lighting and telephone poles, a few transmission line towers/communication towers may suffer damage; and non engineered/semi constructions suffer heavy damage.

Moderate Damage Risk (M)

Loose tiles of clay fly, roofs sheets fixed to battens fly; moderate damage to telephone and lighting poles; moderate damage to non-engineered/semi-engineered buildings.

Low Damage Risk (L)

Loose metal or fibre cement sheets fly; a few lighting and telephone poles go out of alignment; sign boards and hoardings partially damaged; well detailed non-engineered/ semi-engineered buildings suffer very little damage.

Very Low Damage Risk (VL)

Generally similar to “Low Risk” but expected to be very limited in extent.

6.5 Damage Risk Levels for Flood

No detailed building damage reports under flooding appear to have been worked out as yet. Also flood intensities in terms of depth of water, velocity of flow or time duration of inundation are not yet defined. In the absence of such data, no definite recommendation about damage risk levels could be made.

The following damage risks have been adopted from the 2006 which is based on understanding of material behaviour under submergence.

Very High Damage Risk (VH)

Total collapse of buildings; roof and some walls collapse; floating away of sheets, thatch, etc; erosion of foundation; severe damage to life line structures and systems.

High Damage Risk (H)

Gaps in walls; punching of holes through wall by flowing water; parts of buildings may collapse; light roofs float away; erosion of foundation, sinking or tilting; undercutting of floors, partial roof collapse.

Moderate Damage Risk (M)

Large and deep cracks in walls; bulging of walls; loss of belongings; damage to electric fittings.

Low Damage Risk (L)

Small cracks in walls; fall of fairly large pieces of plaster.

Very Low Damage Risk (VL)

Fine cracks in plaster; fall of small pieces of plaster.

6.6 The Housing Vulnerability Tables

Now correlating the house types, the hazard intensities on the maps and the damage risk levels, the housing damage risk tables have been generated. For the country as a whole, for each State and Union Territory also, an overall risk table has been developed. Such tables are then prepared for each of the districts and collected statewise.

Each table also gives at the top of each column of hazard intensities, the percent of total area of the country, State or District covered by the Table, lying under the various hazard intensities. Thus the concerned administrative or professional authority can visualize the extent of damage risk existing to any hazard at one time or the other in the future.

As an example, let us refer to a District Kendrapara (OR 10) of the State of Odisha. It is seen that 87% area of the district lies in seismic intensity MSK VII zone (Zone III) and 100% area in the 50 & 55 m/s wind velocity zone. Also 48.4% of its area is flood prone. The probable maximum precipitation is 716 mm, that is, quite a high figure. According to 2011 census, there are 421,530 housing units in the district, 58.1% of which are of category A (very weak type), 36.5% of category B (moderate strength) and only 1.40% of category C (the strong types). Also 4% houses are of other materials such as bamboo, thatch, grass, leaves. The risk of damage from earthquakes to Category A houses is 'medium', and to Category B (36.5% of total) it is 'low'. The example district lies in the cyclone prone area of the Odisha coastal area and have very high risk to 62.9% [57.9%(Cat.A1) + 1.0%(Cat.C2) + 4.0%(Cat.X)] housing units, hence the life and property of this population living in the district is at great cyclone risk. The district has also great risk of flooding, storm surges & tsunami. Hence serious attention has to be paid to the district from cyclone, tsunami & storm surge disaster prevention, mitigation and preparedness points of view. Other hazards can similarly be analyzed with the help of the table.

It is pertinent to mention here that there are perceptible changes in the area calculation (percent) for earthquake, wind and flood hazards as areas are now calculated based on the administrative boundary data provided by Survey of India including state and district boundaries. Also 47 new districts have been added since 2006 Vulnerability Atlas of India and one more State is added. Further, Basic Wind Speed Map given in National Building Code 2016 have been updated on account of availability of more scientific data. The difference in area is shown in the Table-7 for better comprehension:

TABLE-7

INDIA	Level of Risk under								
	EQ Zone				Wind Velocity m/s				Flood Prone Area in %
	V	IV	III	II	55 & 50	47	44 & 39	33	
	Area in %				Area in %				
Vulnerability Atlas of India - **2018**	11.3	14.4	31.1	43.2	18.0	30.3	45.1	6.6	7.3
Vulnerability Atlas of India - **2006**	10.9	17.3	30.4	41.4	5.0	40.2	48.0	6.7	7.9

7. USE OF VULNERABILITY ATLAS

In preparing the Vulnerability Atlas, it has been realized that the State Governments have the basic mandate for management of disasters and the executive actions are taken at the district levels with the District Collector playing the pivotal role. The Atlas provides some ready information, though at macro-level, for use of the authorities involved in the tasks of disaster mitigation, preparedness and preventive actions. A glance at the hazard maps will bring to the notice of the district authorities, the location and percent areas of the districts most susceptible to hazard occurrence, the probable maximum hazard intensities, the type of housing and its vulnerability and risk to the hazards. it must be realised that most of the human problems arise due to loss of the houses; deaths mostly occur in collapsed houses; and rescue, evacuation, relief and rehabilitation become more acute when houses get lost. Houses are threatened more due to earthquakes and floods, except loss due to wind in coastal areas subjected to cyclones. Landslides and mud flows can totally erase villages and bury them under debris. Rock falls can destroy a building very badly. **Knowing the extent of the problem of future disasters, the district authorities can formulate development plans for (a) preventive actions like hazard resistant construction, retrofitting and upgrading of existing buildings, (b) mitigating the intensity and extent of the disaster, (c) warning system installation and**

drills for its use, (d) instituting a hierarchical structure for preparedness down to the village level, (e) training of manpower in various tasks in the emergency (f) implementation of land zoning regulations in flood plains and coastal areas, and building byelaws with disaster resistant features in various towns and cities, etc.

The District authorities with the help of the people's representatives can create the necessary awareness leading to self help. Also the hazard zoning can be improved at local levels by specific studies carried out in the district particularly for minimising the flood havoc by measures such as suitable vulnerability analysis, hazard reduction measures, and risk mapping, and improved resistance of buildings wherein the local technical institutions and professionals could also be involved.

The Atlas can be used to identify areas in each district of the country which are prone to high risk from more than one hazard. This information will be useful in establishing the need of developing housing designs to resist the combination of such hazards.

8. DEFINITIONS OF SOME DISASTER RELATED TERMS

For the sake of easy understanding, a few of the terms commonly used in dealing with natural disasters are defined here below:

Hazard[1]: a threatening event, or the probability of occurrence of a potentially damaging phenomenon (e.g. an earthquake, a cyclonic storm or a large flood) within a given time period and area.

Disaster[1]: a serious disruption of the functioning of a society, causing widespread human, material, or environmental losses which exceed the ability of the affected society to cope using only its own resources. Disasters are often classified according to their speed of onset (sudden or slow) or according to their cause (natural or man-made).

Disaster[2]: means a catastrophe, mishap, calamity or grave occurrence in any area, arising from natural or man-made causes, or by accident or negligence which results in substantial loss of life or human suffering or damage to, and destruction of, property, or damage to, or degradation of, environment, and is of such a nature or magnitude as to be beyond the coping capacity of the community of the affected areas.

Disaster Management[2]: means a continuous and integrated process of planning, organizing, coordinating and implementing measures which are necessary or expedient for :

i) prevention of danger or threat of any disaster;
ii) mitigation or reduction of risk of any disaster or its severity or consequences;
iii) capacity building;
iv) preparedness to deal with any disaster;
v) prompt response to any threatening disaster situation or disaster;
vi) assessing the severity or magnitude of effects of any disaster;
vii) evacuation, rescue and relief;
viii) rehabilitation and reconstruction.

Risk[1]: the expected number of lives lost, persons injured, damage to property and disruption of economic activity due to a particular natural phenomenon, and consequently the product of specific risk and elements at risk.

Vulnerability[1]: the degree of loss to a given element at risk or set of such elements resulting from the occurrence of a natural phenomenon (or man-made event) of a given magnitude and expressed on a scale from 0.0 (no damage or loss) to 1.0 (total loss).

Mitigation[1]: measures taken in advance of a disaster aimed at decreasing or eliminating its impact on society and on environment.

Mitigation[2]: means measures aimed at reducing the risk, impact or effects of a disaster or threatening disaster situation.

Preparedness[1]: activities designed to minimise loss of life and damage, to organise the temporary removal of people and property from a threatened location and facilitate timely and effective rescue, relief and rehabilitation.

Preparedness[2]: means the state of readiness to deal with a threatening disaster situation or disaster and the effects thereof.

Prevention[1]: encompasses activities designed to provide permanent protection from disasters. It includes engineering and other physical protective measures, and also legislative measures controlling land-use and urban planning.

---

1 A list of disaster management related terms with their definitions to be included in an internationally agreed multilingual glossary" English Version. Third Draft. UNDRO Sectt., Geneva, Dec. 1981.

2 The Disaster Management Act 2005 (No.53 of 2005), 23rd December, 2005, the Gazette of India Extraordinary, December 26, 2005.

9. REFRENCES

1. "Census of India 2011" - Distribution of Census Houses by Predominant Material of roof, wall and floor of Census Houses.
2. "Census of India 2011" – Population Data.
3. "Flood Atlas of India", Central Water Commission, Ministry of Water Resources, Govt. of India, April 1987.
4. "India and Adjacent Countries, 1:2.5 million Map", Survey of India, 1990.
5. "IS 1893 (Part 1):1984 / 2002 / 2016 - Indian Standard Criteria for Earthquake Resistant Design of Structures – Part 1: General Provisions and Buildings, Bureau of Indian Standards, New Delhi.
6. "IS 875 (Part 3):1987, Code of Practice for Design Loads (other than Earthquake) for Buildings and Structures, Part 3, Wind Loads", Bureau of Indian Standards, New Delhi.
7. "IS 875 (Part 3):2015 – Code of Practice for Design Loads (other than earthquake) for Buildings and Structures, Part 2 Wind Loads by Bureau of Indian Standards, New Delhi.
8. SeismotectonicAtlas of India and its Environs, Geological Survey of India Special Publication No. 59, 2000.
9. Geological Map of India, Seventh Edition, Geological Survey of India, 1998
10. "Cyclonic Storms Crossing 1 degree Latitude Zones of Indian Coasts during the period 1877-1990", P.N. Sen and P.V. Pillai, Pre-published Scientific Report No. 1993/1, IMD, Pune, July 1993.
11. "Probable Maximum Storm Surge on the Coast of India and Bangladesh" by S.K. Ghosh, The Aspects of Mechanics, 1983, pp74-92.
12. PMP Atlases by Central Water Commission and Indian Meteorological Department, 2015 and 2017
13. "Meteorological Monograph, Hydrology", India Meteorological Department, No. 11/1988
14. IS 4326 : 2013 - Earthquake resistant design and construction of buildings - Code of practice
15. IS 13827 : 1993 - Improving Earthquake Resistance of Earthen Buildings – Guidelines (Reaffirmed 2013)
16. IS 13828 : 1993 - Improving Earthquake Resistance of Low Strength Masonry Buildings – Guidelines (Reaffirmed 2013)
17. IS 13920 : 2016 - Ductile Detailing of Reinforced Concrete Structures subjected to Seismic Forces - Code Of Practice
18. IS 13935 : 2009 - Seismic Evaluation, Repair and Strengthening of Masonry Buildings – Guidelines (Reaffirmed 2014)
19. IS 15988 : 2013 - Seismic Evaluation and Strengthening of Existing Reinforced Concrete Building – Guidelines
20. IS 15498:2004 - Guidelines for Improving the Cyclonic Resistance of Low Rise Houses and Other Buildings/Structures, Bureau of Indian Standards, New Delhi, (Reaffirmed 2015).
21. IS 15499:2004 - Guidelines for Survey of Housing and Building Typology in Cyclone Prone Areas for Assessment of Vulnerability of Regions and Post-Cyclone Damage Estimation, Bureau of Indian Standards, New Delhi, (Reaffirmed 2015).
22. Report of the Task Force constituted to examine the causes of the problems of recurring floods and erosion in Assam and other neighboring States as well as Bihar, West Bengal and Eastern Uttar Pradesh, Ministry of Water Resources, Government of India, 2004
23. Cyclone Hazard Prone Districts of India : A Report by G.S.Mandal, National Disaster Management Authority and M.Mohapatra, India Meteorological Department, 2010.
24. Vulnerability Atlas of India, 1997 and 2006

TABLE - 1

Approximate relationships between M, MM intensity and felt area

Earthquake magnitude richter, M	Expected global annual number	Maximum expected intensity MM	Radius of felt area (km)	Felt area (km^2)
4.0 - 4.9	6,200	IV - V	50	7,700
5.0 - 5.9	800	VI - VII	110	38,000
6.0 - 6.9	120	VII - VIII	200	125,000
7.0 - 7.9	18	IX - X	400	500,000
8.0 - 8.7	1	XI - XII	800	2,000,000

Source: Earthquakes by Don de Nevi, Celestial Arts, Calif., May 1977, p.102

TABLE - 2

Relationship of Seismic Intensity, Building Type & Damage Grades

(Ref: MSK Intensity Scale 1964 in Annex D, IS:1893(Part-1)-2002)

Types of Buildings	Zone II (MSK VI or Less)	Zone III (MSK VII)	Zone (MSK VIII)	Zone V (MSK IX or More)
Category A	*Many* of Grade 1 *Few* of Grade 2, (Rest no damage)	*Most* of Grade 3, *Few* of Grade 4, (Rest grade 2 or 1)	*Most* of Grade 4, *Few* of Grade 5, (Rest grade 3 or 2)	*Most* of Grade 5, (Rest grade 4 or 3)
Category B	*Few* of Grade 1, (Rest no damage)	*Many* of Grade 2, *Few* of Grade 3, (Rest grade 1)	*Most* of Grade 3, *Few* of Grade 4, (Rest grade 2)	*Many* of Grade 4, *Few* of Grade 5, (Rest grade 3)
Category C	No damage	*Many* of Grade 1, *Few* of Grade 2, (Rest grade 1 or 0)	*Most* of Grade 2, *Few* of Grade 3, (Rest grade 1)	*Many* of Grade 3, *Few* of Grade 4, (Rest grade 2)

Few: About 5% *Many*: About 50% *Most*: About 75%

Grade 1: Slight damage	Fine cracks in plaster; fall of small pieces of plaster
Grade 2: Moderate damage	Small cracks in plaster; fall of fairly large pieces of plaster, pantiles slip off; cracks in chimneys parts of chimney fall down.
Grade 3: Heavy damage	Large and deep cracks in plaster; fall of chimneys
Grade 4: Destruction	Gaps in walls; parts of buildings may collapse; separate parts of the buildings lose their cohesion; and inner walls collapse.
Grade 5: Total damage	Total collapse of the buildings

TABLE - 3

Houses by Material of Roof in India (Census of India 2011 – Housing Data)

	Total number of census houses	Grass/ Thatch/ Bamboo/ Wood/ Mud, etc.		Plastic/ Polythene		Hand made Tiles		Machine made Tiles		Burnt Brick		Stone/Slate		G.I./ Metal/ Asbestos sheets		Concrete		Any other material	
		No. of Houses	%	No. of Houses	%	No. of Houses	%	No. of Houses	%	No. of Houses	%	No. of Houses	%	No. of Houses	%	No. of Houses	%	No. of Houses	%
Rural	206,563,690	42,727,900	20.7	1,459,766	0.7	34,822,769	16.9	20,092,484	9.7	14,860,852	7.2	19,119,151	9.3	34,381,089	16.6	38,238,079	18.5	861,600	0.4
Urban	98,318,758	4,259,769	4.3	613,607	0.6	5,453,980	5.5	6,332,576	6.4	5,394,029	5.5	7,862,543	8.0	15,955,314	16.2	52,005,804	52.9	441,136	0.4
Total*	304,882,448	46,987,669	15.4	2,073,373	0.7	40,276,749	13.2	26,425,060	8.7	20,254,881	6.6	26,981,694	8.8	50,336,403	16.5	90,243,883	29.6	1,302,736	0.4

Houses by Material of Wall in India

	Total number of census houses	Grass/ Thatch/ Bamboo etc.		Plastic/ Polythene		Mud/ Unburnt brick		Wood		Stone not packed with mortar		Stone packed with mortar		G.I./Metal/ Asbestos sheets		Burnt brick		Concrete		Any other material	
		No. of Houses	%	No. of Houses	%	No. of Houses	%	No. of Houses	%	No. of Houses	%	No. of Houses	%	No. of Houses	%	No. of Houses	%	No. of Houses	%	No. of Houses	%
Rural	206,563,690	26,417,331	12.8	762,256	0.4	58,330,614	28.2	2,132,342	1.0	7,751,666	3.8	20,934,124	10.1	1,269,359	0.6	83,618,436	40.5	3,699,096	1.8	1,648,466	0.8
Urban	98,318,758	2,530,263	2.6	335,575	0.3	8,119,213	8.3	648,929	0.7	2,689,476	2.7	12,107,666	12.3	1,062,510	1.1	62,927,369	64.0	7,284,583	7.4	613,174	0.6
Total*	304,882,448	28,947,594	9.5	1,097,831	0.4	66,449,827	21.8	2,781,271	0.9	10,441,142	3.4	33,041,790	10.8	2,331,869	0.8	146,545,805	48.1	10,983,679	3.6	2,261,640	0.7

Houses by Material of Floor in India

	Total number of census houses	Mud		Wood/ Bamboo		Burnt Brick		Stone		Cement		Mosaic/ Floor tiles		Any other material	
		No. of Houses	%	No. of Houses	%	No. of Houses	%	No. of Houses	%	No. of Houses	%	No. of Houses	%	No. of Houses	%
Rural	206,563,690	127,431,172	61.7	2,088,961	1.0	5,345,565	2.6	12,290,562	6.0	51,436,407	24.9	7,434,415	3.6	536,608	0.3
Urban	98,318,758	11,254,774	11.4	486,629	0.5	2,511,582	2.6	11,685,210	11.9	46,620,799	47.4	24,836,212	25.3	923,552	0.9
Total*	304,882,448	138,685,946	45.5	2,575,590	0.8	7,857,147	2.6	23,975,772	7.9	98,057,206	32.2	32,270,627	10.6	1,460,160	0.5

** Excluding locked/vacant houses*

Note : Percentage (%) is calculated with respect to the respective Total Census Houses given in column one

TABLE - 4

Distribution of Houses by Predominant Materials of Roof and Wall and Level of Damage Risk

INDIA

Wall / Roof		Census Houses: No. of Houses	Census Houses: %	Level of Risk under: EQ Zone (Area in %): V	IV	III	II	Wind Velocity m/s (Area in %): 55 & 50	47	44 & 39	33	Flood Prone Area in %
INDIA				11.3	14.4	31.1	43.2	18.0	30.3	45.1	6.6	7.3
WALL												
A1 - Mud & Unburnt Brick Wall	Rural	58,330,614	19.1									
	Urban	8,119,213	2.7									
	Total	***66,449,827***	***21.8***	*VH*	*H*	*M*	*L*	*VH*	*H*	*M*	*L*	*VH*
A2 - Stone Wall not packed with mortar	Rural	7,751,666	2.5									
	Urban	2,689,476	0.9									
	Total	***10,441,142***	***3.4***	*VH*	*H*	*M*	*L*	*H*	*M*	*L*	*VL*	*VH*
Total - Category - A		***76,890,969***	***25.2***									
B - Burnt Bricks Wall & Stone wall packed with mortar	Rural	104,552,560	34.3									
	Urban	75,035,035	24.6									
	Total	***179,587,595***	***58.9***	*H*	*M*	*L*	*VL*	*H*	*M*	*L*	*VL*	*H/M*
Total - Category - B		***179,587,595***	***58.9***									
C1 - Concrete Wall	Rural	3,699,096	1.2									
	Urban	7,284,583	2.4									
	Total	***10,983,679***	***3.6***	*M*	*L*	*VL*	*VL*	*L*	*VL*	*VL*	*VL*	*L/VL*
C2 - Wood wall	Rural	2,132,342	0.7									
	Urban	648,929	0.2									
	Total	***2,781,271***	***0.9***	*M*	*L*	*VL*	*VL*	*VH*	*H*	*M*	*L*	*H*
Total - Category - C		***13,764,950***	***4.5***									
X - Other Materials	Rural	30,097,412	9.9									
	Urban	4,541,522	1.5									
	Total	***34,638,934***	***11.4***	*M*	*VL*	*VL*	*VL*	*VH*	*H*	*M*	*L*	*VH*
Total - Category - X		***34,638,934***	***11.4***									
TOTAL HOUSES*		**304,882,448**										
ROOF												
R1 - Light Weight Sloping Roof	Rural	79,430,355	26.1									
	Urban	21,269,826	7.0									
	Total	***100,700,181***	***33.1***	*M*	*M*	*L*	*VL*	*VH*	*VH*	*H*	*M*	*VH*
R2 - Heavy Weight Sloping Roof	Rural	74,034,404	24.3									
	Urban	19,649,099	6.4									
	Total	***93,683,503***	***30.7***	*H*	*M*	*L*	*VL*	*H*	*M*	*L*	*VL*	*H*
R3 - Flat Roof	Rural	53,098,931	17.4									
	Urban	57,399,833	18.8									
	Total	***110,498,764***	***36.2***	*Damage Risk as per that for the Wall supporting it*								
TOTAL HOUSES*		**304,882,448**										

Housing Category : Wall Types

Category - A : Buildings in field-stone, rural structures, unburnt brick houses, clay houses

Category - B : Ordinary brick building; buildings of the large block & prefabricated type, half-timbered structures, building in natural hewn stone

Category - C : Reinforced building, well built wooden structures

Category - X : Other materials not covered in A,B,C. These are generally light.

Notes *: 1. Flood prone area includes that protected area which may have more severe damage under failure of protection works. In some other areas the local damage may be severe under heavy rains and chocked drainage.*

2. Damage Risk for wall types is indicated assuming heavy flat roof in categories A, B and C (Reinforced Concrete) building

3. Source of Housing Data : Census of Housing, GOI, 2011

Housing Category : Roof Type

Category - R1 - Light Weight (Grass, Thatch, Bamboo, Wood, Mud, Plastic, Polythene, GI Metal, Asbestos Sheets, Other Materials)

Category - R2 - Heavy Weight (Tiles, Stone/Slate)

Category - R3 - Flat Roof (Brick, Concrete)

EQ Zone V : Very High Damage Risk Zone (MSK > IX)

EQ Zone IV : High Damage Risk Zone (MSK VIII)

EQ Zone III : Moderate Damage Risk Zone (MSK VII)

EQ Zone II : Low Damage Risk Zone (MSK < VI)

Level of Risk : VH = Very High; H = High; M = Moderate; L = Low; VL = Very Low

* Total No.of Houses excluding Vacant/Locked Houses

TABLE - 5

Damage Risk to Housing under Various Hazard Intensities

Category Type of Wall		Level of Risk								
		Seismic Zone				Wind Velocity m/s				Flood Prone
		V	IV	III	II	55 & 50	47	44 & 39	33	
A1	Mud and Unburnt Brick	VH	H	M	L	VH	H	M	L	VH
A2	Stone Wall	VH	H	M	L	H	M	L	VL	VH
B	Burnt Bricks Wall	H	M	L	VL	H	M	L	VL	H/M
C1	Concrete Wall	M	L	VL	VL	L	VL	VL	VL	L/VL
C2	Wood wall	M	L	VL	VL	VH	H	M	L	H
X	Other Materials	M	VL	VL	VL	VH	H	M	L	VH
Category Type of Roof										
R1	Light Weight Sloping Roof	M	M	L	VL	VH	VH	H	M	VH
R2	Heavy Weight Sloping Roof	H	M	L	VL	H	M	L	VL	H
R3	Flat Roof	Damage Risk as per that for the Wall supporting it								

Building Category : (By Wall Material)

Category - A : Buildings in field-stone, rural structures, unburnt brick houses, clay houses

Category - B : Ordinary brick building; buildings of the large block and prefabricated type, half-timbered structures, building in natural hewn stone

Category - C : Reinforced concrete building, well built wooden structures

Category - X : Other materials not covered in A,B,C. like light sheets and biomass materials

Note : Damage Risk is indicated assuming heavy flat roof in cases A, B and C (Reinforced Concrete) building

Building Category : (By Roof Material)

Category - R1 : Light Weight Sloping Roof (Grass, Thatch, Bamboo, Wood, Mud, Plastic, Polythene, GI Metal, Asbestos Sheets, etc)

Category - R2 : Heavy Weight Sloping Roof (Tiles, Stone/Slate)

Category - R3 : Flat Roof (Brick, Concrete)

EQ Zone V : Very High Damage Risk Zone (MSK > IX)

EQ Zone IV : High Damage Risk Zone (MSK VIII)

EQ Zone III : Moderate Damage Risk Zone (MSK VII)

EQ Zone II : Low Damage Risk Zone (MSK < VI)

Level of Risk : VH = Very High; H = High; M = Moderate; L = Low; VL = Very Low

Notes:

1. *Flood prone area includes that protected area which may have more severe damage under failure of protection works. In some other areas the local damage may be severe under heavy rains and chocked drainage.*
2. *Source of Housing Data : Census of Housing, GOI, 2011*

TABLE - 5A

Damage Risk to Housing under various Hazard Intensities

Category (Type of Wall and Roof)	EQ Intensity MSK				Wind Velocity m/s				Flood Prone
	≥IX	VIII	VII	≤VI	55 & 50	47	44 & 39	33	
A1. Mud wall (All roofs)	VH	H	M	L	VH	H	M	L	VH
A2.a. Unburned Brick Wall (Sloping roofs)	VH	H	M	L	VH	H	M	L	VH
A2.b. Unburned Brick Wall (Flat roofs)	VH	H	M	L	VH	H	M	L	VH
A3.a. Stone Wall (Sloping roofs)	VH	H	M	L	VH	H	M	L	VH
A3.b. Stone Wall (Flat roofs)	VH	H	M	L	H	M	L	L	VH
B.a. Burned Brick Wall (Sloping roofs)	H	M	L	VL	H	M	M	L	H
B.b. Burned Brick Wall (Flat roofs)	H	M	L	VL	M	L	L	VL	H
C1.a. Concrete Wall (Sloping roofs)	M	L	VL	NIL	H	M	M	L	L
C1.b. Concrete Wall (Flat roofs)	M	L	VL	NIL	L	VL	VL	VL	L
C2. Wood Wall (All roofs)	M	L	VL	NIL	VH	H	M	L	H
C3. Ekra wall (All roofs)	M	L	VL	NIL	VH	H	M	L	H
X1 GI and other metal sheets (All roofs)	M	VL	NIL	NIL	VH	H	M	L	H
X2 Bamboo, Thatch, Grass, Leaves, etc. (All roofs)	M	VL	NIL	NIL	VH	VH	H	L	VH

Building Category

Category - A : Buildings in field-stone, rural structures, unburnt brick houses, clay houses

Category - B : Ordinary brick buildings, building of the large block and prefabricated type, half-timbered structures, building in natural hewn stone

Category - C : Reinforced building, well built wooden structures

Category - X : Other types not covered in A, B, C. These are generally light.

TABLE - 6

Distribution of Houses by Predominant Materials of Roof and Wall and Level of Damage Risk

Table No. : OR 10 **State : ODISHA** **KENDRAPARA**

Wall / Roof		Census Houses: No. of Houses	Census Houses: %	Level of Risk under: EQ Zone V	EQ Zone IV	EQ Zone III	EQ Zone II	Wind Velocity m/s 55 & 50	47	44 & 39	33	Flood Prone Area in %
				Area in %				Area in %				
						87.0	13.0	100				48.4
WALL												
A1 - Mud & Unburnt Brick Wall	Rural	237,793	56.4									
	Urban	6,136	1.5									
	Total	***243,929***	***57.9***			*M*	*L*	*VH*				*VH*
A2 - Stone Wall not packed with mortar	Rural	976	0.2									
	Urban	38	-									
	Total	***1,014***	***0.2***			*M*	*L*	*H*				*VH*
Total - Category - A		***244,943***	***58.1***									
B - Burnt Bricks Wall & Stone wall packed with mortar	Rural	139,540	33.1									
	Urban	14,240	3.4									
	Total	***153,780***	***36.5***			*L*	*VL*	*H*				*H/M*
Total - Category - B		***153,780***	***36.5***									
C1 - Concrete Wall	Rural	1,451	0.3									
	Urban	286	0.1									
	Total	***1,737***	***0.4***			*VL*	*VL*	*L*				*L/VL*
C2 - Wood wall	Rural	3,866	0.9									
	Urban	434	0.1									
	Total	***4,300***	***1.0***			*VL*	*VL*	*VH*				*H*
Total - Category - C		***6,037***	***1.4***									
X - Other Materials	Rural	16,090	3.8									
	Urban	680	0.2									
	Total	***16,770***	***4.0***			*VL*	*VL*	*VH*				*VH*
Total - Category - X		***16,770***	***4.0***									
TOTAL HOUSES*		**421,530**										
ROOF												
R1 - Light Weight Sloping Roof	Rural	289,583	68.7									
	Urban	10,984	2.6									
	Total	***300,567***	***71.3***			*L*	*VL*	*VH*				*VH*
R2 - Heavy Weight Sloping Roof	Rural	4,484	1.1									
	Urban	456	0.1									
	Total	***4,940***	***1.2***			*L*	*VL*	*H*				*H*
R3 - Flat Roof	Rural	105,649	25.1									
	Urban	10,374	2.5									
	Total	***116,023***	***27.6***	*Damage Risk as per that for the Wall supporting it*								
TOTAL HOUSES*		**421,530**										

Probable Maximum Precipitation at a Station of the district in one day for arial extent of 1000 sqm. **716 mm**

Housing Category : Wall Types

Category - A : Buildings in field-stone, rural structures, unburnt brick houses, clay houses

Category - B : Ordinary brick building; buildings of the large block & prefabricated type, half-timbered structures, building in natural hewn stone

Category - C : Reinforced building, well built wooden structures

Category - X : Other materials not covered in A,B,C. These are generally light.

Notes *: 1. Flood prone area includes that protected area which may have more severe damage under failure of protection works. In some other areas the local damage may be severe under heavy rains and chocked drainage.*

2. Damage Risk for wall types is indicated assuming heavy flat roof in categories A, B and C (Reinforced Concrete) building

3. Source of Housing Data : Census of Housing, GOI, 2011

Housing Category : Roof Type

Category - R1 - Light Weight (Grass, Thatch, Bamboo, Wood, Mud, Plastic, Polythene, GI Metal, Asbestos Sheets, Other Materials)

Category - R2 - Heavy Weight (Tiles, Stone/Slate)

Category - R3 - Flat Roof (Brick, Concrete)

EQ Zone V : Very High Damage Risk Zone (MSK > IX)

EQ Zone IV : High Damage Risk Zone (MSK VIII)

EQ Zone III : Moderate Damage Risk Zone (MSK VII)

EQ Zone II : Low Damage Risk Zone (MSK < VI)

Level of Risk : VH = Very High; H = High; M = Moderate; L = Low; VL = Very Low

* Total No.of Houses excluding Vacant/Locked Houses