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by

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TECHNICAL PAPER

Seismic risk assessment of reinforced concrete buildings in Koyna-Warna region through EDRI method

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Abstract

The Koyna-Warna region of Maharashtra, India, is one of the most significant worldwide examples for reservoir-induced seismicity. The area is highly vulnerable to earthquakes, and it has experienced over 1 lakh number of shocks since 1963. The largest known earthquake of magnitude 6.5 (Richter scale) occurred on 10th December 1967. Many low and moderate earthquake events have occurred over the past 50 years. A structured survey using rapid visual screening was carried out for existing RC buildings. The seismic risk index depends on three parameters, viz. hazard, exposure, and vulnerability. Many existing RC buildings in the Koyna-Warna region are designed to resist the gravity loads only without any seismic resistant provisions. Hence, there is a need to study the risk index of these RC buildings to assess future serious risks. In this study, the rapid visual survey of 120 existing RC buildings has been done through a modified EDRI method (Earthquake Disaster Risk Index) to evaluate the seismic risk index of the Koyna-Warna region (Zone-IV as per IS: 1893–2016). The results depict that the risk index of RC buildings in the Koyna-Warna region is in severe damage condition and hence there is a need to take an initiatives for earthquake preparedness plan, with emphasis on retrofitting measures, to reduce the loss of human life and damage to physical infrastructure in future seismic events.

Keywords RVS · EDRI · Risk index · Seismicity · Koyna-Warna region

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Abbreviations

R Risk index
H Hazard
V Vulnerability
E Exposure

Introduction

India has experienced several devastating earthquakes in the past resulting in massive damage to the RC buildings and huge number of deaths [1–5]. In India, most of the RC buildings are non-engineered constructed based on the thumb rule basis and also are not designed to resist seismic forces [1, 2]. The Indian subcontinent has suffered some great earthquakes with a magnitude exceeding 8.0, so there is a need to address the safety of our built environment [2]. The term seismic risk consists of the combined effect of three components as shown in Fig. 1: (1) Seismic hazard means shaking of the ground, (2) structural vulnerability means how the buildings are weakened to resist the lateral load, and (3) exposure means how many people get exposed to seismic

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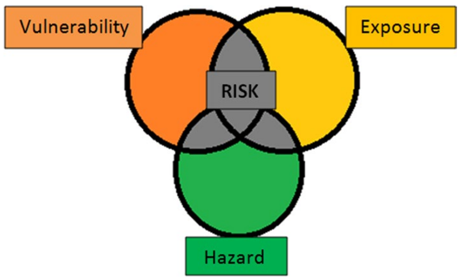


Fig. 1 Seismic risk assessment

hazard. Exposure incorporates the two terms: importance factor and FSI (Floor Space Index) of the building [6]. The vulnerability and exposure terms are more significant cause to increase the risk profile of the region.

Rai [7] has reviewed various methods for seismic evaluation of existing buildings which are available in the literature. The documents from the USA, New Zealand, India, Europe, and UNDP projects have been studied, and a comparison is made based on the fundamental concepts of evaluation processes. FEMA 310 [8] is the handbook for seismic evaluation of buildings developed by the USA. This document described the three-tier process for evaluation: (1) screening phase, (2) evaluation phase, and (3) detailed evaluation phase. NZDC (New Zealand Draft Code) begins with a rapid evaluation procedure, which is based on a visual screening procedure, and it can be carried out from external viewing of the building. The damage potential of the buildings is indicated by structural score through RVS. A detailed structural assessment has been performed at the component level. SERC (Structural Engineering Research Center) report has given guidelines for the assessment of existing buildings for both masonry and reinforced concrete structures. The assessment begins with RVS test. Two types of scores have been used, viz. basic structural score, and structural score modifier. The procedure is similar to FEMA-310, but demand base shear is different based on different response reduction factors. UNIDO (United Nations Industrial Development Organization, 1985) document examines the existing structure for the aspects of principles of a good structural concept. Based on the value of the *R*-index, structures are classified in different categories and strengthening has been done. ASCE/SEI 31–03 provides a standard procedure for the evaluation of existing buildings similar to FEMA-310.

Mishra [9] worked on guidelines regarding rapid visual screening of buildings for seismic hazard. In this book, author described the seismic safety features of both masonry and RC buildings. This book is developed based on the TARU's experience of conducting a vulnerability assessment of different buildings. The author explained the integrated RVS of buildings, which includes building name and address, building types, function, built-up area, age of the building, etc. The RVS score evaluation is based on many parameters like building height, frame action, pounding effect, structural integrity, diaphragm action, etc. Each component has some weightage to get the performance score of the building. Also, the preliminary vulnerability assessment procedure explained in detail includes the collection of drawings, identification of the sizes of structural members, load calculation; strength related checks, etc., and for the detailed assessment requires modelling the selected building by using the finite element method or applied element method to study the behaviour of buildings.

Patil [10] worked on rapid visual screening of existing buildings in Pophali village. During the Koyna earthquake (1967), the Pophali village was greatly affected by the earthquake vibration. The data collection form has been filled based on visual observation of building parameters like storey height, irregularity, short column, pounding effect, etc. The RVS method developed by Jain and Mitra [3] was utilized for this study. From this study, authors concluded that total 31 buildings require detailed evaluation out of 55 for its further use and 24 buildings do not require any detailed evaluation at the current stage based on RVS score of the buildings.

Tesfamariam et al. [11] worked on seismic risk assessment of RC buildings using fuzzy rule-based (FRB) modelling. In this study, walk down survey is handled through fuzzy set theory. The proposed method is illustrated through the use of Bingol Earthquake (2003) damage observations. In this paper, the basic risk parameters for building vulnerability assessment have been adopted: (i) building type, (ii) vertical irregularity, (iii) plan irregularity, (iv) year of construction, and (v) construction quality. The authors concluded that the FRB modelling of the Bingol earthquake (2003) shows a good correlation with observed damage. The proposed method has to be implemented in a GIS-based platform to capture spatial variability.

Haldar et al. [12] worked on capacity curve parameters for Indian RC-infilled buildings. The parametric study is carried out for low rise, mid-rise, and high-rise buildings. The buildings are classified into three stages as (a) designed for gravity load only, (b) designed for earthquake load, OMRF case, and (c) designed for earthquake load, SMRF case. The nonlinear static analysis has been performed in SAP-2000 to calculate capacity curve parameters. These parameters have been implemented in the seismic risk assessment tool 'SeisVARA'. Capacity spectrum parameters (S_{d}, S_{a}) at yield and ultimate point have been evaluated for vulnerability assessment.

El-Betar [13] worked on the seismic vulnerability of two existing RC buildings in Egypt. The two case studies were selected for seismic evaluation purposes as (1) Old school building and (2) New School building after 1990. The rapid evaluation procedure is based on FEMA P-154. ASCE 41–13 [14] includes three tiers of seismic evaluation as (1) Tier 1—screening phase, (2) Tier 2—deficiency-based evaluation procedure, (3) Tier 3—systematic evaluation. From this study, the authors concluded that the priority of evaluation should be given for the old and non-engineered buildings in high seismic regions. An old school building shows more vulnerable under high seismic load.

The attempts were made in the past to develop the earthquake vulnerability assessment methodologies by considering physical, social, and economical parameters. The first significant effort of developing the risk index was started by the USA, where apart from physical risk, the effect of social fragility and resilience of the society also were considered in defining the overall risk [15]. Various methodologies have been developed to define the disaster risk index at different levels internationally. The urban earthquake risk, buildings, lifelines, transportation and infrastructure have been incorporated by Federal Emergency Management and Agency (FEMA) in developing software, HAZUS (FEMA-NIBS 1999). However, the methodology suggested by HAZUS is complicated for urban earthquake risk assessment approach, and its application is limited to the American physical and social conditions. Relative Seismic Risk Index method applied in the Tehran city of Iran is another holistic seismic risk assessment approach proposed for urban areas. The proposed approach estimates the risk indicator associated with each parameter as a product of vulnerability factor and hazard factor. As per the Davidson [15], the main contributing factors, namely: hazard, exposure, vulnerability, external context, emergency response and recovery capability, are important to evaluate the earthquake disaster risk. As compared to other international methods, the present modified EDRI method contains the major contributing factors, namely: hazard, vulnerability and exposure of the particular region/city are more suitable and sufficient for the Indian context [6].

Murthy et al. [16] observed damages in RC buildings due to open ground stories, short columns, irregular configurations, etc. An important feature of the RC buildings in Ahmedabad was a highly irregular pattern of column placement, leading to a lack of frame action of the structural system. During the Koyna earthquake (10th December 1967), more than 80% of the houses were damaged in Koyananagar township, around 180 deaths occurred, and over 2,200 people were also injured, a and minor damage (cracks) was observed on the concrete gravity dam [6].

In this study, we have discussed the damage condition and observed deficiencies of RC-buildings in the Koyna-Warna region through a modified EDRI method and suggested a seismic risk mitigation plan for future unpredictable seismic activities.

Koyna-Warna region

Seismic activities have been experiencing continuously for more than 50 years in the Koyna-Warna region (Zone-IV as per IS: 1893–2016. There have been 9 earthquakes of $M > 5$, about 96 earthquakes of $4 \leq M < 5$, and thousands of smaller earthquakes since 1963 [17]. Understanding the seismic activity in the Koyna-Warna region is important because the region has been experiencing continuous earthquakes since 1963. A lot of research is going on the geophysical part, but there is a need to study: the effect of seismic activity on the built environment. The map of Koyna-Warna seismic region is shown in Fig. 2.

The above map describes the Koyna-Warna seismic zone. The triangles show the locations of the seismograph, diamonds show the major geographic features nearby towns, and tomoDD-determined epicentres. The inset shows outlines of India and the State of Maharashtra (MS) [18]. There are 30 villages surveyed in Koyna-Warna region for the risk assessment study based on the map of Koyna-Warna region.

Risk assessment methodology

EDRI (Earthquake Disaster Risk Index) method was modified by NDMA (National Disaster Management Authority), Govt. of India, to suite the Indian conditions, and it has been used for the risk assessment of Koyna-Warna region based on rapid visual screening of individual building. In this study, the risk assessment part is related to reinforced concrete buildings.

Risk index (R) is a product of seismic hazard (H), exposure (E), and vulnerability (V). Out of these exposure and vulnerability are the controllable pre-earthquake factors because exposure is in the hand of government bodies like municipalities and vulnerability is in the hand of architects and engineers.

$$\text{Risk } (R) = H \times V \times E \tag{1}$$

Hazard is divided into two sub-factors, namely collateral hazard and ground shaking as shown in Fig. 3. Similarly, the vulnerability parameter is divided into two sub-factors, viz. Life-Threatening Factors (LTF) and Economic Loss Inducing Factors (ELIF) as shown in Fig. 4. Life-Threatening Factors are directly related to the life loss, and Economic Loss Inducing Factors are related to expected damage in the building. The procedure for risk calculation of individual structure involves a set of questions related to siting issues, soil and foundation condition, architecture features, structural aspects and construction details. Each question has a particular weightage based on its importance and remaining parameter namely, exposure depends on the importance factor and FSI (Floor Space Index) of building as shown in Fig. 5. The risk is estimated for individual RC building through the EDRI method in a Koyna-Warna region, and finally, risk index of the Koyna-Warna region is evaluated using the total number of buildings in that area. The 0.4 risk

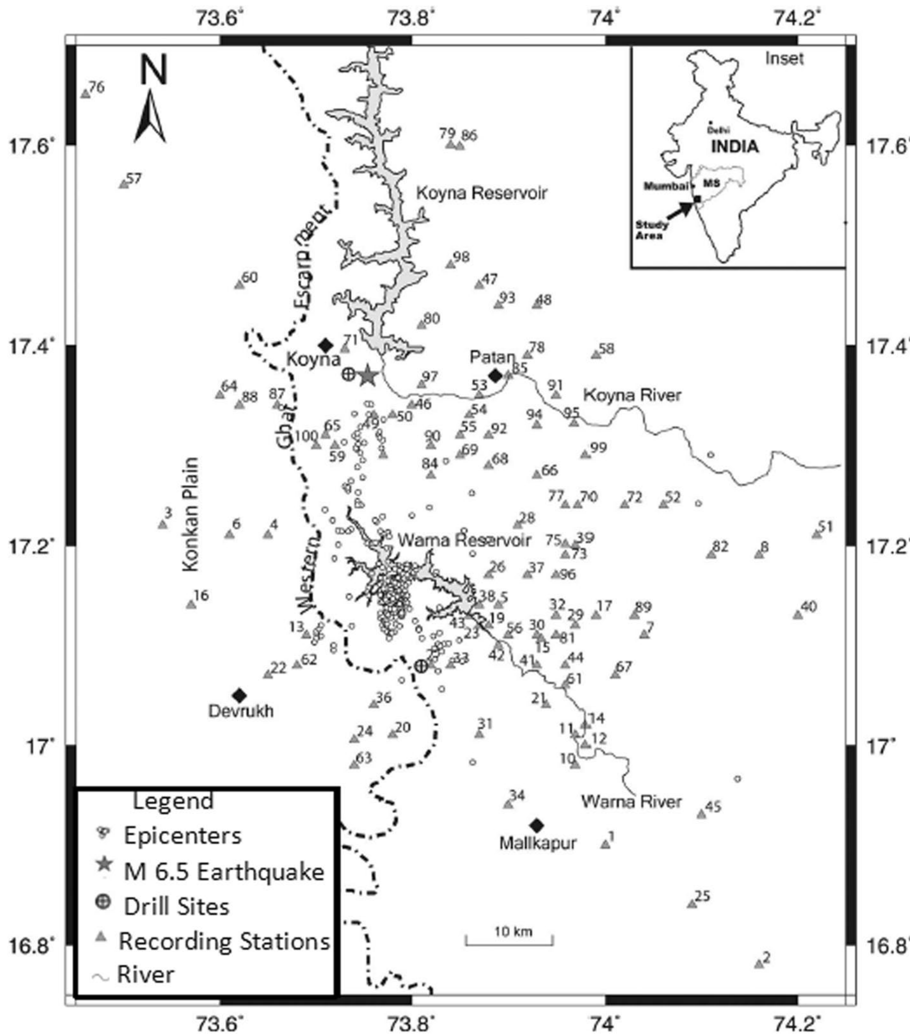


Fig. 2 Map of the Koyna-Warna seismic region [18]

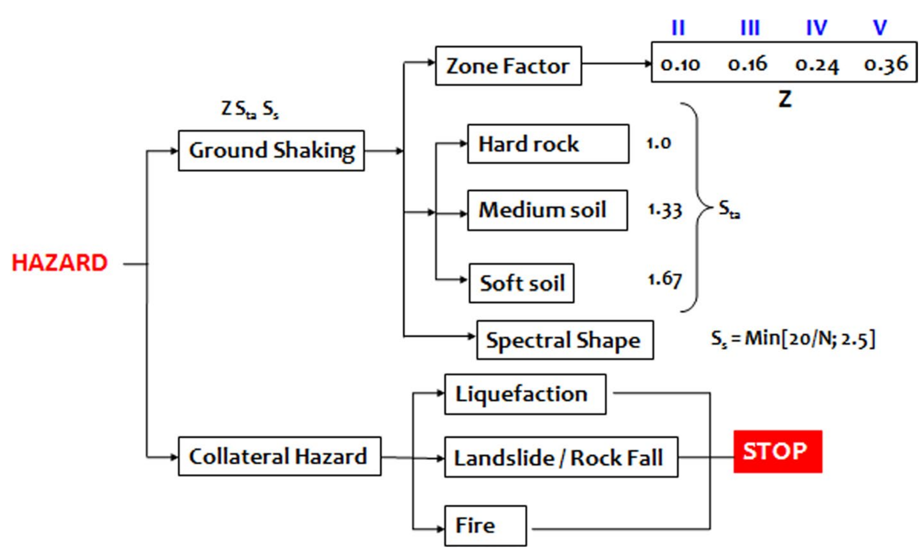


Fig. 3 Flowchart of hazard parameter [6]

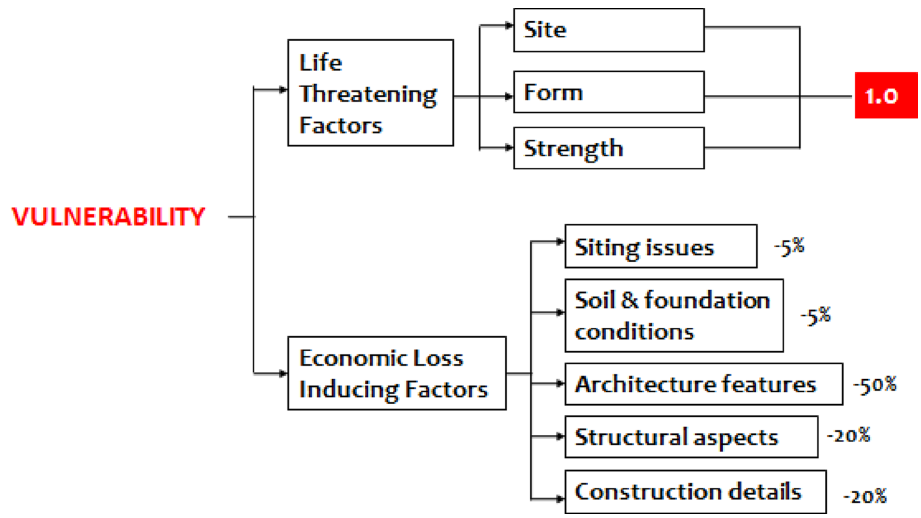


Fig. 4 Flowchart of vulnerability parameter [6]

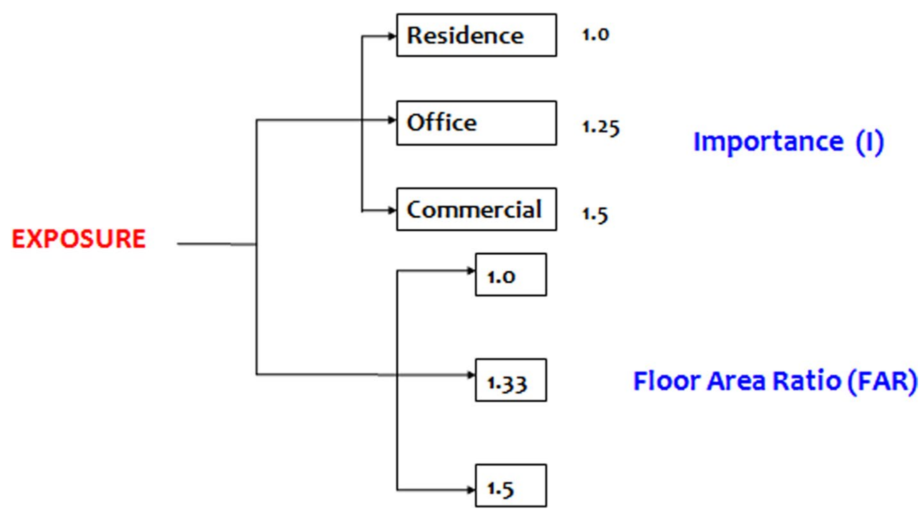


Fig. 5 Flowchart of exposure parameter [6]

Table 1 Correlation of risk index with level of damage [6]

Risk index	Level of damage
0.0–0.2	No damage
0.2–0.4	Slight damage
0.4–0.6	Moderate damage
0.6–0.8	Severe damage
0.8–1.0	Collapse

index number is the alarming number for further evaluation of buildings. The correlation between risk index and type of damage is shown in Table 1.

1. EDRI of Koyna-Warna region for RC buildings

$$\mathrm{EDRI}_{\text{konya - warna}} = \frac{N_1R_{b1} + N_2R_{b2} + \ldots + N_TR_{bT}}{N_1 + N_2 + \ldots + N_T}$$

N_1 = Number of buildings of typology 1(Reinforced Concrete).

R_{b1} = Average of risks of buildings of typology 1(Reinforced Concrete).

General context of field survey

There are 120 reinforced concrete buildings surveyed in the Koyna-Warna region. They involved one-storey, two-storey, and three-storey buildings. Most of the buildings are in pitched roof shapes due to heavy rainfall condition. In this field study, we have covered a total 30 villages from three districts, viz. (1) Satara, (2) Sangli and (3) Ratnagiri around Koyna-Warna region based on the epicentre map. The name of the villages are: Koynanagar colony, Goshtwadi, Rammala, Chafer (Mirgaon), Karate, Helwak, Kadoli, Taloshi, Waghane, Devghar, Gavare, Nav, Gothane, Maneri, Lendhori, Kille-Morgiri, Gunjale, Nehmbe-chirambe, Humbarli, Kamargaon, Chandoli, Charan, Arala, Shedgewadi, Mandure, Pophali, Taliye, Sangamnagar, Wanjoli and Patan Town. While doing the surveying of each building, we have taken the photographs and noted the structural and construction deficiencies. Also, we have conducted the rebound hammer test on different columns to get present material strength and measured the column and beam dimensions to check the current construction practice in an earthquake prone area. To calculate the FSI of building, the built-up area and plot area of buildings are measured and finally, the data collection form (RVS form) has been filled based on the visual observation of the building. The sample buildings of the Koyna-Warna Region are shown in Fig. 6.

Common construction and structural deficiencies and associated damages in RC buildings

The construction of RC buildings had started after 1985. Even though the RC construction was started in the early 1985, the engineered buildings are observed in only government quarters as per the design drawing and visual observation. Almost 80% of existing RC buildings are either owner-built constructions constructed with the help of contractors by using thumb rules based on the discussion with owners, contractors and engineers. In the Koyna-Warna region, the reinforced concrete buildings are constructed up to three-storey height due to regional seismicity. Most of the buildings are being designed and built for gravity load only. Architects play a major role in the design of buildings in this earthquake prone area. The government buildings follow the earthquake resistant design philosophy. Most of the commercial buildings do not follow the FSI (Floor Space Index) rules as per the measured dimensions. The Koyna-Warna region is a hilly area so it is risky to construct mid-rise and high-rise buildings. All the government buildings constructed in this area are mostly single/double storey. Non-structural element, i.e. shade, is provided on the roof of each RC building. Common structural and construction deficiencies and associated damages as observed during the field visit are summarized in the following sections.

Soft storey

As we know, soft-storey (Open ground storey) failure in RC building is one of the major structural deficiencies. Most of the soft-storey RC buildings have collapsed during the Bhuj earthquake (2001), and hence, these buildings are more dangerous in earthquake-prone area due to the absence of infills at ground storey. In soft-storey RC building, the ground storey is to be kept open for car parking purpose. In the field study, it was observed that one of the RC buildings is a soft-storey building present in such an earthquake-prone area (Patan town) shown in Fig. 7 and it is more vulnerable to earthquakes. The column dimension is 250 × 375 mm. As per the IS 13920: 2016 (ductile detailing code) minimum dimension of column shall not be less than 300 mm. Here we observed most of all columns having a minimum dimension are 250 mm which is not good for the building.

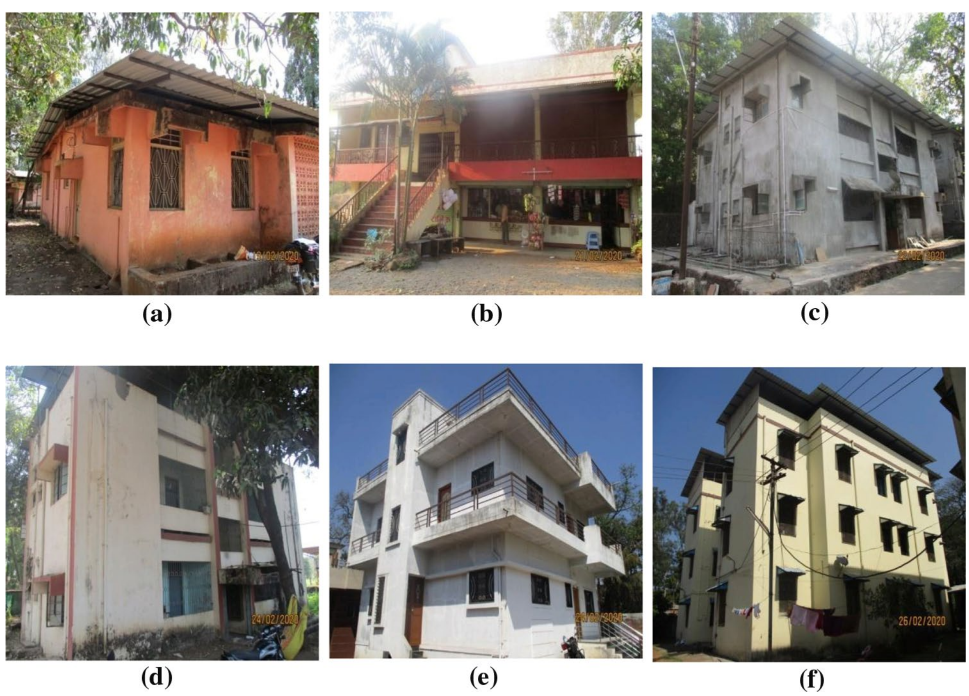


Fig. 6 Sample buildings of Koyna-Warna region

Fig. 7 Open ground storey RC building constructed in Patan town

Vegetation on building

Vegetation on the building is one of the deficiencies. In the field study, we have observed that vegetation occurred on the roof, chajja, wall, etc., due to the heavy rainfall in this particular region as well as drainage pipe leakage. Initially, this vegetation seems to be in green colour after a few months it appears to in brown colour and ultimately it converts into black colour. This vegetation may lead to the carbonation of concrete. The owner should keep maintenance of the building periodically to avoid such conditions. In this study, we observed such deficiency on many buildings as shown in Fig. 8.

Deterioration of structural elements

Structural elements are very important to maintain the structural integrity of the building. In the field study, we have observed the damage condition of structural members like spalling of cover concrete, corrosion of reinforcement, etc. In many of the constructions, the inadequate concrete cover is provided, so due to less concrete cover provision reinforcements are exposed and corroded. Similarly, in the case of slab we observed reinforcements are corroded and exposed out due to many of the reasons, namely material deterioration due to environmental condition, poor quality of material and workmanship, also provision of less concrete cover, etc. In this study, we have seen the concrete cover provided to the column is around 20 mm as shown in Fig. 9 (b), and as per codal provisions, it should be 40 mm. So the structural failure is like a nightmare and it haunts the construction industry.

Fig. 8 Growth of vegetation on roof, chajja, wall and parapet wall

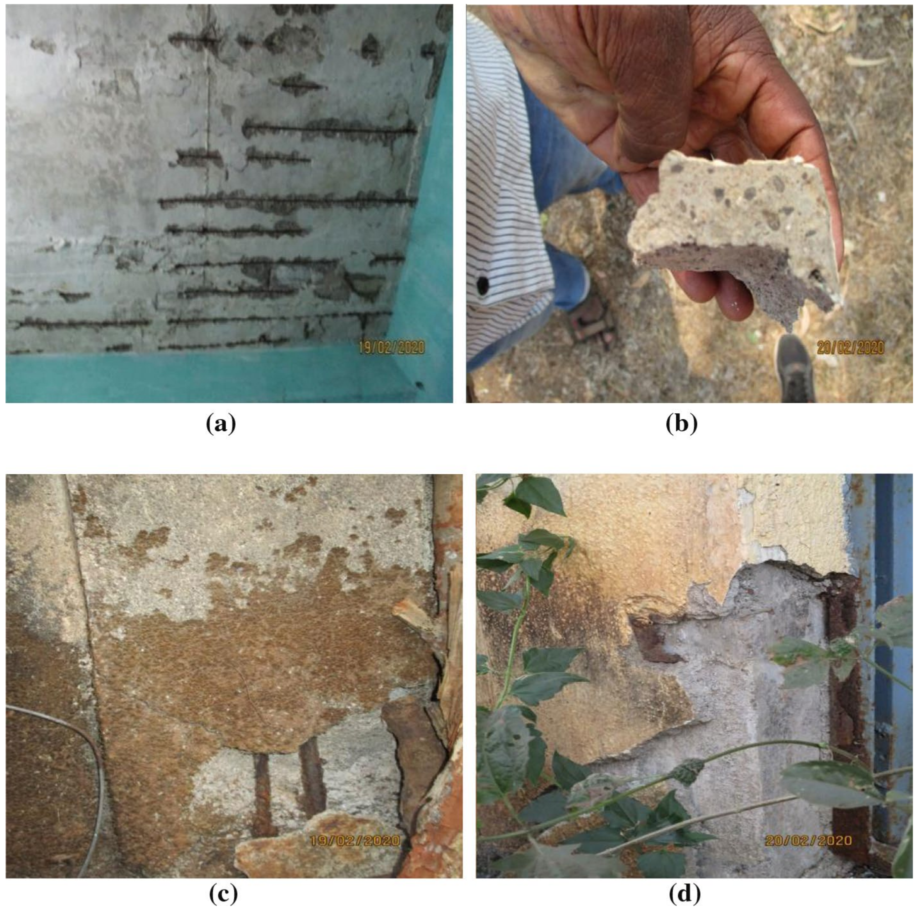


Fig. 9 **a** Reinforcement are exposed in slab, **b** Sample of cover concrete of column, **c** Corrosion of reinforcement, **d** Spalling of cover concrete

Building asymmetry and other deficiencies

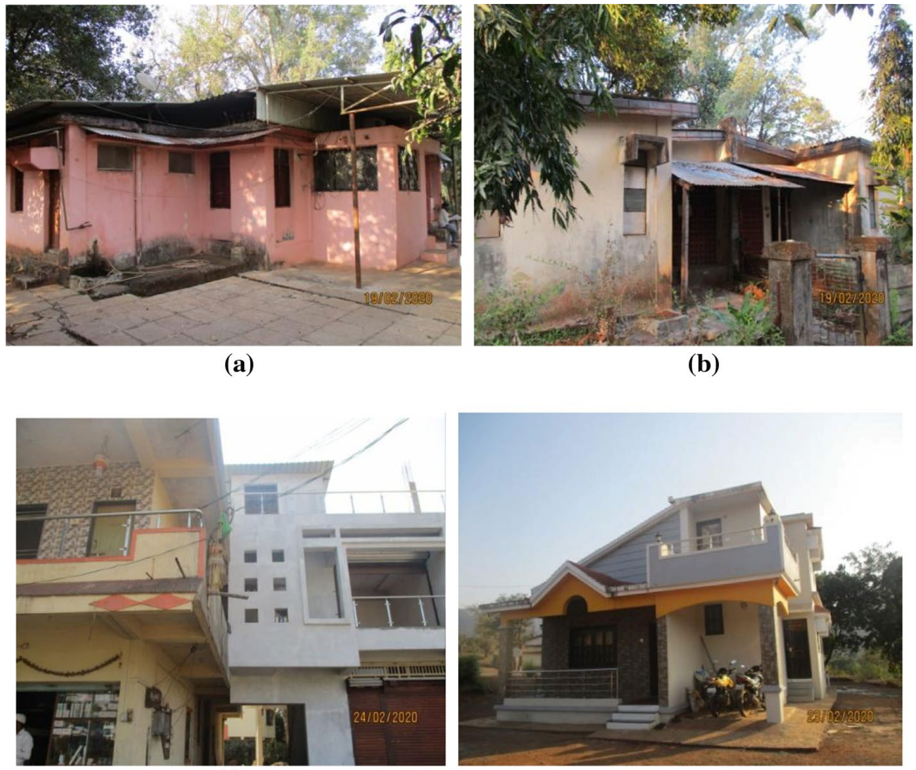
As we know, the geometrical configuration of the building is very important from earthquake point of view. As per Fig. 10, we have observed buildings having both plan irregularity and vertical irregularity. To avoid the torsion effect, the building must be symmetric in plan and should not have vertical irregularities. Also, the reentrant corners are present in most of the buildings. In Koyna-Warna region, all the buildings are in a pitched roof due to heavy rainfall condition. Also few buildings are in split roof condition which is not good from earthquake point of view. Frames don't have symmetric lateral stiffness along both plan direction in most of the cases based on the observation. Few buildings are touching each other, and so, there may be a possibility of pounding effect in future earthquake event.

Cracks in building

Crack propagation is the starting point for the failure of any structure. In this field study, we have observed many different kinds of cracks in the buildings. Out of that few are structural (> 2 mm) and the remaining are non-structural crack (< 2 mm). Many columns of buildings are observed with a structural crack in which most probably diagonal shear crack due to inadequate stirrups spacing. Peeling of plaster on the wall was observed due to dampness**.** Shrinkage cracks are also observed on the wall. Horizontal crack propagation below the slab was observed due to the deflection of the slab or corrosion of reinforcement in the beam. Vertical cracks were observed at the junction of wall and column due to improper bond between the frame and infill. Shear cracks were observed at the corner of the opening for windows due to the concentration of stresses. All the observed cracks are shown in Fig. 11.

Settlement of buildings

Settlement of a building is a geotechnical problem. In the field study, we have observed that one commercial building is constructed in the hilly region and behind the portion of a building was the valley region. The backside ground portion of the building is settled moderately due to loss of strength of soil. So the corner column foundation is slightly



(a) (b) (c) (d)

Fig. 10 **a** Reentrant corner present in split roof structure, **b** Pitched roof structure, **c** Two RC buildings connected with each other, **d** Irregular structure

damaged and the temporary constructed infill wall is damaged completely. The major crack was propagated through the ground due to the settlement problem. This building is most vulnerable in a future earthquake event. The failure of a building is shown in Fig. 12.

Reinforcement in structural members

Reinforcement is the most important building material. In field study, we have observed that reinforcement bars are kept open at the terrace as well as roof level in most of the buildings, so the bars get corroded due to contact with the environment. Stirrups bend provision in column and beam is 90° based on the discussion with local engineers and contractors. As per the ductile detailing code, stirrups should be bent in 135°. Relevant pictures of the reinforcements are shown in Fig. 13.

Results and Discussion

The major findings of the seismic risk assessment study are summarized here. A sample data collection form (RVS form) filled duly is presented in "Appendix 1". The risk of the RC buildings in Koyna-Warna region (seismic Zone IV) is discussed in detail. These results are expected to help in identifying the need for retrofitting the buildings located in such an earthquake-prone area. The risk of all the surveyed buildings is evaluated. Finally, the score (risk index) collected over sample buildings (120) has been extrapolated to all RC buildings in the Koyna-Warna region. A calculation of hazard, exposure, vulnerability and risk of all RC moment resistant frame (MRF) buildings is presented in Table 2.

Justification for the risk assessment (EDRI) result

The building (No. 24) presented in the paper is a residential ordinary moment-resisting RC framed building (Fig. 14), located in Zone IV (Koyna-Warna Region) as per IS 1893 Part-1:2016 code. The building was constructed in 1990. Figure 15 shows the floor plan of the building. The building is a single-storied pitched roof building. The height of the roof is 4.25 m from the ground level. The plan dimensions of the building are 11.9 m × 4.04 m. The construction drawing specifies that M15 grade of concrete and Fe 415 grade of steel were used for the construction. The floor slabs in the building were assumed to act as rigid diaphragms. The seismic weight and design base shear of the existing building are 1753.16 kN and 15.31 kN, respectively. The response reduction factor and importance factor are 3 and 1, respectively, based on the frame system and its function. The spectral acceleration coefficient is 2.5. The plinth beam is considered

Fig. 11 **a** Pop out of plaster, **b** horizontal crack propagate below the slab, **c** Shear crack at the corner of window, **d** Shrinkage cracks on wall, **e** Diagonal shear crack on column, **f** Crack on the junction of column and wall

in the modelling located at ground level (1.5 m above from footing). The stiffness for columns and beams was taken as 0.7EI and 0.5EI, respectively, for accounting the cracks in members as per IS 15988:2013 code. The plan and model of the building is shown in Figs. 15 and 16, respectively. Tables 3 and 4 show the column and beam dimensions, respectively.

Pitched roof structures are generally more vulnerable as compared to plane roof structures in earthquake-prone areas due to their less in-plane stiffness of slab. There is a need to seismically assess the single-storey RC existing building due to its common construction and structural deficiencies, namely reentrant corners, pitched roof, structural distress ike cracking of structural elements, spalling of cover concrete, etc., which were previously discussed in detail. Here single-storey existing reinforced concrete building has been analysed with nonlinear static adaptive pushover analysis by using SeismoStruct software. To check the damage patterns of the structures, the performance criteria based on material strain used in the present numerical simulation are (1) yield strain limit for steel: 0.002, (2) crushing strain limit for unconfined concrete in beam: 0.0035, (3) crushing strain limit for unconfined concrete in column: 0.002, (4) crushing strain limit for confined concrete: 0.008, and (5) fracture strain limit for steel: 0.06 [19–23]. The pushover curve and damage pattern of the building are shown in Figs. 17 and 18,

Fig. 12 **a** Building constructed on hill top **b** Backside portion of building **c** Collapsed wall due to settlement of soil, **d** Corner column foundation slightly damaged and loss of upper soil strata up to the foundation depth

respectively. Also the risk index of Koyna-Warna region is shown in Table 5.

As per Fig. 18, the first yielding of steel occurs at a base shear of 150.12 kN and displacement of 25.15 mm. The first crushing of the unconfined concrete column occurs at base shear 340.12 kN and displacement 90.41 mm. Similarly, the first crushing of unconfined concrete beam occurs at base shear 350.73 kN and displacement 110.39 mm.

Conclusive statement

The base shear corresponding to yielding of steel is 150.12 kN which is lower than the design base shear of the building, i.e. 175.31 kN. Here we can conclude that the deformation of the building started very early, so the building is vulnerable to earthquake based on adaptive pushover analysis. 0.4 risk index is the threshold damage limit for vulnerable buildings and here as per the EDRI method risk index of the building is 0.48 which means the existing single-storied RC building is in vulnerable case.

Possible damage state

Based on the Fig. 19, it was found that the Koyna-Warna region has 45.8% of reinforced concrete sample buildings falling in the possible collapse category because many buildings in the region are constructed on sloping ground, the aging of structures, and heavy rainfall conditions. About 0.8% and 21.7% of sample buildings are falling in no damage and slight damage conditions. The percentage of RC buildings in moderate and severe damage stages is 10.8% and 20.8%, respectively. Also, irregular plan shapes, absence of continuous lintel bands, cracks in structural members, and vegetation on the wall are common in buildings that make them seismically more vulnerable.

Need of further evaluation

As per Fig. 20, there is a need to evaluate 93 buildings for their further use because of their present moderate, severe and collapse damage conditions that are dangerous to the health of buildings. And there is no need to evaluate 27 buildings which are in no and slight damage condition.

Damage distribution based on number of storey

Based on Fig. 21, there are 78 single-storey buildings surveyed in the Koyna-Warna region. Out of these, 1% and 33% of buildings are in no and slight damage stages, respectively. The percentage of buildings in moderate and severe damage stages is 17% and 30%, respectively. Out of all buildings, 19% of buildings are in the collapse stage, 51% of buildings are in no, slight, and moderate damage conditions, and 49% of buildings are in severe and collapse damage conditions.

Based on Fig. 22, there are 35 two-storey buildings surveyed in the Koyna-Warna region. Out of these, 6% and

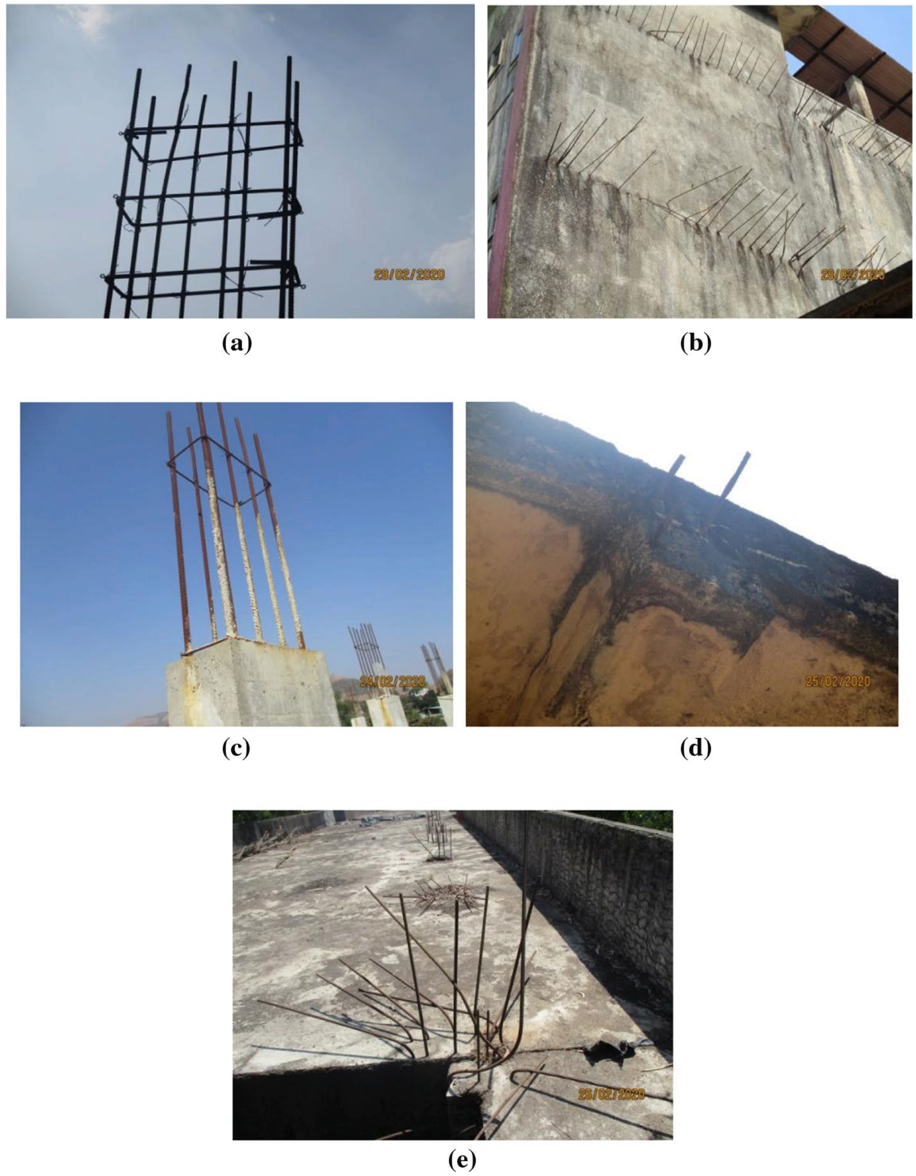


Fig. 13 **a** Reinforcements are exposed to environment at terrace and stirrups bent at 90°, **b** reinforcements are exposed to environment at roof level, **c** corroded reinforcement bars, **d** reinforcements are exposed from beam, **e** condition of reinforcement bars at terrace

94% of buildings are in severe and collapse damage stages, respectively. There is no building in no, slight and moderate damage conditions. As the storey of building increases, the exposure term will increase, resulting in the risk index of building increased ultimately. Hence, all two-storey buildings may be in severe and collapse damage stages, and there is a need to seismically evaluate these buildings for adequate earthquake preparedness.

Based on Fig. 23, there are 7 three-storey buildings surveyed in the Koyna-Warna region. Out of these, all buildings are in the collapse damage stage. There is no building in no, slight, moderate and severe damage conditions. As the storey of the building increases, the exposure term will increase, so ultimately the risk index of the building also increases. Hence, all three-storey buildings may be in the collapse damage stage.

Rebound hammer test on buildings

Schmidt rebound hammer test which is one of the non-destructive methods most used for the recognition of the condition of building structures. This test is quick and easy, and it makes it possible to control the quality of the construction and to indirectly measure the compressive strength of concrete in situ. In the present study, we have conducted the rebound hammer test on columns of the buildings. If the compressive strength of concrete column predicts less than 15 MPa, then this factor belongs to life threatening factor, so the vulnerability parameter shows red alert (Fig. 4), and ultimately it impacts on the risk index of the structure. Hence, the compressive strength of the column should not be less than 15 MPa. The following few pictures are shown in Fig. 24 while taking the rebound hammer test.

Table 2 Details of hazard (H), exposure (E) and vulnerability (V) of all RC existing buildings

Sr. No	H actual	H allowable	E actual	E allowable	V actual	V allowable	R actual	R allowable	Risk	Damage
1	0.80	0.80	0.25	1.00	1	1.00	0.20	0.80	0.25	Slight
2	0.80	0.80	0.24	1.00	1	1.00	0.19	0.80	0.24	Slight
3	0.80	0.80	0.23	1.00	1	1.00	0.18	0.80	0.23	Slight
4	0.80	0.80	0.18	1.00	1	1.00	0.14	0.80	0.18	No
5	0.80	0.80	0.32	1.00	1	1.00	0.26	0.80	0.32	Slight
6	0.80	0.80	0.32	1.00	1	1.00	0.26	0.80	0.32	Slight
7	0.80	0.80	0.32	1.00	1	1.00	0.26	0.80	0.32	Slight
8	0.80	0.80	0.33	1.00	1	1.00	0.26	0.80	0.33	Slight
9	0.80	0.80	0.32	1.00	1	1.00	0.26	0.80	0.32	Slight
10	0.80	0.80	0.42	1.00	1	1.00	0.34	0.80	0.42	Moderate
11	0.80	0.80	0.34	1.00	1	1.00	0.27	0.80	0.34	Slight
12	0.80	0.80	0.35	1.00	1	1.00	0.28	0.80	0.35	Slight
13	0.80	0.80	0.43	1.00	1	1.00	0.34	0.80	0.43	Moderate
14	0.80	0.80	0.34	1.00	1	1.00	0.27	0.80	0.34	Slight
15	0.80	0.80	0.33	1.00	1	1.00	0.26	0.80	0.33	Slight
16	0.80	0.80	0.33	1.00	1	1.00	0.26	0.80	0.33	Slight
17	0.80	0.80	0.32	1.00	1	1.00	0.26	0.80	0.32	Slight
18	0.80	0.80	0.31	1.00	1	1.00	0.25	0.80	0.31	Slight
19	0.80	0.80	0.26	1.00	1	1.00	0.21	0.80	0.26	Slight
20	0.80	0.80	0.38	1.00	1	1.00	0.30	0.80	0.38	Slight
21	0.80	0.80	0.38	1.00	1	1.00	0.30	0.80	0.38	Slight
22	0.80	0.80	0.35	1.00	1	1.00	0.28	0.80	0.35	Slight
23	0.80	0.80	0.41	1.00	1	1.00	0.33	0.80	0.41	Moderate
24	0.80	0.80	0.48	1.00	1	1.00	0.38	0.80	0.48	Moderate
25	0.80	0.80	0.48	1.00	1	1.00	0.38	0.80	0.48	Moderate
26	0.80	0.80	0.42	1.00	1	1.00	0.34	0.80	0.42	Moderate
27	0.80	0.80	0.45	1.00	1	1.00	0.36	0.80	0.45	Moderate
28	0.80	0.80	0.48	1.00	1	1.00	0.38	0.80	0.48	Moderate
29	0.80	0.80	0.55	1.00	1	1.00	0.44	0.80	0.55	Moderate
30	0.80	0.80	0.35	1.00	1	1.00	0.28	0.80	0.35	Slight
31	0.80	0.80	0.41	1.00	1	1.00	0.33	0.80	0.41	Moderate
32	0.80	0.80	0.37	1.00	1	1.00	0.30	0.80	0.37	Slight
33	0.80	0.80	0.56	1.00	1	1.00	0.45	0.80	0.56	Moderate
34	0.80	0.80	0.90	1.50	1	1.00	0.72	1.20	0.60	Severe
35	0.80	0.80	0.71	1.50	1	1.00	0.56	1.20	0.47	Moderate
36	0.80	0.80	1.88	1.50	1	1.00	1.50	1.20	1.00	Collapse
37	0.80	0.80	0.88	1.00	1	1.00	0.70	0.80	0.88	Collapse
38	0.80	0.80	1.32	1.50	1	1.00	1.05	1.20	0.88	Collapse
39	0.80	0.80	0.81	1.00	1	1.00	0.65	0.80	0.81	Collapse
40	0.80	0.80	0.98	1.00	1	1.00	0.78	0.80	0.98	Collapse
41	0.80	0.80	0.96	1.00	1	1.00	0.77	0.80	0.96	Collapse
42	0.80	0.80	0.83	1.00	1	1.00	0.66	0.80	0.83	Collapse
43	0.80	0.80	0.81	1.00	1	1.00	0.65	0.80	0.81	Collapse
44	0.80	0.80	0.96	1.00	1	1.00	0.77	0.80	0.96	Collapse
45	0.80	0.80	0.98	1.00	1	1.00	0.78	0.80	0.98	Collapse
46	0.80	0.80	0.32	1.00	1	1.00	0.26	0.80	0.32	Slight
47	0.80	0.80	1.27	1.00	1	1.00	1.01	0.80	1.00	Collapse
48	0.80	0.80	1.22	1.00	1	1.00	0.97	0.80	1.00	Collapse
49	0.80	0.80	0.29	1.00	1	1.00	0.23	0.80	0.29	Slight
50	0.80	0.80	0.29	1.00	1	1.00	0.23	0.80	0.29	Slight

Table 2 (continued)

Sr. No	*H* actual	*H* allowable	*E* actual	*E* allowable	*V* actual	*V* allowable	*R* actual	*R* allowable	Risk	Damage
51	0.80	0.80	0.29	1.00	1	1.00	0.23	0.80	0.29	Slight
52	0.80	0.80	1.36	1.25	1	1.00	1.09	1.00	1.00	Collapse
53	0.80	0.80	1.13	1.50	1	1.00	0.90	1.20	0.75	Severe
54	0.80	0.80	0.91	1.25	1	1.00	0.73	1.00	0.73	Severe
55	0.80	0.80	0.83	1.25	1	1.00	0.66	1.00	0.66	Severe
56	0.80	0.80	0.36	1.00	1	1.00	0.29	0.80	0.36	Slight
57	0.80	0.80	1.92	1.50	1	1.00	1.53	1.20	1.00	Collapse
58	0.80	0.80	1.10	1.50	1	1.00	0.87	1.20	0.73	Severe
59	0.80	0.80	1.22	1.50	1	1.00	0.97	1.20	0.81	Collapse
60	0.80	0.80	0.98	1.50	1	1.00	0.78	1.20	0.65	Severe
61	0.80	0.80	2.49	1.50	1	1.00	1.99	1.20	1.00	Collapse
62	0.80	0.80	2.49	1.50	1	1.00	1.99	1.20	1.00	Collapse
63	0.80	0.80	2.49	1.50	1	1.00	1.99	1.20	1.00	Collapse
64	0.80	0.80	2.40	1.50	1	1.00	1.92	1.20	1.00	Collapse
65	0.80	0.80	1.11	1.50	1	1.00	0.89	1.20	0.74	Severe
66	0.80	0.80	1.09	1.00	1	1.00	0.87	0.80	1.00	Collapse
67	0.80	0.80	2.18	1.50	1	1.00	1.74	1.20	1.00	Collapse
68	0.80	0.80	1.23	1.50	1	1.00	0.98	1.20	0.82	Collapse
69	0.80	0.80	1.63	1.00	1	1.00	1.30	0.80	1.00	Collapse
70	0.80	0.80	2.81	1.50	1	1.00	2.24	1.20	1.00	Collapse
71	0.80	0.80	3.92	1.50	1	1.00	3.12	1.20	1.00	Collapse
72	0.80	0.80	0.91	1.00	1	1.00	0.73	0.80	0.91	Collapse
73	0.80	0.80	1.64	1.00	1	1.00	1.31	0.80	1.00	Collapse
74	0.80	0.80	3.92	1.50	1	1.00	3.12	1.20	1.00	Collapse
75	0.80	0.80	2.64	1.50	1	1.00	2.11	1.20	1.00	Collapse
76	0.80	0.80	2.54	1.50	1	1.00	2.02	1.20	1.00	Collapse
77	0.80	0.80	1.67	1.00	1	1.00	1.33	0.80	1.00	Collapse
78	0.80	0.80	1.67	1.00	1	1.00	1.33	0.80	1.00	Collapse
79	0.80	0.80	4.13	1.50	1	1.00	3.29	1.20	1.00	Collapse
80	0.80	0.80	1.11	1.50	1	1.00	0.89	1.20	0.74	Severe
81	0.80	0.80	0.92	1.50	1	1.00	0.73	1.20	0.61	Severe
82	0.80	0.80	1.26	1.50	1	1.00	1.01	1.20	0.84	Collapse
83	0.80	0.80	0.85	1.00	1	1.00	0.68	0.80	0.85	Collapse
84	0.80	0.80	0.73	1.00	1	1.00	0.58	0.80	0.73	Severe
85	0.80	0.80	1.53	1.00	1	1.00	1.22	0.80	1.00	Collapse
86	0.80	0.80	1.19	1.50	1	1.00	0.95	1.20	0.79	Severe
87	0.80	0.80	0.88	1.00	1	1.00	0.70	0.80	0.88	Collapse
88	0.80	0.80	0.63	1.50	1	1.00	0.50	1.20	0.42	Moderate
89	0.80	0.80	0.62	1.00	1	1.00	0.49	0.80	0.62	Severe
90	0.80	0.80	0.90	1.50	1	1.00	0.72	1.20	0.60	Severe
91	0.80	0.80	2.35	1.00	1	1.00	1.88	0.80	1.00	Collapse
92	0.80	0.80	2.35	1.00	1	1.00	1.88	0.80	1.00	Collapse
93	0.80	0.80	0.84	1.25	1	1.00	0.67	1.00	0.67	Severe
94	0.80	0.80	2.28	1.50	1	1.00	1.82	1.20	1.00	Collapse
95	0.80	0.80	0.99	1.50	1	1.00	0.79	1.20	0.66	Severe
96	0.80	0.80	0.80	1.00	1	1.00	0.64	0.80	0.80	Collapse
97	0.80	0.80	2.00	1.25	1	1.00	1.60	1.00	1.00	Collapse
98	0.80	0.80	1.51	1.00	1	1.00	1.20	0.80	1.00	Collapse
99	0.80	0.80	1.59	1.00	1	1.00	1.27	0.80	1.00	Collapse
100	0.80	0.80	0.74	1.00	1	1.00	0.59	0.80	0.74	Severe

Table 2 (continued)

Sr. No	*H* actual	*H* allowable	*E* actual	*E* allowable	*V* actual	*V* allowable	*R* actual	*R* allowable	Risk	Damage
101	0.80	0.80	0.69	1.00	1	1.00	0.55	0.80	0.69	Severe
102	0.80	0.80	0.69	1.00	1	1.00	0.55	0.80	0.69	Severe
103	0.80	0.80	0.69	1.00	1	1.00	0.55	0.80	0.69	Severe
104	0.80	0.80	0.69	1.00	1	1.00	0.55	0.80	0.69	Severe
105	0.80	0.80	0.75	1.00	1	1.00	0.60	0.80	0.75	Severe
106	0.80	0.80	0.72	1.00	1	1.00	0.57	0.80	0.72	Severe
107	0.80	0.80	0.75	1.00	1	1.00	0.60	0.80	0.75	Severe
108	0.80	0.80	0.75	1.00	1	1.00	0.60	0.80	0.75	Severe
109	0.80	0.80	1.64	1.00	1	1.00	1.31	0.80	1.00	Collapse
110	0.80	0.80	1.64	1.00	1	1.00	1.31	0.80	1.00	Collapse
111	0.80	0.80	1.64	1.00	1	1.00	1.31	0.80	1.00	Collapse
112	0.80	0.80	1.91	1.25	1	1.00	1.53	1.00	1.00	Collapse
113	0.80	0.80	0.93	1.00	1	1.00	0.74	0.80	0.93	Collapse
114	0.80	0.80	2.52	1.50	1	1.00	2.01	1.20	1.00	Collapse
115	0.80	0.80	1.01	1.25	1	1.00	0.81	1.00	0.81	Collapse
116	0.80	0.80	0.99	1.50	1	1.00	0.79	1.20	0.66	Severe
117	0.80	0.80	3.39	1.50	1	1.00	2.71	1.20	1.00	Collapse
118	0.80	0.80	0.84	1.00	1	1.00	0.67	0.80	0.84	Collapse
119	0.80	0.80	0.89	1.00	1	1.00	0.71	0.80	0.89	Collapse
120	0.80	0.80	1.06	1.25	1	1.00	0.85	1.00	0.85	Collapse

Table 3 Column dimensions and detailing of the single-storey RC building

Column	Size (mm)	Main reinforcement	Shear reinforcement
All columns of Building	250 × 350	4 nos. of 20 mm diameter at corner	6 mm Dia. @ 250 mm c/c

Fig. 14 Photograph of the single-storey RC building understudy

Damage condition of buildings

Figure 25 shows the different damage conditions of surveyed sample buildings. The slab leakage problem is observed almost in all buildings due to heavy rainfall. Structural cracks on the column, corroded reinforcement and spalling of cover concrete observed in columns, reinforcements are exposed outside from slab, scaling of plaster, etc. There might be possible carbonation of concrete in the slab, column of old buildings.

Based on the observation, damages have been occurred in current construction practices due to the following deficiencies:

1. Poor workmanship and maintenance of RC buildings.
2. Aging of structures.
3. The less concrete cover was provided to structural members.
4. Corrosion of reinforcement in structural members.
5. 90° hook is provided in the stirrups.
6. The present material strength of the column was reduced due to the deterioration of material.

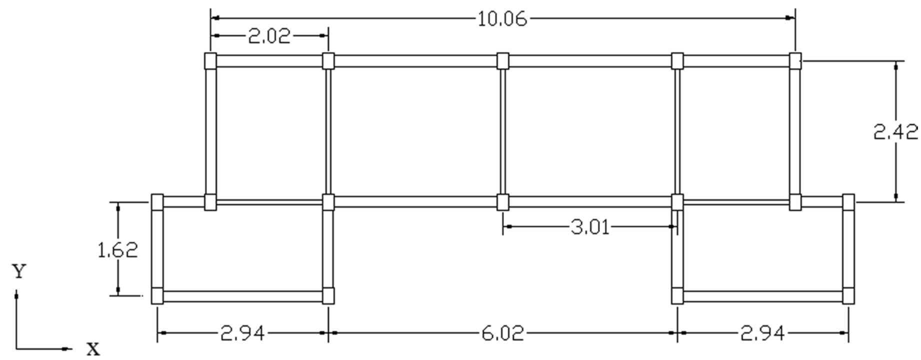


Fig. 15 The plan of the single-storey RC building

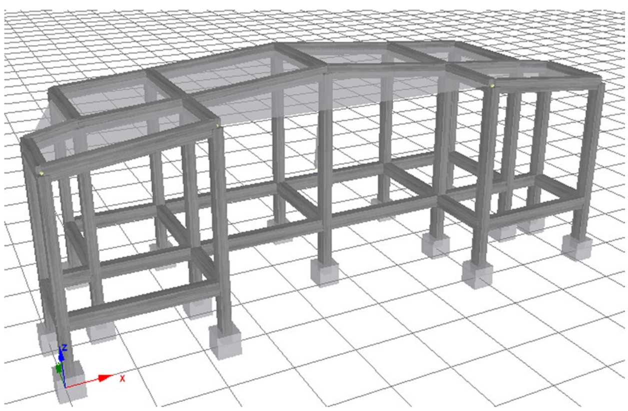


Fig. 16 The model of the single-storey RC building

Seismic risk mitigation plan

The following risk mitigation plan will be helpful to minimize future seismic risk.

1. Current construction practice should follow the ductile detailing as per: IS:13920-2016 code [24].
2. Cosmetic modification of buildings is required for every two–three years due to heavy rainfall in the area.
3. Engineers should give an earthquake-resistant design as per IS:1893–2016 code [25] in the Koyna-Warna region.
4. The owner should keep the regular maintenance of the building.
5. Government authorities should set up a periodic structural audit to ensure safety.
6. Government authorities should establish the demonstration unit to make people aware of the earthquake and make them understand the severity of the risk.

Table 4 Beam dimensions and detailing of the single-storey RC building

Beam/plinth beam	Size (mm)	Main reinforcement	Shear reinforcement
All beams of building at top and bottom	250 × 350	2 nos. of 12 mm diameter	6 mm Dia. at 200 mm c/c

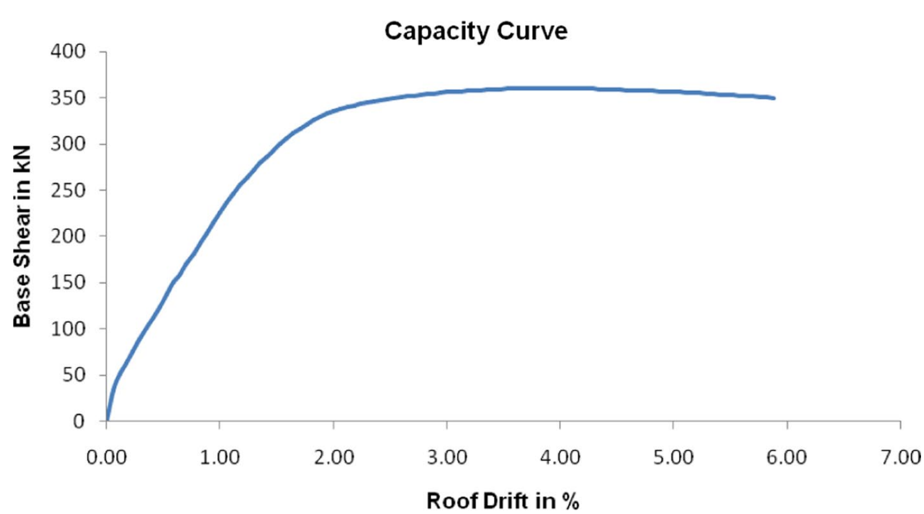


Fig. 17 Pushover curve of the single-storey RC building

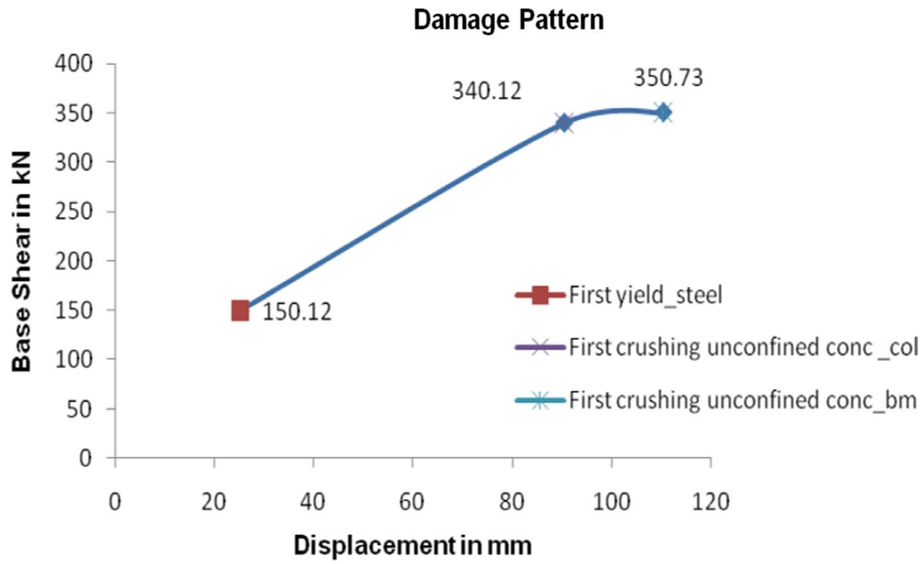


Fig. 18 Damage pattern of the single-storey RC building

Table 5 Calculation of EDRI of all surveyed buildings and EDRI of Koyna-Warna region

Structure	EDRI calculation for surveyed RC building			EDRI calculation from census data		
	No. of buildings	Sum of risk	EDRI vulnerable	Approx. No. of RC buildings	Sum of risk	EDRI of Koyna-Warna region
RC-MRF	120	84.18	0.7	5500	3858	0.7

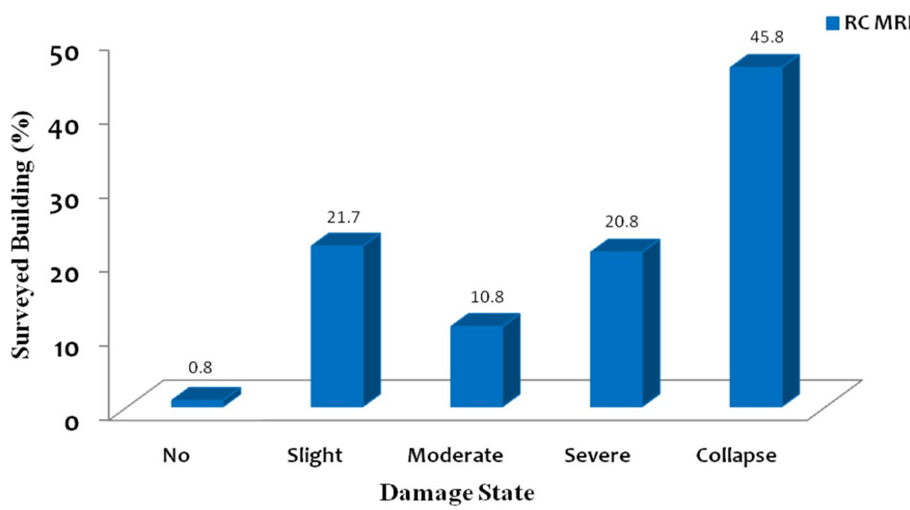


Fig. 19 Possible damage state of RC buildings in Koyna-Warna region

7. Introduce a course curriculum on retrofitting of structures in graduate and postgraduate students as a part of the study.
8. The remedial measures against the deficient structures are: (a) Global retrofitting i.e. addition of shear wall, addition of infill wall, addition of bracing, wall thickening, mass reduction, supplemental damping and base isolation, etc. (b) Local retrofitting i.e. RC-jacketing, FRP-jacketing, steel plating, etc.

Conclusions

Based on the present study, seismic risk index of RC buildings has been evaluated by using "EDRI" method in the Koyna-Warna Region. Also, some common structural and construction deficiencies have been discussed in detail. The following conclusions can be outlined:

1. Seismic risk of RC buildings in the Koyna-Warna region has been evaluated to create the awareness in govern-

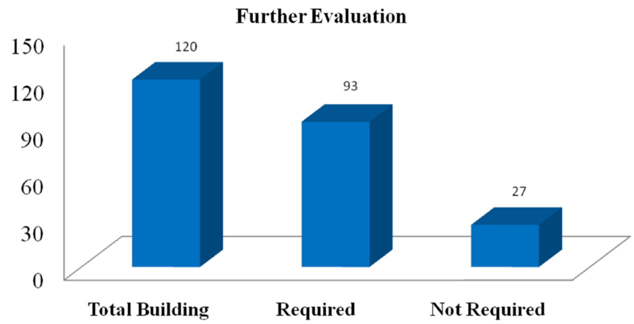


Fig. 20 Further evaluation of RC buildings in Koyna-Warna region

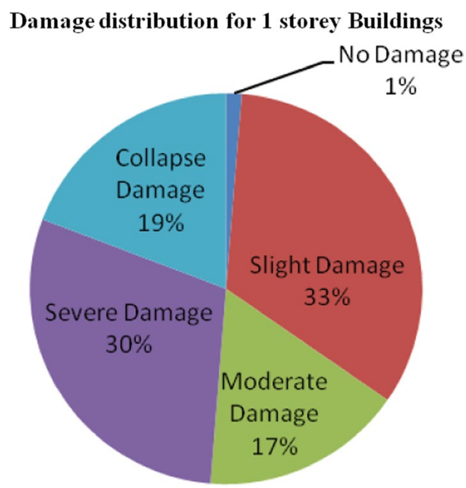


Fig. 21 Damage distributions of single-storey surveyed buildings

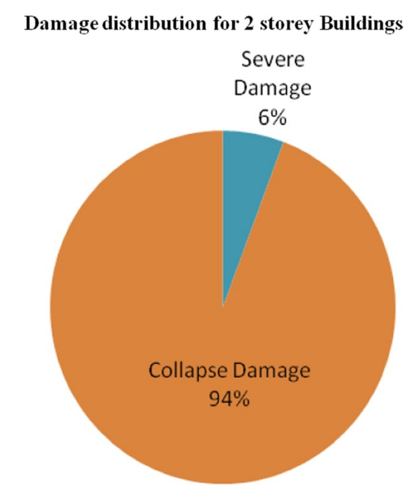


Fig. 22 Damage distributions of two-storey surveyed buildings

ment bodies, engineers, architects and local people to take an initiative for the risk mitigation program.
2. Seismic risk of RC buildings in Koyna-Warna region is in the severe damage stage, which is dangerous to the physical infrastructure as well as life safety.

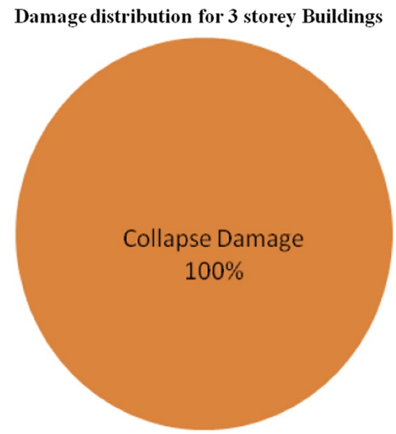


Fig. 23 Damage distribution of three-storey surveyed buildings

3. There is an urgent need to go for a detailed evaluation of 93 RC buildings out of 120 for its further use due to its moderate, severe, and collapse damage condition.
4. Based on the RVS study of 120 surveyed RC buildings, the percentage of reinforced concrete buildings in the collapse stage is 45.8% which is maximum as compared to other damage stages due to the high contribution of exposure and vulnerability term. RC buildings in moderate and severe damage stage are 10.8% and 20.8%, respectively. The percentage of RC buildings falling in no and slight damage condition is 0.8% and 21.7%.
5. Single-storey buildings are more safer as compared to two-storey and three-storey buildings in the Koyna-Warna region because of seismicity of the region.
6. Based on the visual observation, some structural defects have been observed in the surveyed RC buildings, namely the corrosion of reinforcement starts due to inadequate concrete cover provided to the structural members, poor construction practice, deterioration of concrete due to heavy rainfall condition, shear cracks on columns due to inadequate stirrup spacing, diagonal cracks that occurred at the opening of windows due to inadequate sill band, most of the opening of windows closer to the corner, etc.
7. This RVS study will help the executive authorities to take initiative for the earthquake preparedness plan of the Koyna-Warna region.

The conclusions of the present study are limited to reinforced concrete buildings only.

Fig. 24 Rebound hammer test conducted on columns of the building

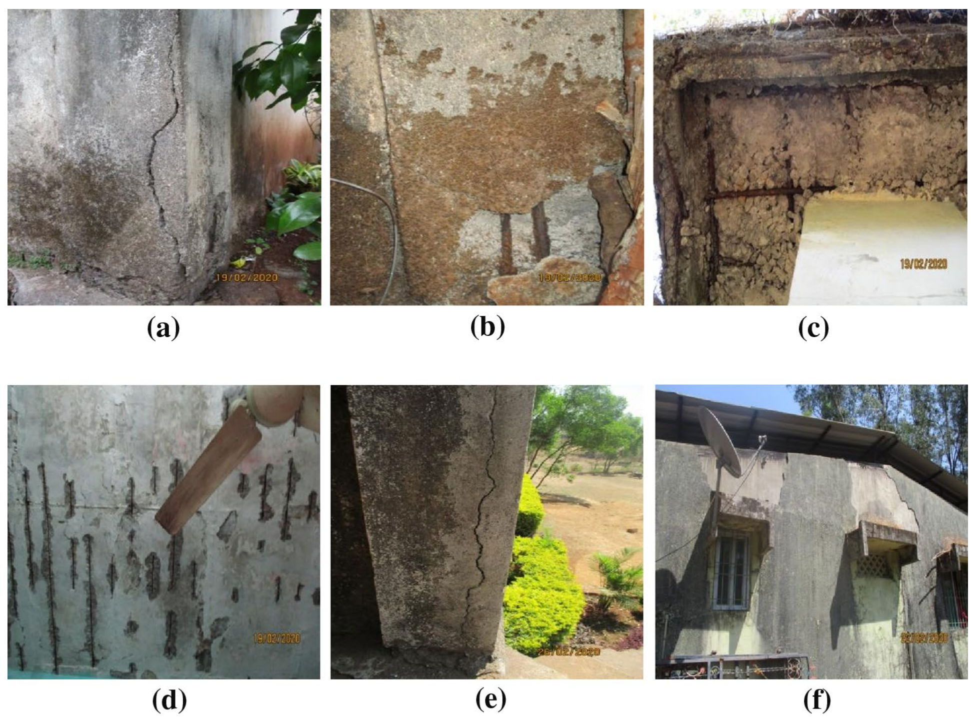


Fig. 25 Damage condition of sample buildings

Appendix 1: A sample RVS form

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Rapid Visual Screening of RC Buildings (EDRI Method):

Remark on Building: Insufficient curing, shrinkage crack, Scaling on wall. Need to plaster on wall.	Address: Patan Town, Dist: Satara. Pin 415206
	GPS Location: Lat N17° 21' 56.85" Long: E 73° 53' 44.93"
	No. Stories 2 Year Built 2018
Owner name: Vijay Shelar	Screener Mangesh Date: 24/02/2020
Address: Patan town, Rampur	Built up Area: (Sq. ft.) 2244 Plot Area: (Sq. ft.) 1368
	Building Name: Home
Mob No: 7218494361	Use: Residential
	Year Built: 2018
BA :- 34' x 33' x 2 PA :- 38' x 36' Column St^th :- 16.50 MPa 21.50 MPa 12.50 MPa Avg. St^th = 16.83 MPa Partially started vegetat^n on cracks.	 Photograph
Risk Index: 1 Type of Damage: collapse. Detailed Evaluation Required: Yes / No	
Surveyor's Sign: Mgshevekar	

Note: Risk index: 0 – 0.2 = No Damage, Risk index: 0.2 – 0.4 = Slight Damage, Risk index: 0.4 – 0.6 = Moderate Damage, Risk index: 0.6 – 0.8 = Severe Damage, Risk index: 0.8 – 1 = Collapse Damage

Sr. No				
Latitude				N17°21'56.8"
Longitude				E 73°53'44.3"
Hazard	**Collateral Hazard**	Liquefaction		N
		Landslide/Rock Fall		N
		Fire		N
	Ground Shaking	Zone Factor		0.24
		Soil Type	Hard Rock (1), Medium Soil (1.33), Soft Soil(1.67)	1.33
		Spectral Shape	No. of Stories	2
			Min (20/N, 2.5)	2.5
	Hazard Factor Actual			0.798
	Hazard Factor Allowable			0.798
Exposure	**Importance (I)**	Residential (1), Office (1.25), Commercial (1.5)		1
	Floor Area Ratio	Built up Area (Sq. Ft.)		2244
		Plot Size Length (Ft.)		38
		Plot Size Width (Ft.)		36
		FAR Actual		1.64
		FAR Allowable		1
	Exposure Actual			1.64
	Exposure Allowable			1
Vulnerability	**Life Threatening Factors**	Siting Issues		UNSAFE
		Soil and Foundation Conditions		SAFE
		Architectural Features		SAFE
		Structural Aspects		SAFE
		Construction Details		SAFE
	Economic Loss Factor	Siting Issues (-5%)		N
		Soil & Foundation Condition (-5%)		0
		Architecture Features (-50%)		-6
		Structural Aspects (-20%)		-20
		Construction Details (-20%)		-4
	Vulnerability Factor Actual			1
	Vulnerability Factor Allowable			1
Risk Actual				1.31
Risk Allowable				0.80

Vulnerability

			Sr. No	
			Latitude	
			Longitude	
				Y/N
Life Threatening Factors	**Sitting Issues**		(a) The building is built on hill slopes that can slide, OR	Y
			(b) The building is built on river terraces that can slide/creep, OR	N
			(c) The building is built on hill slopes /adjacent to hill slopes (even though on flat ground), but vulnerable to falling debris from the hill top.	N
	Soil & Foundation Condition		(a) The soil underneath the building is liquefiable, OR	N
			(b) The soil in the area adjoining the site is liquefiable and can flow laterally to move the soil from underneath the building.	N
	Architecture Features		(a) The building has an open ground storey that is not designed to resist lateral loads, with/without structural walls in the ground storey, OR	N
			(b) The building is almost touching or located close to an adjacent seemingly unsafe building/construction, whose collapse can damage it.	N
	Structural Aspects		(a) The minimum transverse dimension of columns is 200mm, AND	N
			(b) The ties in columns have 90° hooks, AND	N
			(c) The structural design of the building has not been performed by a competent engineer.	N
	Construction Details		(a) Concrete used in columns is of grade M15 or lesser, OR	N
			(b) Concrete used in columns is hand-mixed, OR	N
			(c) Concrete placed in columns is not vibrated by any mechanical device	N
Economic Loss Factor	**Sitting Issues (-5%)**		The building is built on sloped ground with access at two or more levels, i.e., at ground, intermediate floor & roof (-5)	N
	Soil & Foundation Condition (-5%)	**Suitability of soil type**	Soft soil (-2)	N
			Weak soil (-2)	N
			High water table (-1)	N
			Soil with moisture (-2)	N
		Foundation	Footings on non-uniform soil with no tie beams (-3)	N
			Footings on non-uniform soil with tie beams (-1)	N
			Footings on soft soil with no tie beams (-3)	N
			Footings on soft soil with tie beams (-1)	N
			Mat foundation on non-uniform soil (-2)	N
			SUM of above actual parameters	0
	SUM (Maximum Sub Total -5)		i.e., MAX(SUM of above actual parameters,-5)	0

Architecture Features (-50%)	**Plan Shape**	Large room sizes (-5)	N
		Irregular orientation of rooms (-3)	N
		Complex overall shape with reentrant corners (-5)	N
	Elevation profile	Wider top, narrower bottom (-5)	N
		Heavier top (-5)	N
		Large projections or overhangs (-3)	N
		Split roof (-5)	N
		Large storey heights (-5)	N
		Differences in storey heights (-5)	N
		Unsymmetrical staircase location with respect to plan (-5)	Y
		Open ground storey not designed to resist earthquake shaking (-40)	N
	Door and window openings in walls	Rare single window close to corners (-1)	Y
		About half of openings close to corners (-2)	N
		Almost all openings close to corners (-4)	N
		Large area window openings (-4)	N
		Large area door openings (-6)	N
	Distance from adjacent building	Houses touch each other (-3)	N
		Houses have insufficient gap between them (-3)	N
	Parapets, objects on roof or projections	Not secured to the structural system (-4)	N
		Large and heavy projections and overhangs (-5)	N
	Staircases	Narrow (-1)	N
		Too few in number (-1)	N
		Too far to reach (-1)	N
		SUM of above actual parameters	-6
SUM (Maximum Sub Total -50) i.e., MAX(SUM of above actual parameters,-50)			-6
Structural Aspects (-20%)	**Frame Grid**	Grid of parallel planar frames only along one plan direction (-5)	N
		No grid of parallel planar frames along both plan directions (-10)	N
		Frames have symmetric lateral stiffness along one plan direction (-5)	N
		Frames don't have symmetric lateral stiffness along any plan direction (-10)	Y
		Frames have symmetric lateral strength along one plan direction (-5)	N
		Frames don't have symmetric lateral strength along any plan direction (-10)	N
	Roof/Floor slab design	Heavy roof/floor slab (-10)	N
		Pitched roof/floor slab (-5)	N
		Split roof/floor slab (-10)	N
		Roof/floor slab with large size openings, especially located along the edge of the slab (-10)	N

	Roof/floor – column connection	No/insufficient anchorage of horizontal reinforcement from beams to columns at roof/floor levels (-10)	N
	Member proportioning	Column weaker (in moment capacity) than beams framing into it at each joint (-20)	N
	Column and column – foundation connection	No/insufficient anchorage of reinforcement from columns to foundation (-5)	N
		All longitudinal bars in column lapped at same location (-15)	N
	Staircase	Unsymmetrical location (-5)	Y
		Both top and bottom integrally built into the building frame (-5)	Y
		Staircase not adequately separated from the house (-10)	Y
	Large water tanks on roof	Not anchored to the structural system (-4)	N
		SUM of above actual parameters	-30
SUM (Maximum Sub Total -20) i.e., MAX(SUM of above actual parameters,-20)			-20
Construction Details (-20%)	Type of materials	Poor quality of sand (-10)	N
		Poor quality aggregates (-5)	N
		Poor quality cement (-10)	N
		Poor quality bricks (-5)	N
	Workmanship	Poor geometries of masonry and roof (-3)	N
		Insufficient curing (-10)	N
	Concrete mix	Concrete prepared using nominal mix (-4)	N
		Concrete ingredients measured by volume batching (-4)	Y
		SUM of above actual parameters	-4
SUM (Maximum Sub Total -20) i.e., MAX(SUM of above actual parameters,-20)			-4

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Declarations

Conflict of interest The authors declare that there is no conflict of interest.

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