Chapter

Natural Hazards - Impacts, Adjustments and Resilience

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Abstract

Reinforced concrete is a global material, the utilization of which has no limits. India is a country that uses mostly RC framed structures as the routine building construction type. The building is made of inter-connecting elements in horizontal and vertical directions. To showcase the effectiveness of high grade of concrete and confining reinforcement much research has been carried out till date from 1980s. However, in design of structures we do not consider the effect of confining reinforcement in resisting stress in any member element. Various tools have been developed to find the capacity of member at element level to resist forces. For performance-based design of buildings, it is necessary to evaluate the performance at individual local level and at global levels. In this study, the effect of available tools (for section analysis) and design codes for member limit calculation is demonstrated and structure is evaluated for the threshold limits given in ASCE-41. It is observed that the code designed members are sufficient to resist lateral earthquake forces effectively for the estimated hazards if proper design tools are employed.

Keywords: disaster mitigation, resilient structures, performance-based design, design tools, displacement-based design, seismic performance evaluation

1. Introduction

Indian subcontinent is a region experiencing seismic activities since ancient times. According to BIS seismic zoning map, over 65% of the country is prone to earthquakes of intensity MSK VII or more, putting 38 cities in high risk zones. In 2011, there were 80 earthquakes in India, with magnitude ranges between 3.5 M to 6.5 M on Richter scale. The year 2012 was an equally eventful year with 19 earthquakes by 5th March. Great earthquake having magnitude of 8.0 M or higher occurs somewhere in the world every year. Seismic engineering of structures is in discussion since decades while the aspects of risk mitigation and hazard assessment are relatively new in this field which are in concern with our preparedness for future events. The aim of a structural design engineer is always the safety as against the sole aim of economy. However, architectural needs and budget compromises the higher target of an engineer to bring resilience as an important consideration in design of buildings in seismic prone regions. The code provisions give legal benefit to developers while the resilience aspects highlight the need to bring better scientific methods to safeguard the community during strong earthquakes. With the advancement in knowledge and promotion of performance-based design procedures, it has become possible to safeguard our interests against the fury of nature.

The Bhuj earthquake (2001), had caused severe damage to property and more than 20,000 people were killed in Kuchchh area [1]. The reported PGA of the earthquake was 0.38 g having magnitude 7.7 Mw. Around 70 multistorey buildings collapsed in Ahmedabad, with reported PGA of 0.1 g for which the damage observed was higher than expected. Hence, the influence of present process of design of buildings on the performance of RC structures needs further check. There is another significant parameter for design consideration - the accurate hazard estimation. The observed damages better indicate hazard than the PGA values especially for mid-high rise buildings. The attenuation in Ahmedabad city is found to be around 1.8–2.0 [2], not considered in design. This is the serious limitation of force-based design wherein inaccurate estimate of hazard will give a sense of design to the engineer but is a gross-error in seismic design force calculations.

The expression of risk gives a good overview of each part that contributes to either the safety or to the weakness. In the equation, the term Hazard (H) represents the severity of earthquake expected in the region considered for risk estimation (refer Eq. (1)).

$$\text{Risk} = \text{Hazard (H)} \times \text{Vulnerability (V)} \times \text{Exposure (E)/Asset} \tag{1}$$

If the estimation of hazard is an under-estimate, then the risk increases substantially, though the design may be done with utmost care. Seismic micro-zonation of Ahmedabad gives understanding of hazard to design engineers.

The building typology and design methods followed in a region suggest vulnerability aspects. Without disturbing the cultural heritage of local region, the capacity of existing buildings can be increased to reduce the quantum of vulnerable stock to various intensities of earthquake likely to hit there [3]. The role of developer, owner and administration plays a vital role in upgradation of vulnerable facilities and investing efforts towards the mitigation of earthquake hazard by identifying the vulnerability (V) component in a region. The density of buildings in an area, important structures, and the type of facility under threat is covered by the risk as the exposure or asset (E) parameter to estimate the threat susceptibility. The impact of earthquakes in India show the concern due to recent earthquakes (2001;2005) on the number of people succumbed due to lesser engineering (refer **Table 1**).

Hence, if we are better able to know our region, dedicated in identifying weak structures for upgradation and protect the important assets by identifying their importance, we can control the impact of earthquakes on our habitat. This study focuses on adopting resilience in mid-rise buildings using design tools.

Event	Year	Magnitude	PGA	Intensity	Casualty
India-Burma	1988	7.2	0.34 g	VIII	709
Garhwal	1991	7.1	0.3 g	VIII	768
Uttarkashi	1991	7	0.29 g	IX	>2000
Koyna	1967	6.5	0.4 g	VIII	1500
Chamoli	1999	6.6	0.34 g	VIII	103
Bhuj	2001	7.7	0.38 g	VIII	20,000
Kashmir	2005	7.6	0.23 g	VIII	>80,000
Sikkim	2011	6.9	0.35 g	VI	111
Nepal	2015	7.9	—	IX	>8000

Table 1.
List of severe earthquakes in India (7 Mw): Magnitude-PGA-intensity.

DOI: http://dx.doi.org/10.5772/intechopen.94303

2. Methodology

2.1 Problem description

A fifteen storey reinforced concrete building located in Ahmedabad city of Gujarat state is to be designed using Indian Standards (IS 456; IS 1893). The performance of this force-based design building will be evaluated using displacement-based method for performance-based design (PBD) using the procedures mentioned in **Figure 1**. The plan and section details are given in **Figure 2**.

2.2 Literature review

The building design code for earthquake was first developed in Japan to consider 10% of dead weight as the lateral load. The code procedure developed based on understanding of severe damages in strong earthquakes around the globe [4]. Seismic risk mitigation is dependent on understanding exposure and vulnerability apart from seismic hazard for which effective design provisions are required for built environment to sustain the next event [5]. The present codes include the cyclic behavior through simpler procedures for performance-based design of building structures with reduced vulnerability [6–9]. TEC-2007 has been upgraded to

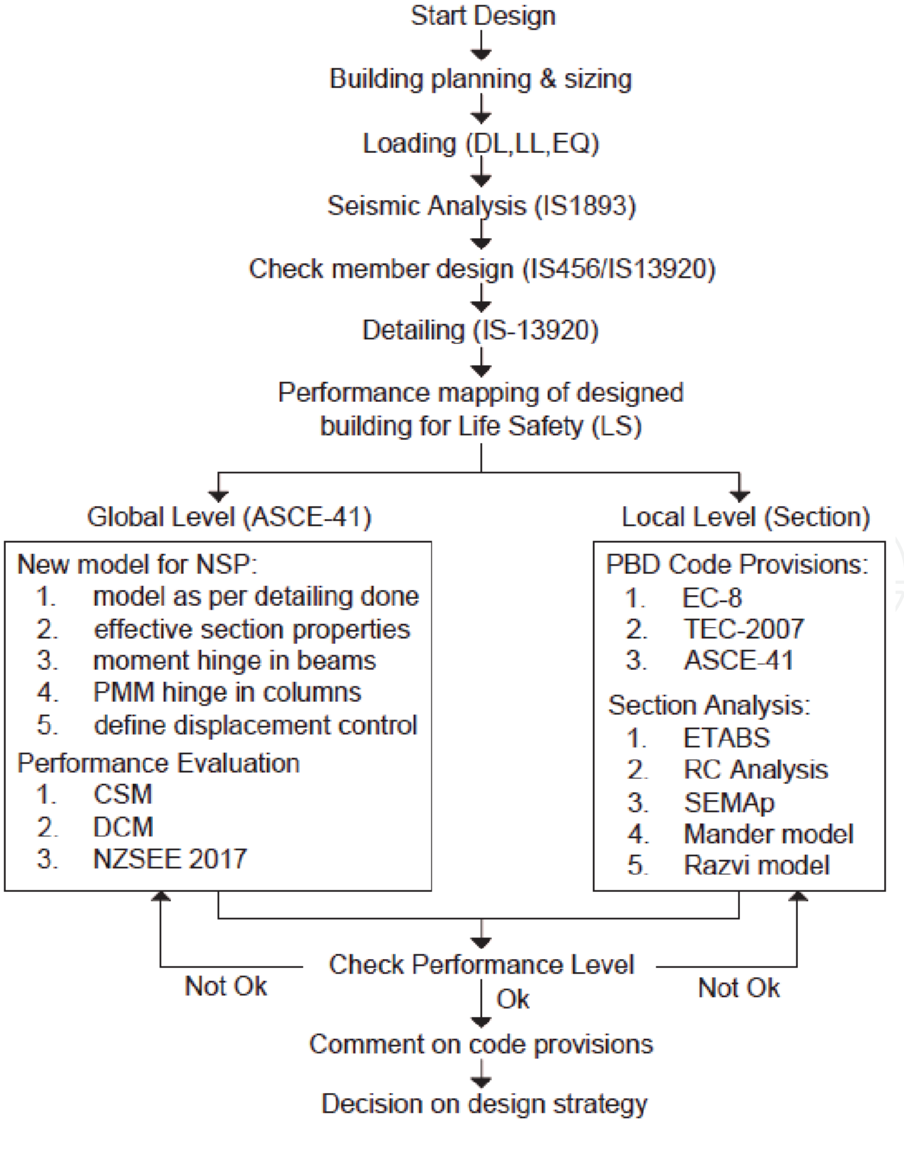

Figure 1.
Scheme for performance-based design method for standardization.

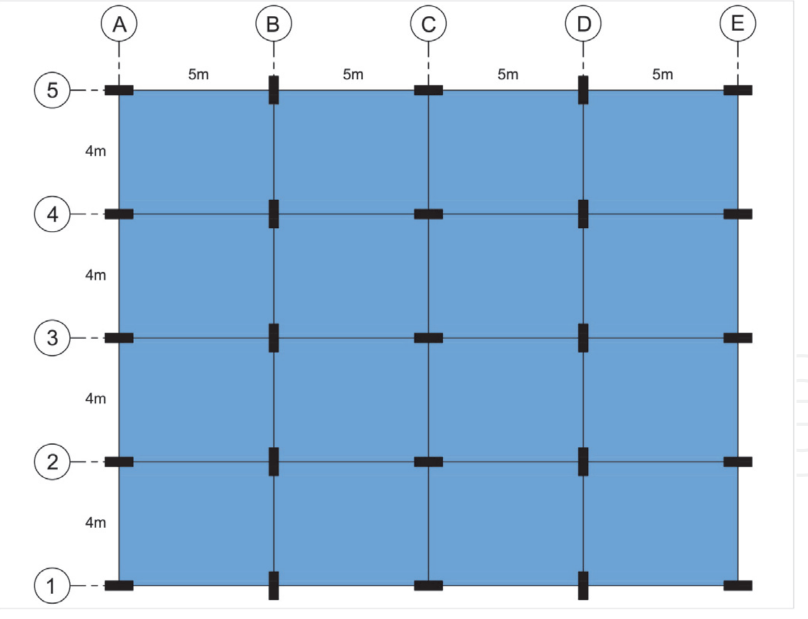

Figure 2.
Plan and section sizes of building (20 m × 16 m).

TBEC-2018 for design of new buildings with taller stature [10]. Also, the design of buildings with FIB Model Code 2010 is considered to upgrade the force-based provisions of EC-8 to displacement-based procedure [11]. Various studies have suggested competence of EC-8 towards better design of buildings compared to Indian and ACI codes [12]. SIRCO tool is developed to simulate and estimate seismic risk in Portugal to plan, prevent and respond to future earthquakes [13]. Engineering parameters are identified to rate the world-wide seismic code quality index and formally 166 countries have some form of seismic code with 510 revisions since 1900 [14]. Optimum solution technique is proposed to reduce computational efforts towards performance-based design using displacement procedure [15].

The above literatures do not focus towards mapping of performance of building and its elements using design codes and design tools to move towards standardization in performance-based design. The effectiveness of code provisions for building design and detailing are put under the lens, in-order to plan structures for the future H-V-E model in seismic prone regions.

3. Performance evaluation of building

The aim of design engineers is always towards the optimum use of materials with proper strength regulations. Seismic engineering requires separate framework to keep the structures functioning or regulate damages under multiple earthquake events. The providence of ductility and sizing hierarchy through strong column-weak beam philosophy is a different routine for design of structures. The importance of appropriate seismic hazard (PGA/PGV/Mw), modeling parameters, methodology and mapping of required performance thresholds are part of performance-based design procedure. The performance of building is evaluated following ASCE-41. The performance target for the building is Life Safety (LS) under MCE level earthquake (7.0 M in Bhuj, located at 250 kms from building).

3.1 Estimation of hazard for seismic demand

The building is in a city where risk reduction measures are employed after observing severe damages in Bhuj earthquake in 2001. The hazard actions are handled by Institute of Seismological Research (ISR) and mitigation measures are suggested by Gujarat State Disaster Management Authority (GSDMA). The understanding of local seismic hazard of Ahmedabad city is done and there seems to be under-estimation of hazard in BIS zoning map (refer **Figure 3**). Hence, the three hazard levels suggested for Ahmedabad city will be used to check the performance of building using capacity-spectrum method (CSM, FEMA-440) and displacement-coefficient method (DCM, ASCE-41). The equivalent static analysis results are shown in **Table 2**.

Building information:

No. of stories: 15	Full height: 45 m
Location: Ahmedabad city	Distance from fault: 250 kms
Time period (X,Y): (0.9,1.0)s	Base shear: refer **Table 2**

Hazard information:

BIS hazard zone: III (0.16 g)	Attenuation: 1.5–2 (ISR)
PSHA maps: 0.22 g (NDMA)	Seismic micro-zonation: 0.18 g (ISR)

3.2 Performance evaluation using seismic design codes and ASCE-41

Bureau of Indian Standards (BIS) is the governing body that regulates the professional minimum standards to be followed in India. The codes that are applicable for seismic design of buildings are IS 1893 (P1)-2016 and IS 13920–2016. The building is designed using these provisions and the capacity of building at structure level is noted for comparison with design standards of US (ACI-318) and Europe (EC-8). This can be a significant evaluation criterion in terms of performance evaluation, as the design and evaluation standards are different due to lack of performance evaluation guidelines in India.

The nonlinear static analysis (NSA) is a simpler means to evaluate performance and behavior of buildings under multiple excitations, (4 Mw – 7 Mw). The capacity spectrum method (CSM) is much debated as the demand-capacity are compared in one graph where hazard may be a partial information. Displacement

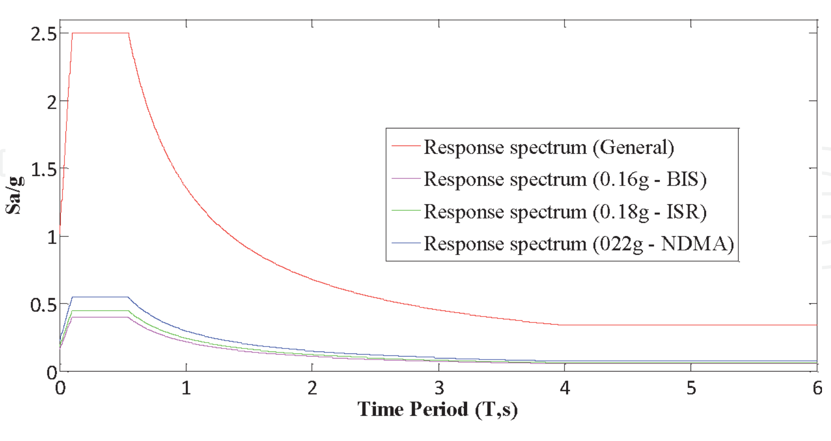

Figure 3.
Response spectrum for different hazard levels as per IS 1893–2016.

Time period (s)	Weight (W)	Acceleration (A_h)		Base Shear (V_B)
X dir. = 0.9	31461.54 kN	BIS	0.058	1636 kN
Y dir. = 1.0	DL = 100%	ISR	0.065	2054 kN (+25%)
(with infill)	LL = 25%	NDMA	0.079	2485 kN (+52%)

Table 2.
Equivalent static analysis as per IS-1893-2016.

coefficient method (DCM) is a better means to employ performance-based design procedure (PBD) as displacement gives better control. The target displacement (δ_t) is estimated to obtain nonlinear displacement limit at structure level (refer Eq.(3)).

$$\delta_t = C_0 C_1 C_2 S_a \frac{T_e^2}{4\pi^2} g \tag{2}$$

δ_t = (306.50, 348.60, 420.01) mm for three hazard levels

The building passes Life Safety (LS) performance under MCE level earthquake in case of 0.16 g and 0.18 g seismic hazard in Ahmedabad city for IS code-design case (refer **Figure 4**). Also, the building designed with IS code had performance of Collapse Prevention (CP) level while the building design with ACI-318 and EC-8 will collapse in 0.22 g hazard level. However, the location of failure hinge shown in **Figure 5**, describes the better behavior of structure designed using US and EN code provisions for buildings as only the base columns are failing. The columns at 4th and 7th level are failing in IS design case, hence the energy dissipation in the graph is poor. Important to note the strength of building designed as per IS code is highest and ductility achieved is more than the other design codes though the location of failure is not acceptable.

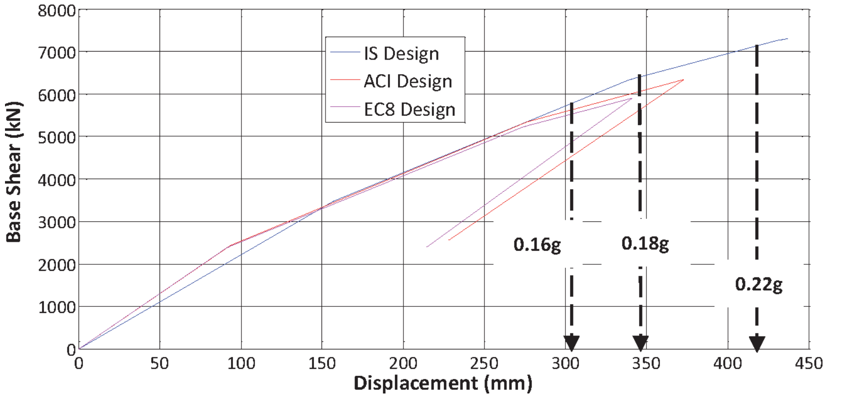

Figure 4.
Comparison of capacity curve of building as per design codes.

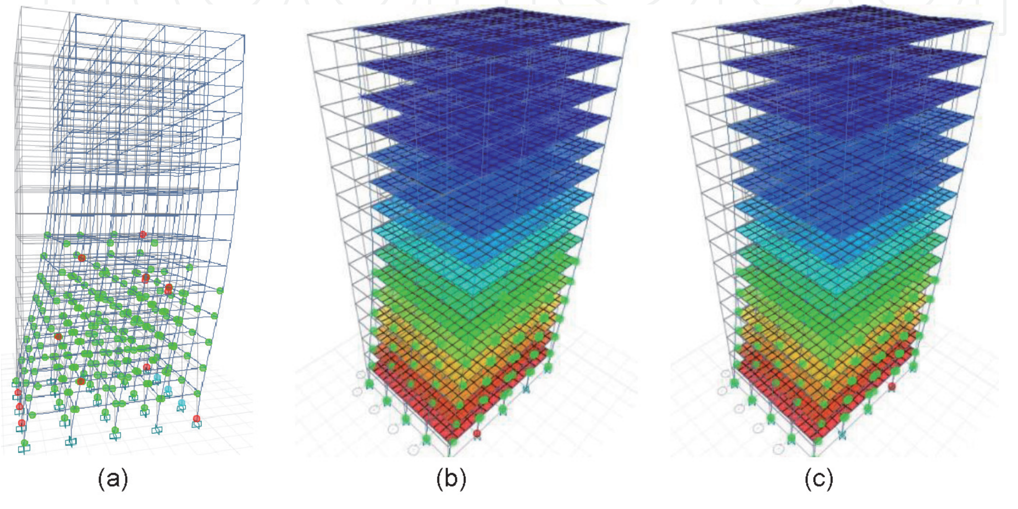

Figure 5.
Location of failure hinge at the end of POA. (a) IS design. (b) ACI design. (c) EC8 design.

DOI: http://dx.doi.org/10.5772/intechopen.94303

3.3 Element wise performance in the building using ETABS v15.0

The performance of building at structure level is shown in previous section, which gives the global picture of stability in the building and the performance level achieved at the end of pushover analysis. However, the deformation in each element of building (beam and column) during each step of nonlinear analysis gives the local performance level for that element and the concerned storey of building as the weak link may be established. The elements are modeled in ETABS using confined concrete model [16]. The performance of elements that failed in the structure at end of POA are shown in **Figure 6**. Performance of elements designed as per ACI and EN code is found to be higher in terms of post yield deformation and hence better performance will be available at local level.

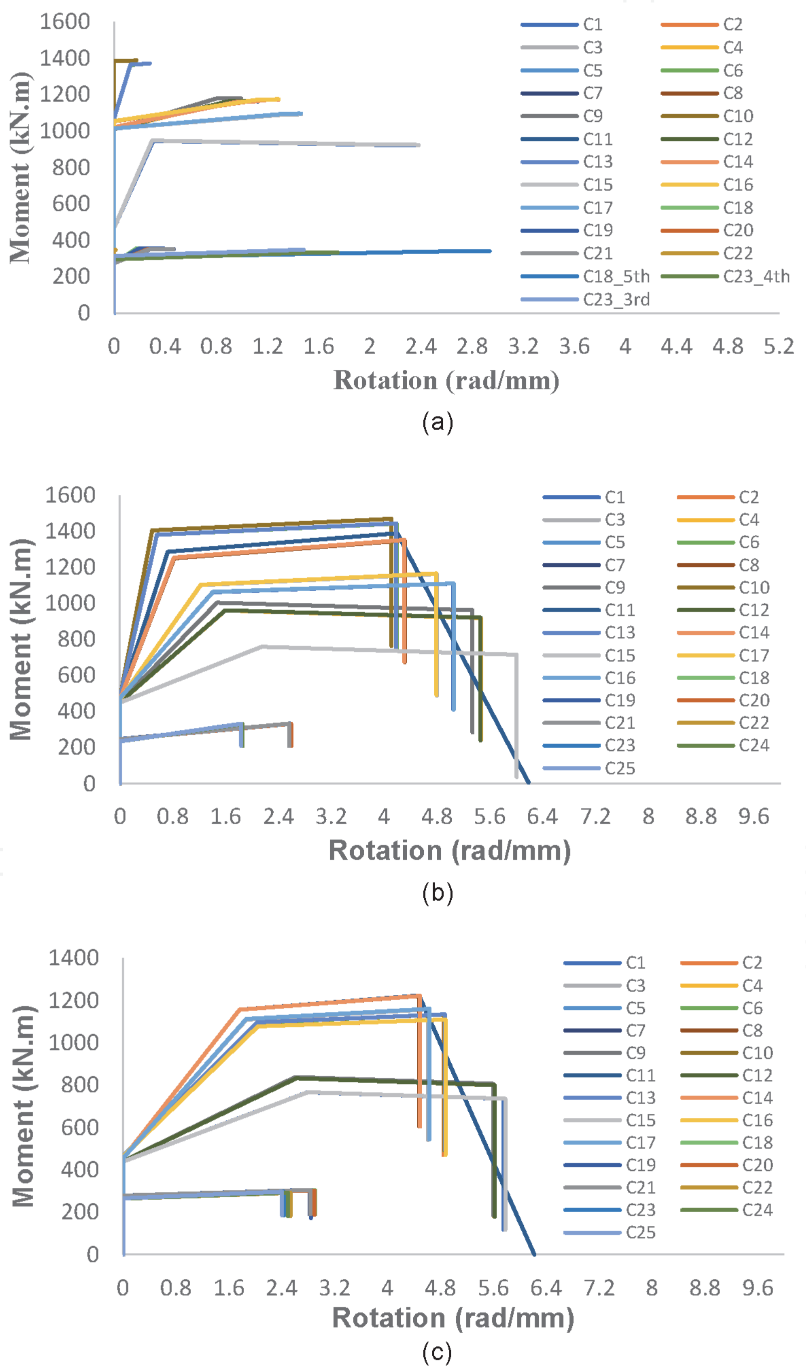

Figure 6.
Results of $M - \theta$ of all columns of building (ETABS 2015) at ground floor. (a) Ground storey column hinge results for IS code designed building. (b) Ground storey column hinge results for ACI code designed building. (c) Ground storey column hinge results for EC8 code designed building.

4. Use of design tools for element level performance estimation

The building is designed using ETABS software which gives the structure and element level performance of building. The performance of building elements can be evaluated using prevalent concrete models of confined concrete and high strength concrete. RC Analysis-Columns [17], web-portal is developed by Virtual Laboratory for Earthquake Engineering (VLEE, UTPL). Also, the SEMAp software developed by Ozmen (2007) gives the element capacity based on four concrete models [18]. The element level performance is suggested by Euro-code and Turkish-code for design of buildings for earthquakes [8, 9]. Hence, evaluating the performance of columns (i.e. failed element at the end of POA) using ETABS, EC-8, RC-Analysis (RCA) and SEMAp is interesting segment for assessing the performance.

4.1 Understanding the element deformations

The change in geometry of elements is picturized in form of curvature (φ), rotation (θ) and displacement (δ). The ductility in these elements will give them ability to absorb seismic forces and display higher performance before failure. The curvature ductility (φ_u/φ_y) is more meaningful than rotational ductility (θ_u/θ_y) as the calculation of yield rotation is not singular value [19].

The testing of beams and columns under transverse loading will be the basis for element level performance (refer **Figure 7c**). The building elements follow double curvature and under lateral loading both ends undergo plastic deformations

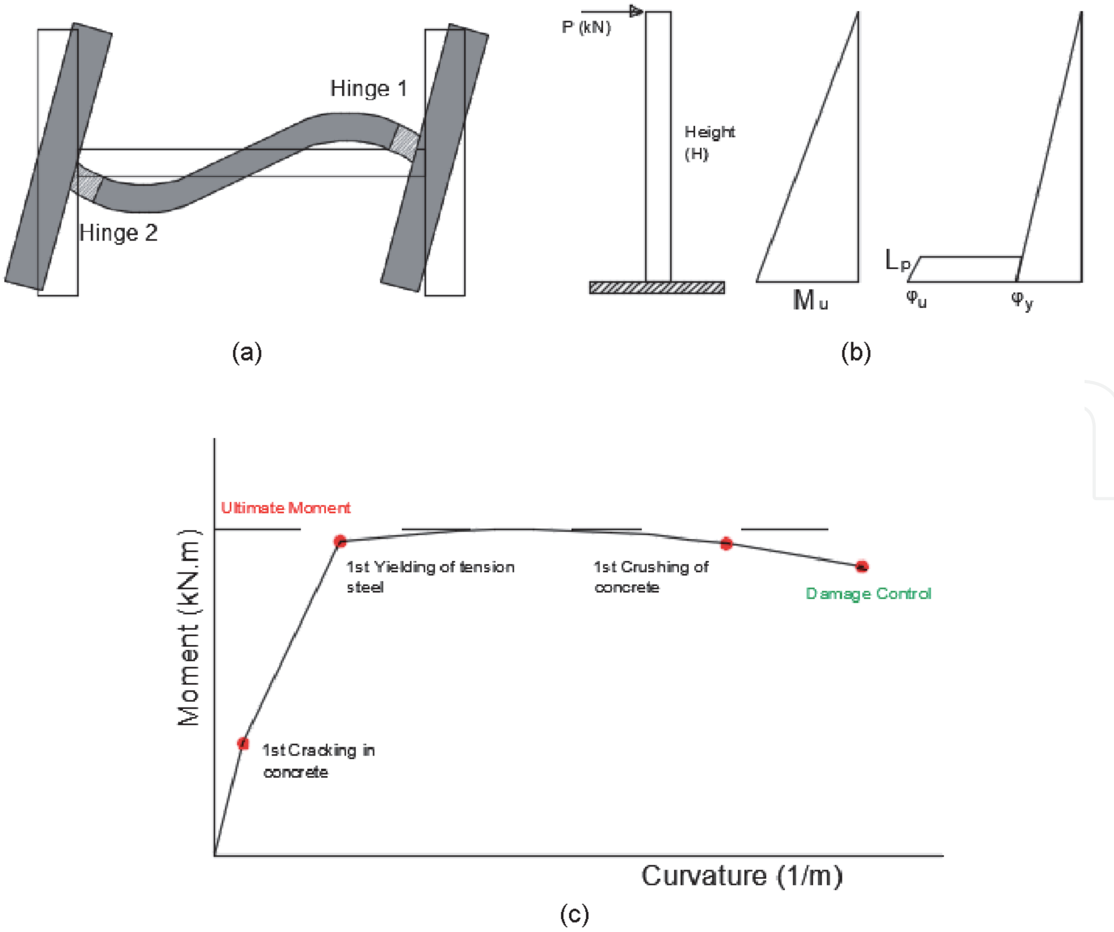

Figure 7.
Element level analysis framework under transverse loading. (a) Double curvature in beams/columns. (b) Plastic analysis of column. (c) Testing of elements under transverse loading.

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forming two hinges (refer **Figure 7a**). The curvature can be found using strain rates and member ($\boldsymbol{M} - \boldsymbol{\varphi}$) curve is used for managing performance at element level. The number of lateral load resisting beams and columns that can be accepted to undergo damage is the decision of either the regulatory bodies or the stakeholders which will influence the target performance to be achieved by design engineer. A sample performance level prescribed by TEC-2007 for Life Safety (LS) gives the basis for defining and making a building with mitigated risk (refer **Figure 8**).

However, such limits are not prescribed by IS-1893 and makes it more critical for engineers to select and debate performance levels with their clients or stakeholders. Similarly, ASCE-41 suggests the rotation limits for Life Safety (LS) performance level which is 75% use of post-elastic rotation of the member (refer **Figure 9**).

The ultimate rotation limit is suggested by EC-8 for Near Collapse (NC) performance i.e. 100% use of post-yield deformation and Life Safety (LS) is 75% of ultimate rotation limit (refer Eqs. (4)–(7)).

Ultimate chord rotation capacity for Near Collapse (NC) performance level:

$$\theta_{um} = \theta_y + \left(\varphi_u - \varphi_y\right) L_{pl} \left(1 - \frac{0.5 L_{pl}}{L_V}\right) \tag{3}$$

Chord rotation at yield:

$$\theta_y = \varphi_y . L_V / 3 \tag{4}$$

Length of plastic hinge:

$$L_{pl} = 0.025 L_V + 0.125 h + 0.02 d_b f_y \tag{5}$$

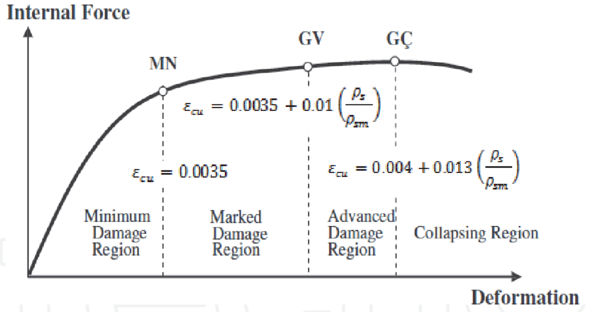

Figure 8.
Definition of criteria for life safety (LS) performance limit (TEC 2007).

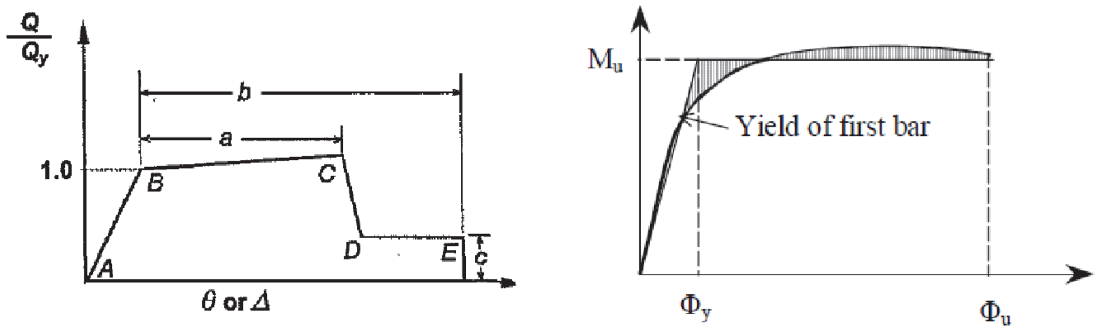

Figure 9.
Definition of criteria for life safety (LS) performance limit (ASCE-41).

Ultimate compression strain in concrete (EC8):

$$\varepsilon_{cu} = 0.004 + 1.4\rho_s f_{yh} \varepsilon_{sm} / f'_{cc} \tag{6}$$

f'_{cc} = confined compressive strength of concrete
f_l = confining pressure
A_{sh} = area of confinement reinforcement

4.2 Tools for section analysis of building elements

The section analysis of confined concrete is dependent on the type of detailing done for beams and columns which undergo in-elastic deformations. ETABS software uses *Mander*-model for confined concrete to estimate increased strength due to lateral reinforcements. However, without complete detailing of the column reinforcement it is not suitable to directly assume the performance. Hence, it is suitable to use a separate tool to generate $(\boldsymbol{M} - \boldsymbol{\varphi})$ and $(\boldsymbol{\sigma} - \boldsymbol{\varepsilon})$ plots and the results of which can be uploaded in ETABS software to give more accuracy in terms of overall performance of building. The two such tools are RCA and SEMAp, which are used to compare the performance limits (refer **Figures 10–12**).

4.3 Mapping of section analysis using design tools and design codes

The mapping of threshold limits using design tools and codes gives an envelope for comparison. The ultimate rotation (θ_u) is sum of yield rotation (θ_y) and plastic rotation (θ_p). The length of plastic hinge is taken as 0.5D and absolute concrete strain (ε_{cu}) is calculated [20, 21]. It is observed that for IS designed building, the

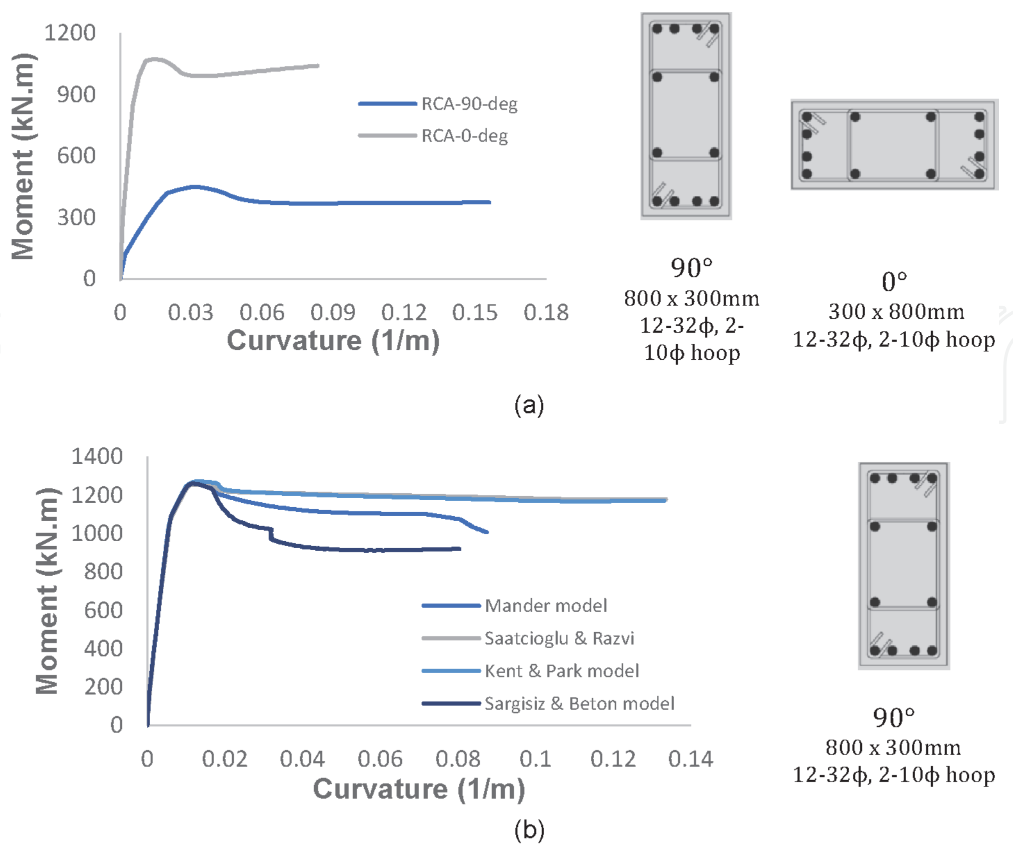

Figure 10.
Section analysis results for RC column designed as per IS code. (a) $M - \varphi$ curve as per RC analysis tool for column designed as per IS code. (b) $M - \varphi$ curve as per SEMAp tool for column designed as per IS code.

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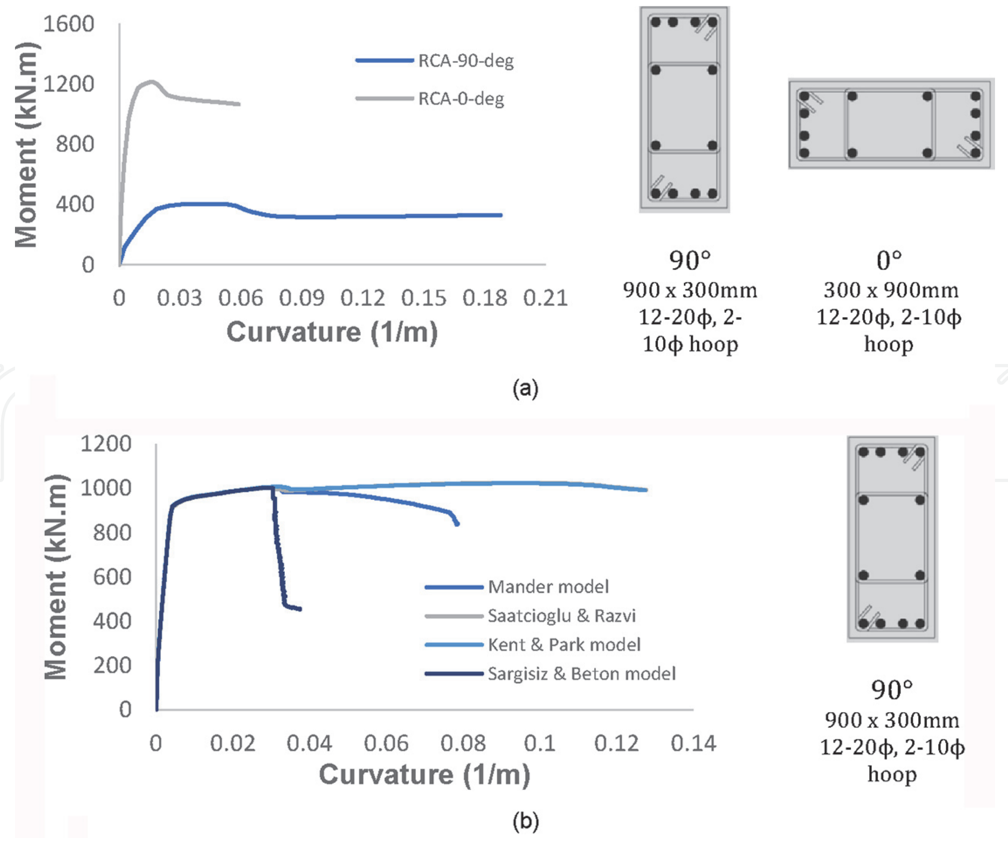

Figure 11.
Section analysis results for RC column designed as per ACI-318 code. (a) $M - \varphi$ curve as per RC analysis tool for column designed as per ACI-318 code. (b) $M - \varphi$ curve as per SEMAp tool for column designed as per ACI-318 code.

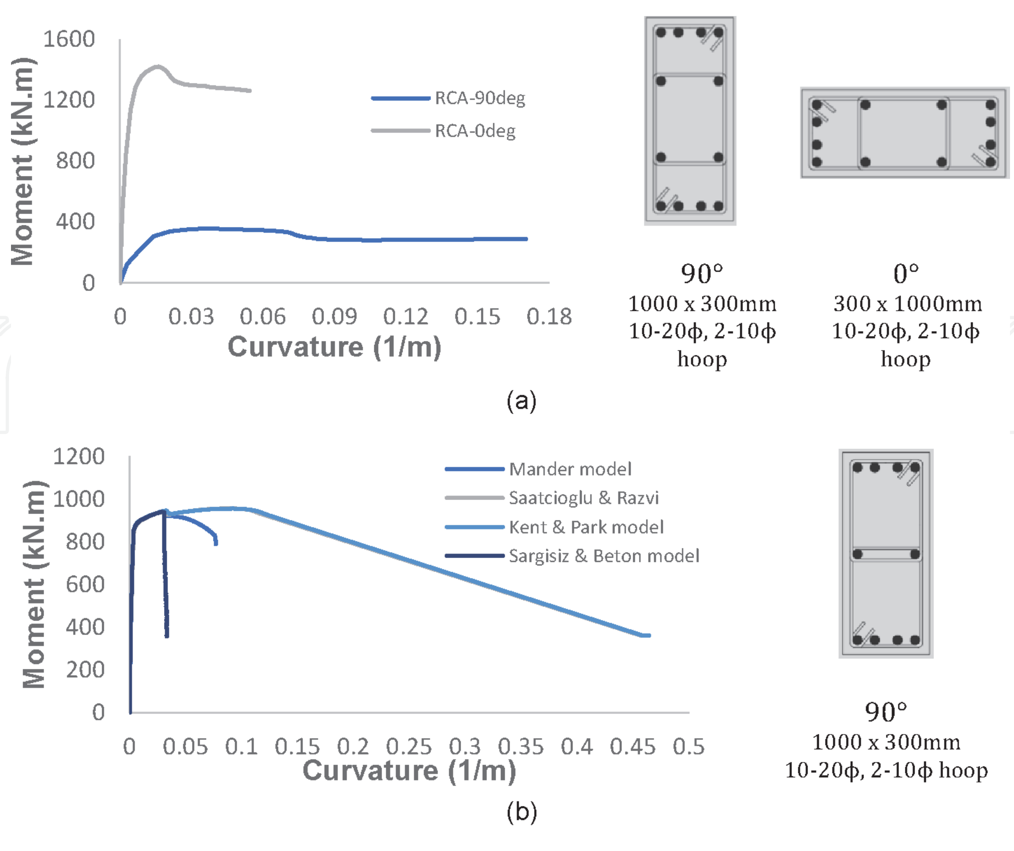

Figure 12.
Section analysis results for RC column designed as per EC8 design code. (a) $M - \varphi$ curve as per RC analysis tool for column designed as per EC8 design code. (b) $M - \varphi$ curve as per SEMAp tool for column designed as per EC8 design code.

[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]
Design case	Tool/Code	M_y (kN.m)	M_N (kN.m)	M_u (kN.m)	φ_y (1/m)	φ_N (1/m)	φ_u (1/m)	ε_{cu}	θ_u
IS Design 300 × 800 12-32ϕ	RCA	120.42	539.86	560.82	0.0021	0.02	0.22	0.024	0.032
	SEMAp	94.78	430.98	364.14	0.0025	0.025	0.22	0.035	0.036
	TEC'07	—	—	369.65	0.0025	0.025	0.139	0.018	0.029
	EC8	—	—	361.06	—	—	—	0.032	0.053
	ETABS	314.58	314.58	348.49	—	—	—	—	0.003
ACI Design 300 × 900 12-20ϕ	RCA	120.77	399.97	329.53	0.0028	0.03	0.187	0.025	0.038
	SEMAp	103.16	259.14	183.21	0.0035	0.028	0.245	0.030	0.044
	TEC'07	—	—	369.65	0.0035	0.028	0.139	0.018	0.031
	EC8	—	—	366.34	—	—	0.192	0.026	0.055
	ETABS	234.53	234.53	330.91	—	—	—	—	0.002
EC8 Design 300 × 1000 10-20ϕ	RCA	125.92	314.63	293.42	0.0026	0.043	0.133	0.011	0.035
	SEMAp	103.2	248.95	173.86	0.0033	0.027	0.218	0.028	0.042
	TEC'07	—	—	372.58	0.0033	0.027	0.103	0.018	0.025
	EC8	—	—	366.16	—	—	0.193	0.026	0.041
	ETABS	265.30	265.30	296.86	—	—	—	—	0.003

Table 3.
Section analysis using design tools and design codes (limits mapping).

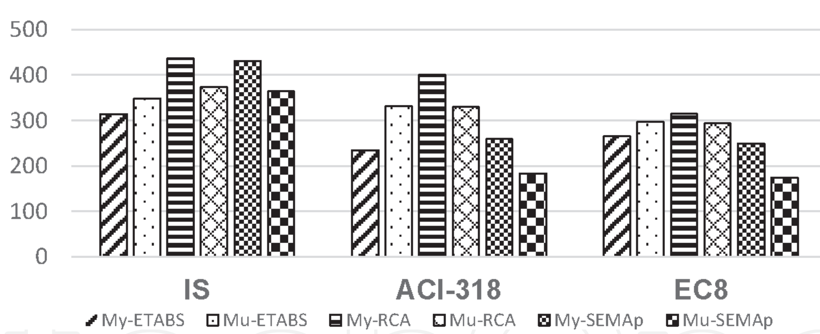

Figure 13.
Comparison of moment (M) at yield and ultimate state for column C19.

results of RCA and SEMAp are matching in terms of moments (**Table 3**; [5]). The results of ultimate strain limits for NC-PL of EC-8 and SEMAp are matching (**Table 3**; [9]). Similarity is there in ultimate rotation values of RCA and SEMAp (**Table 3**; [10]). The ultimate rotation values of columns designed using ACI-318 and EC-8 are found to be in similar range and are higher than rotation limit of IS designed building (**Table 3**; [10]). The variation in moments for all cases is shown in **Figure 13**.

5. Discussion of the problem and its results

The discussion on results is based on design output for three seismic design codes for buildings to mark the comparisons. The details of performance and failure

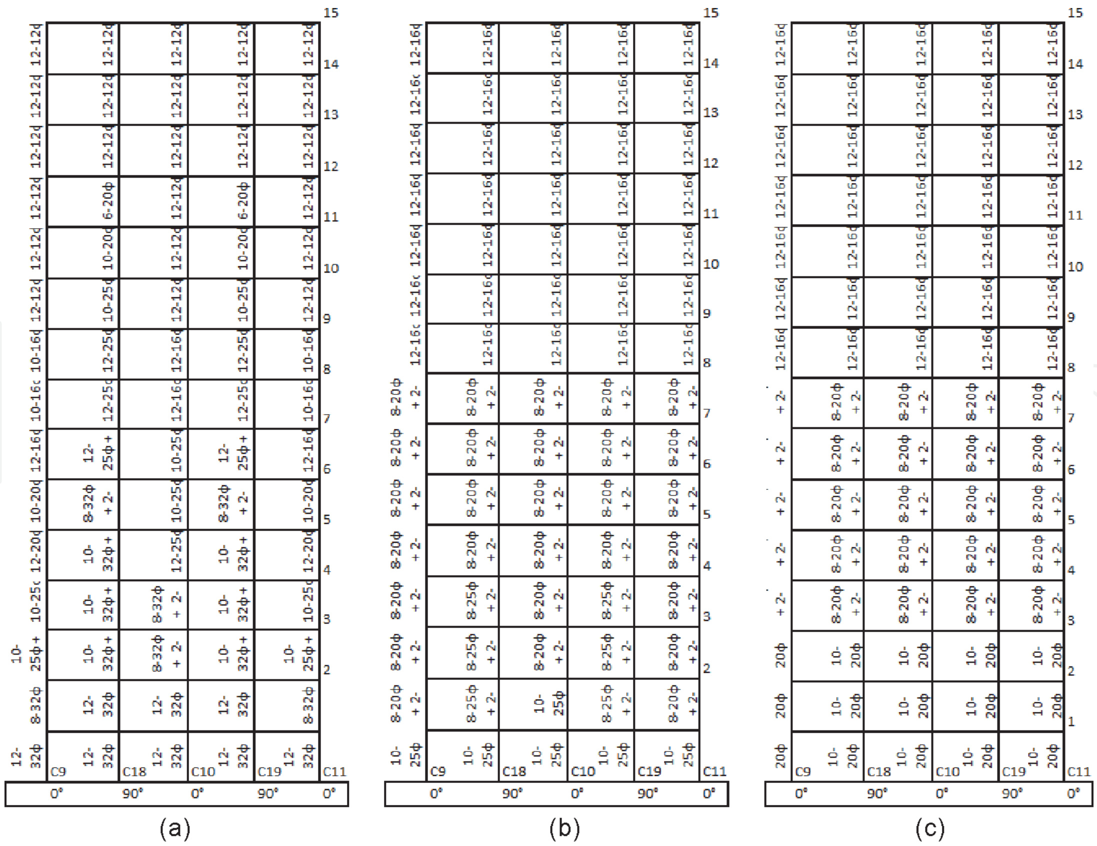

Figure 14.
Comparison of reinforcement in columns. (a) IS code design. (b) ACI-318 code design. (c) EC8 design.

pattern in the following part are discussed to encompass: hinge results, hinge locations, performance point and element level indexes.

5.1 Comparison of design codes on building performance

- The building designed as per Indian Standard codes lead to higher performance in terms of overall capacity of building owing to section sizes and higher rebar requirements. The distribution of steel is better in building designed using ACI-318 and EC-8 (refer **Figure 14**).

- The concept of formation of hinges in columns is not appreciated by seismic design engineers for which the beam to column capacity ratio is maintained in all seismic design codes viz. 1.2 in ACI and 1.4 in IS-13920. Hence, strong column-weak beam is the basic philosophy followed by all codes in different capacities (refer **Figure 15**).

5.2 Comparison based on nonlinear static analysis in ETABS

- It was found that the building designed using IS code resulted in the formation of hinges in columns and the failed columns were at the GF, 3rd, 4th and 5th storey (refer **Figure 5a**). The hinge locations for three designs are given in **Figure 16**. The performance point is compared in **Figure 17**.

- The capacity of building designed as per IS code is higher due to higher percentage of steel in the building elements:

  Case 1: IS-1893 V (kN): 7200 D (mm): 430

Case 2: ACI-318 V (kN): 6200 D (mm): 360

Case 3: EC-8 V (kN): 6000 D (mm): 340

5.3 Element level performance evaluation: Code & tool comparisons

- The yield strain (ε_y) is dependent on yield moment (M_y) and ultimate strain (ε_{cu}) is given by section properties as per EC-8 and TEC-2007. This helps the design engineer to make buildings with specific target.

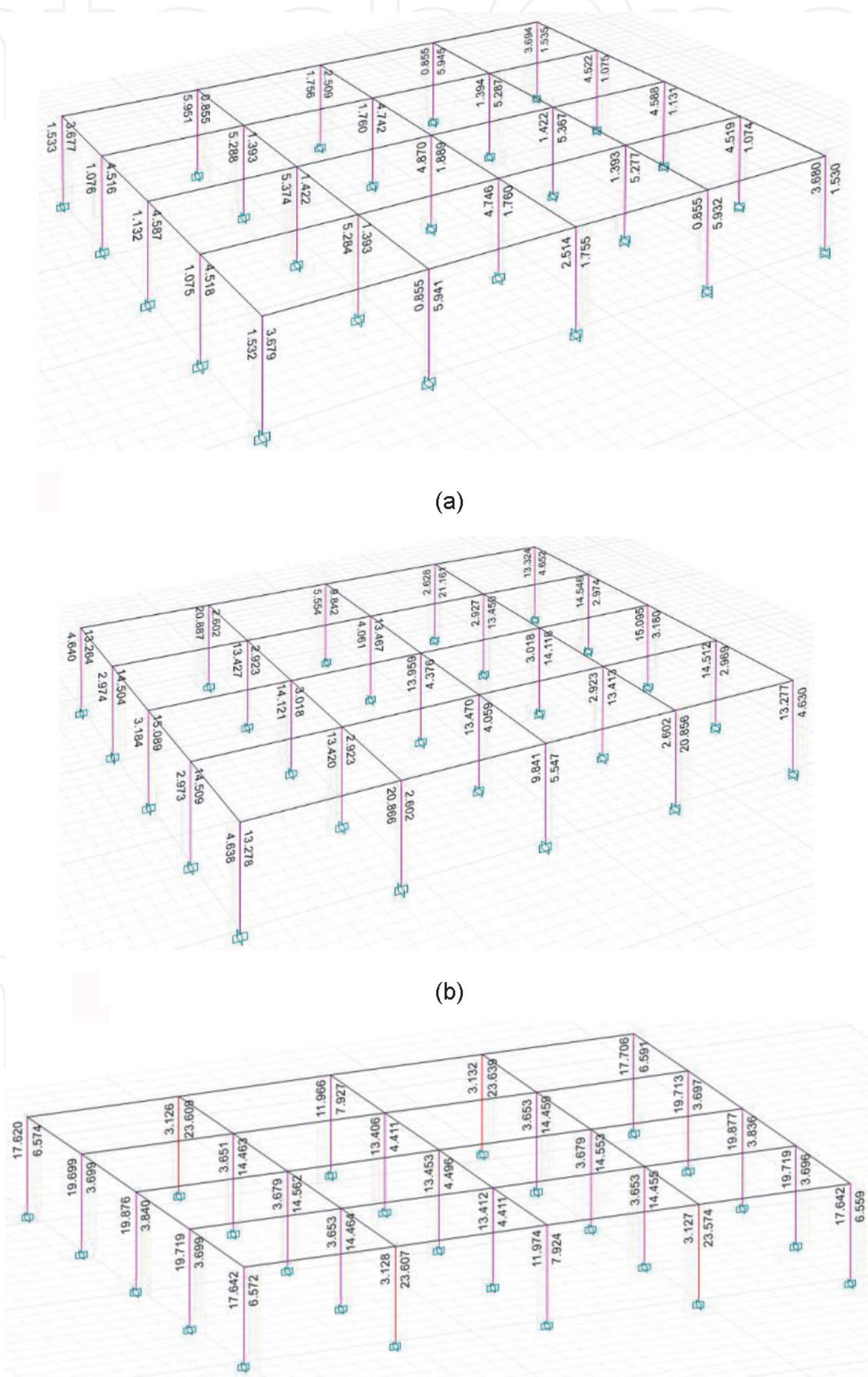

Figure 15.
Comparison of column to beam capacity ratio for GF elements. (a) Design as per IS-13920: Minimum 1.4 ratio in strong direction. (b) Design as per ACI-318: Minimum 2.6 in weak direction. (c) Design as per EC-8: Minimum 3.13 in weak direction.

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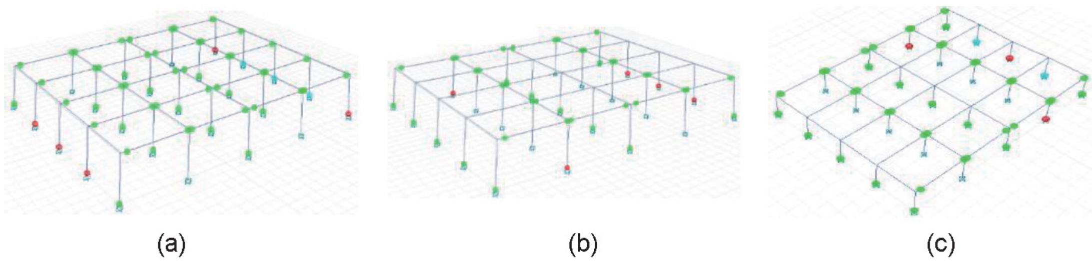

Figure 16.
Failure hinges in GF elements designed as per seismic codes. (a) IS design. (b) ACI design. (c) EC-8 design.

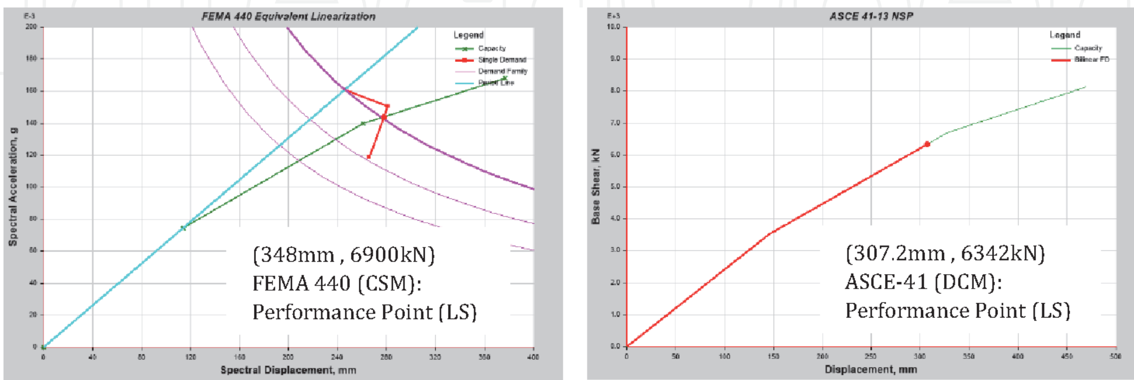

Figure 17.
Performance point of building designed as per IS codes.

- The moment estimates using ETABS, RCA and SEMAp show similarities. The ultimate moment estimation of ETABS and RCA are nearer while the estimate of yield moment of ETABS and SEMAp are nearer. The ductility values are different in RCA and SEMAp (refer **Table 4**).

- RCA and SEMAp tools have distinct advantages to explore. Both the platforms help to exercise performance-based design. These tools give engineers the domain to evaluate elements considering different concrete models and different expressions for plastic hinge length to give more practical output in terms of performance.

- The mapping of threshold limits for Life Safety (LS) performance for column C19 is done based on results of **Table 3**. The ultimate curvature values obtained from RCA and SEMAp are the same i.e. 0.22 (1/m). However, the difference in LS threshold for C19 is in the limiting moment (refer **Figure 18**).

- To map the threshold limits based on the ultimate strain (ε_{cu}), the moments vary significantly when seen from the window of TEC-2007, EC-8, RCA and SEMAp (refer **Figure 19**). Based on the strain limit values, SEMAp is able to map the criteria set by EC-8 for LS performance while RC analysis results show the EC-8 (LS) threshold to be at Near Collapse (NC) performance.

Tool	IS-1893	ACI-318	EC-8
RCA	6.67	6.23	3.09
SEMAp	7.32	8.75	8.07

Table 4.
Curvature ductility (φ_u/φ_y) for column C19.

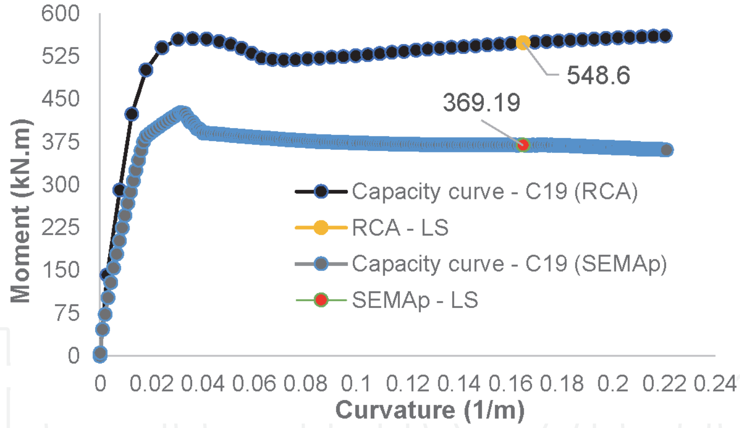

Figure 18.
Comparison of column C19 limits based on ultimate curvature.

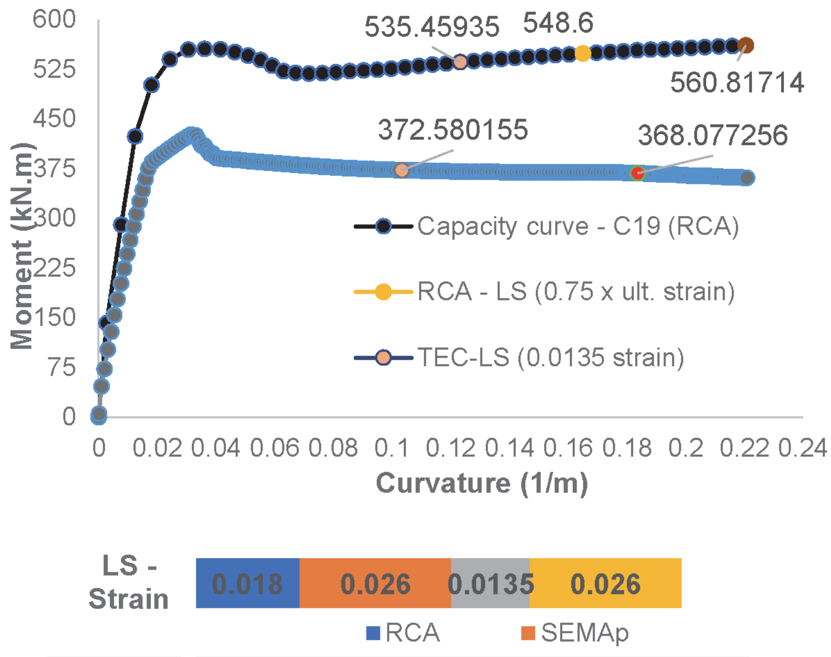

Figure 19.
Comparison of column C19 thresholds based on strain-limits.

5.4 Evaluation of effectiveness of code provisions for target performance

- The building designed using IS codes showed Life Safety (LS) performance level under 0.16 g and 0.18 g hazards while the building performance was Near Collapse (NC) for 0.22 g hazard.
- The building designed using ACI-318 and EC-8 behaved better in terms of failure mode, but it did not meet the LS performance target in three hazard levels. The effectiveness of ACI and EC-8 design provisions as the performance under defined hazard of 0.16 g was better in all respects.
- Controlling the element performance is necessary for improving the overall performance. The use of EC-8 provisions, which shows lowest capacity of building in current case, is suggested. ASCE-41 can be used for existing buildings while the provisions of EC-8 apply towards design of building and leads to less iterations for achieving LS-NC performance level.
- Similarly, TEC-2007 is systematic towards achieving target performance.

DOI: http://dx.doi.org/10.5772/intechopen.94303

6. Conclusion

The building is designed as per current versions of seismic design codes (IS, US, EN) to understand the parameters that swing the performance. The effectiveness of design provisions was evaluated using the non-linear static analysis procedures outlined in ASCE-41 and tools available to support performance-based design. The following points can be summarized from the study:

- Though, pushover analysis and displacement procedures have inaccuracy for capturing higher modes, they significantly contribute towards understanding design problems and highlight limitations of code designed buildings.

- The building to be designed in Ahmedabad city shall consider higher hazard levels than that suggested by BIS.

- Code provisions need to be updated for Gujarat state as it is having five seismic zones (0.36 g – 0.1 g) and a hazard map is required to consider it in design of buildings. BIS provisions are based on intensity parameters, but the seismic-micro-zonation results are not considered in IS-1893.

- The building designed as per IS-1893 can sustain hazard of 0.22 g though it is designed for 0.16 g, due to higher reinforcement in elements (4.2% against 2% in ACI/EN for C19). However, the building did not satisfy the beam mechanism principle and hinges formed in mid stories.

- The building designed as per ACI and EC have better performance in terms of energy dissipation and control of failure. EC-8 has better potential to apply more control for achieving target performance.

- Design tools have significant effect on performance evaluation of building. RCA is based on ACI-08 while SEMAp covers TEC-07 & ACI-08 parameters.

- SEMAp software gives results for four concrete models which can be a feature to use in performance evaluation and hence it has a wider range as compared to RCA tool.

- RCA has feature of generating multiple curves for analysis of many sections and hence it can give faster results. Also, RCA tool has other important curves that can show better analysis insights.

- The results of SEMAp for four concrete models show significant variations that can lead to change in local and global performance of building. This feature is a support to the design and quick method to attempt PBD.

- The tools and software packages shall be checked for failure modes before applying them in design. Hence, correlation of results with physical testing shall be done.

- The design tools support the outputs for new design as they simulate results better for flexure failure. The limitations are discussed in literature [22].

Without knowledge of hazard, design of building is a fluke attempt and seismic-micro-zonation helps in mitigation plan. The vulnerability is judged by design principles and its effectiveness towards safety. The study was concentrated towards design of buildings which will reduce its vulnerability in MCE level earthquakes.

The exposure can be controlled only when design engineers with wholesome view of hazards, methods and safety are able to change the outcome from local level to global level which is the new norm of *fib*-MC2010 [11]. Optimization in design using analysis procedures for code provisions is needed [23]. Attempt shall be towards reduction in non-fatal injuries which form about 96% of the claims of government expenses post disaster [24]. NZSEE 2017 proposes index for existing buildings with design having hazard under-estimated to manage the next earthquake [25].

The focus in India is towards use of ASCE-41 performance limits while this scheme in design is not yet achieved. The performance of buildings has improved from past and newer methods are getting a place in design offices, yet the mechanism to control the performance of buildings shall be the way ahead in line with the disaster mitigation needs. Tools for displacement-based approaches need to be further developed. Experimental and computational procedures cannot be alienated.

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