2nd International Conference on Current Research Trends in Engineering and Technology
© 2018 IJSRSET | Volume 4 | Issue 5 | Print ISSN: 2395-1990 | Online ISSN : 2394-4099
Themed Section: Engineering and Technology

Assessment of Seismic Damage Indices for RC Frame Building Using Non Linear Static Pushover Analysis

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ABSTRACT

This study represents the assessment of seismic damage indices for 4 storey RC frame building designed by conventional force based design (FBD) approach as per IS 1983:2016 (Part I). RC frame building is designed for the base shear coefficient based on empirically obtained period of building as recommended in IS 1893. Then RC frame building is analyzed using nonlinear static pushover analysis. In this study, assessment of seismic damage of 4 storey RC frame building is considered based on the energy dissipated by the structure along its complete displacement path. In present study, three methods are used to identify damage state of structure. The damage is calculated as the ratio of energy at any displacement to the total energy capacity of the structure. The energy dissipation capacity of structure is estimated using pushover analysis.

Keywords: Pushover analysis, RC frame building, force based design (FBD), damage index, expanded energy, total energy

I. INTRODUCTION

Earthquakes are natural and it has high damage potential. By using several principals, it is possible to classify and reduce the resulting social and economic losses, which mainly include loss of human being, destruction to major industrial amenities, structural frames and lifelines.

In the past years many methodologies have been developed for the seismic analysis and damage prediction. Recently, the structural design criteria for new structure are renewed and importance of the assessment of seismic buildings have widened the objectives of the seismic design. Hence, a great effort has been made to advance the existing earthquake resistant design method in order not only to avoid collapse under a critical earthquake but also to limit the damage under reasonable earthquake. However; the application of all these new concepts involves the definition of qualitative damage index and measure.

Many damage indices were used to quantify seismic damage sustaining by whole RC frame structure, each storey in them or individual element. Damage indices are categorized as local and global damage indices. Local Damage indices means damage in individual members, at individual joints or at a particular cross section and global damage indices means damage in entire building. A global damage indices used in literature are assessed combining with overall structure response quantities and local deformation quantities. Damage models can be classifies based on parameters such as deformation based models, hysteresis energy based models, and model based on dynamic parameters and combined models. In the present study, damage estimation methods are based on expanded energy at any deformation. It includes both non-linear deformation and strength degradation of the structure to calculate the damage. Parameters which are used in the damage methods can be evaluated by non-linear pushover analysis.

Pushover analysis is a simplified procedure for the seismic performance evaluation of the structure. The ATC-40[12] and FEMA-356[11] documents have developed modeling parameters, acceptance criteria and procedure for pushover analysis. Krawinkler and Seneviratna pointed out that pushover analysis would offer insight into structural aspects which control performance during earthquakes. Furthermore it was observed that the structure which vibrates primarily in its fundamental mode, the pushover analysis procedure would offer good estimates of local as well as global rigid deformation demands. Pushover analysis methodologies are under continuous development. Gupta and Kunnath[3] observed adaptive pushover analysis method in which external profile is adjusted in each analysis step taking into account the structure's dynamic characteristics and spectra which are used for the determination of seismic loading. Goel and Chopra[4] presented a modal pushover analysis (MPA) which accounts for the contribution of higher modes by conducting separate pushover analysis with external force profile proportional to the structure's significant modes and combing results with the SRSS rule.

In recent decades as construction projects in urban areas have become bigger and their concentration more dense, the construction industry has felt the need for a practical construction risk management based on seismic methods. In India, the 2001 Bhuj earthquake has given a serious damage to many existing RC buildings. Therefore seismic damage evaluation of these building is required. To reestablish an earthquake damaged community as rapidly as possible, a well-organized reconstruction approach is most essential. A destructive damage to buildings occurs when an earthquake strikes a community. Instantaneous damage inspection is necessary to classify the buildings which is safe and which are not to aftershocks. However, since such rapid assessments are performed within a short period of time, the result may be certainly coarse. Several methodologies have been developed to identify seismic damage evaluation of structures and time by time these methodology have been improved.

II. GLOBAL DAMAGE METHODS

Changes in displacement and curvature derived from non-linear static response can be of RC frame use as a good damage indicators even for a small amount of damage, using only one case of loading. This is because the pushover analysis procedure which assume that dynamic response of structure mainly depend on first modal response is a simple and feasible way to assess the non-linear deformation of RC frame, and can be used to calculate the energy capacity of the structure.

In this study, new approach is presented for seismic damage assessment of RC frame structures, using a simple static non-linear static analysis, which consider plastic deformation and strength degradation of the structure. The advantage of the method is, it calculates damage at any point of plastic displacement path and evaluates the margin left for total failure. This involves less calculation and helps in quick assessment of damage state of the structure. Based on capacity curve, the damage state of the structure is estimated at any displacement. Accumulative dissipated energy function is used to evaluate the condition of damage of a multistory RC frame structures.

In the damage methods, the total inelastic energy dissipated by complete RC frame in each load incremental step of the pushover analysis is calculated. Using energy function, the damage state of a structure in each load incremental step of the pushover analysis is estimated and obtaining the capacity curve of the structure (roof displacement vs base shear) can be represented as five stages, as shown in figure 1.

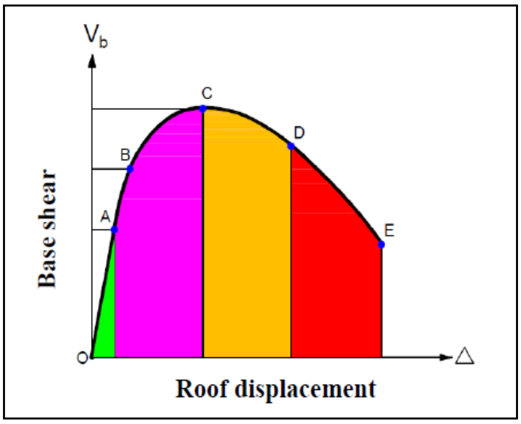


Fig. 1 Damage index estimation methods critical points

Point A represent the elastic state of the structure, point B represent the point at which the initial tangent of the curve deviate by 15%, point C represent the decisive strength of the structure, point D indicate the stage of the structure at which the ultimate strength drops by 15% and point E represent the total collapse stage. The strength carrying capacity of the structure increases in non-linear state in the region O to C. This region is called 'load control region'. As the displacement increases from point C to E, the strength of the structure reduces, so this range is called 'displacement control region'. Possible damage ranges are shown in table 1.

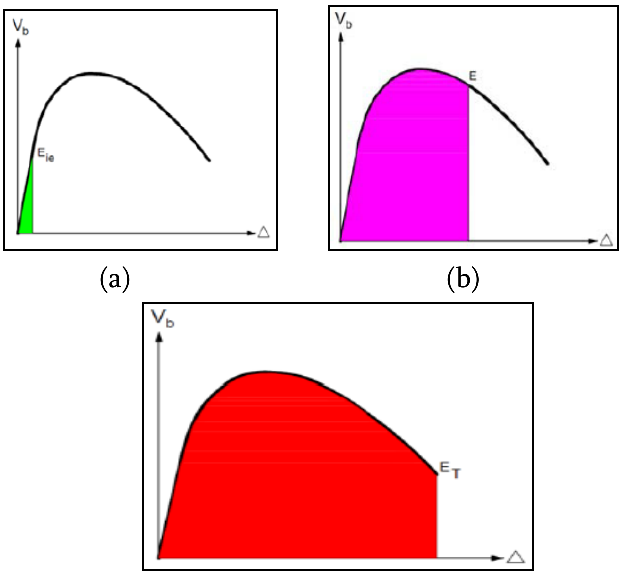
TABLE 1 DAMAGE RANGES

Range of deformation	**Behaviour**	**State**
OA	Elastic	No damage
AB	Strain hardening	Light damage
BC	Ultimate strength	Moderate damage
CD	Strength reduction	Severe damage
DE	Imminent collapse	Extreme damage and collapse

Damage Method - 1

The damage index (Di) is the ratio of expanded energy to the total energy capacity of the structure. Figure 2 indicates the damage parameters used in the model. The initial elastic energy (E_{ie}) is estimated as the area under the curve up to point 'ie' that point is the first yield point of the structure as shown in fig. 2(a). E is the energy absorbed by the RC frame structure, up to point 'i', from where the damage is calculated as shown in fig. 2(b). The total energy capacity E_T of the structure is estimated as the total area under the pushover curve of RC frame as shown in fig. 2(c).

$$D = \frac{(E - E_g)}{(E_T - E_g)} * 100$$



(a) (b)

(c)

Fig. 2 Damage estimation parameter for Method-1

Where E – Represents the energy dissipated at any displacement by the structure, where the damage is to be estimated.

E_{ie} – Represents the energy absorbed by the structure under linear displacement

E_T – Represents the total energy dissipation capacity of the structure.

Damage Method - 2

In this method, the damage parameters are E, E_e, E_T, and E_{ie}, where E_e represents restored elastic energy at point i, all other parameters are same as damage method 1. The damage index (D_i) is represented as the ration of inelastic energy at any point 'i' to the total energy capacity of the RC frame structure.

In this method, instant inelastic energy (E_e) at any point i, is the area of triangle as shown in figure 3. When the damage is to be calculated at the displacement i, where the structure is unloaded and it is assumed that the structure comes back to its static position by moving parallel to the initial tangent of the curve.

$$D = \frac{(E - E_e)}{(E_T - E_{ie})} * 100$$

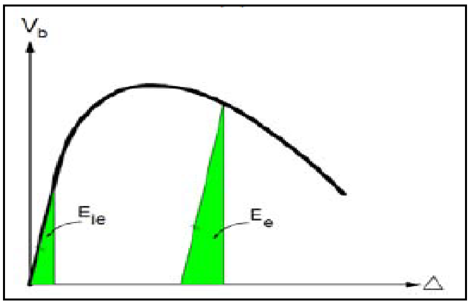


Fig. 3 Damage estimation parameter for Method-2

Where E_e – Represents the instant elastic energy when the structure attains static position.

Damage Method – 3

In this method, damage parameters are energy dissipated under linear response (E_L) and energy dissipated under non-linear response (E_{NL}). At any point i, the damage index (D_i) is stated as the ratio of expanded energy to cause damage at point 'i', to the total energy capacity of the structure to resist damage as shown in fig 4.

$$D = \frac{(E_L - E_{NL})}{(E_{LT} - E_{NLT})} * 100$$

Where E_L – Energy under linear response at a displacement where the damage is to be estimated.

E_{NL} – Energy under non-linear response as a displacement where the damage is to be estimated.

E_{LT} – Energy under linear response at maximum displacement of the structure.

E_{NLT} – Energy under non-linear response at maximum displacement of the structure.

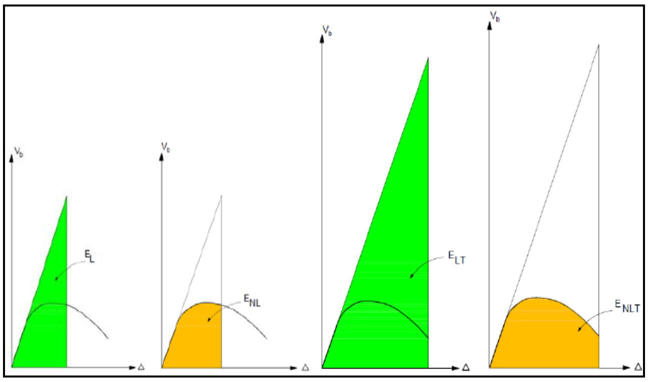


Fig. 4 Damage estimation parameters for Method-3

III. STRUCTURAL SYSTEM CONSIDERED

The buildings are designed for the relevant Indian design codes, employing a linear elastic analysis in SAP 2000 nonlinear software. For this purpose, the beam and column is modelled as 2D frame component with relevant section properties. The design base shear has been calculated by applying mode superposition technique and scaled to the base shear obtained using the relevant empirical formulae for design period, as suggested in IS 1893:2016(Part-I).

The structural system considered for this study are a symmetric in-plane RC Frame structure having 4-storey configuration. Dead load on the building is assigned according to IS 875 (Part I) and Floor Finish load and live load are considered as 1 kN/m² and 4 kN/m² respectively. The buildings are analysed and designed as per IS 1893:2016 (Part I)[15] for seismic zone V with zone factor 0.36 on soil type II, and IS 456 and ductile detailing of RC sections are done as per IS 13920. Columns were assumed to be fixed at base. Grade of concrete and steel assumed were M25 and Fe415 respectively.

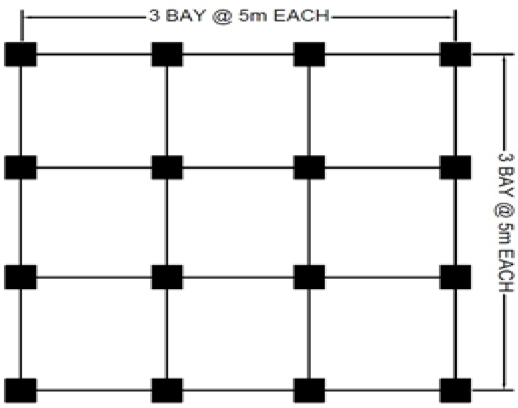


Fig. 5 Plan of 4 storey RC frame

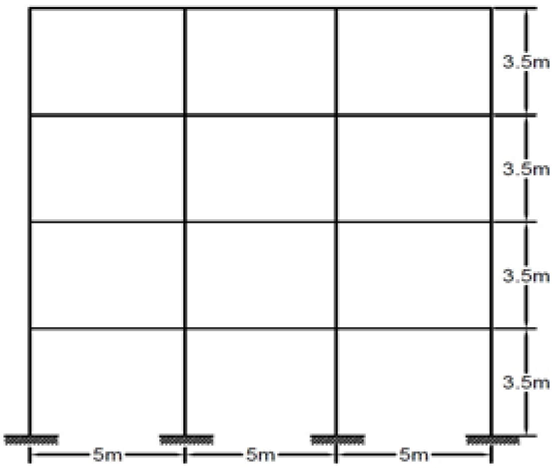


Fig. 6 Elevation of 4 storey RC frame

In this study, a frame building is considered with plan and elevation are as shown in Figure 5 & 6. The storey height has been kept constant as 3.5m. External and internal walls are considered on frame having thickness of 230mm and 115mm. For various loading classes mentioned in IS 875, design seismic load shall be computed using sum of full amount of dead load and appropriate fraction of imposed load as given in IS 1893:2016. The seismic weight of the building is the sum of seismic weight of all floors [14].

$$W = \sum W_i \quad (1)$$

Where, W = Total seismic weight of building and Wi = Seismic weight of ith floor.

The fundamental natural period for buildings are given in IS 1893:2016, clause 7.6.1 as:

$$T = \frac{0.09\,h}{\sqrt{d}} \quad (2)$$

Where, h = Height of building (m), d = Base dimension of building at plinth level (m).

Design horizontal seismic coefficient (Ah) can be calculated from equation suggested in IS 1893:2016, clause 6.4.2 as [14],

$$A_h = \frac{Z\,I\,S_a}{2\,R\,g} \quad (3)$$

Where, Ah = Design horizontal seismic coefficient, Z = Seismic zone factor, I = Importance factor for the corresponding structures, R = Response reduction factor for the given structures, Sa/g = Design acceleration coefficient.

From calculating Total seismic weight and design horizontal seismic coefficient, we can calculate Base shear as,

$$V_B = A_h . W \quad (4)$$

Also we can calculate vertical distribution of Base shear at each floor (Qi) as,

$$Q_i = \frac{W_i h_i^2}{\sum_{i=1}^{n} W_i h_i^2} V_B \quad (5)$$

Where, Qi = Design lateral force at floor i, Wi = Seismic weight of the floor i and hi = Height of the floor i.

Further details on these frames, such as total height, fundamental period, total seismic weight, and design base shear are provided in Table 2.

TABLE 2 SEISMIC PARAMETER FOR RC FRAME

Frame	Height (m)	T_a (sec)	W (kN)	A_h	V_B (kN)
4-Storey	14	0.325	2798.14	0.108	331.08

As stated earlier, the selected structural design for a building is not a distinctive answer available for the demand calculated. Based on an equivalent demand, different designers could choose different design solutions. The RC design solution are designated for these buildings based on common practices adopted by design engineer. For an example, in a RC frame, all the internal column in a storey are selected to have an equivalent section and correspondingly the beam in a particular floor. On the building height, the column sections remain the same over two storeys. Table 3 shows seismic lateral load distribution as per the IS 1893 (part-1).

TABLE 3 LATERAL LOAD DISTRIBUTION

FLOOR	W_i (kN)	h_i (m)	$W_i h_i^2$	Q_i (kN)	V_i (kN)

4	476.37	14	93369.5	128.06	128.06
3	863.06	10.5	95152.48	130.51	258.57
2	863.06	7	42289.99	58	316.57
1	863.06	3.5	10572.5	14.50	331.08
		SUM	241384.5		

Load combinations considered for design of RC section according to IS 1893:2016 are:

1.5(DL+IL)

1.2(DL+IL±EL)

1.5(DL±EL)

0.9DL±1.5EL

TABLE 4 SECTION DETAIL FOR 4 STOREY RC FRAME

Frame	**Members**	**Width (mm)**	**Depth (mm)**	**Reinforcement details**
1st & 2nd Storey	Beam (Top)	250	550	8-20#
	Beam (Bottom)	250	550	6-20#
	Column	475	475	10-25#
3rd & 4th Storey	Beam(Top)	250	550	6-20#
	Beam (Bottom)	250	550	4-20#
	Column	475	475	8-25#

IV. PUSHOVER ANALYSIS AND RESULTS

The performance of complete RC frame structure and its component is defined by the acceptance criteria and provide desirable information for the evaluation or retrofit of building. It refers to the specific limiting values for the deformations and loadings, for deformation-controlled and force-controlled components respectively which constitute for the 'acceptable' seismic performance. ATC-40 and FEMA-273 documents defines the acceptance criteria for pushover analysis. In fig.7 five points stated as A, B, C, D and E are given to define as the force-deflection behaviour of the hinge and three different points mentioned as IO, LS and CP are given to define the acceptance criteria for hinge.

For estimation of the nonlinear static response of the considered building models, lumped-plasticity models representing the potential failure modes in numerous members are developed. Uniaxial moment (M3) plastic hinges and axial force - biaxial moment (P-M2-M3) interaction hinges are assigned at each ends of beams and columns, respectively. The idealized force-deformation curve of ASCE 41-06 (2007) has been assigned to every plastic hinge. The acceptance criteria for various performance levels (IO, LS, and CP) in RC members have also been considered consistent with the ASCE 41 guidelines.

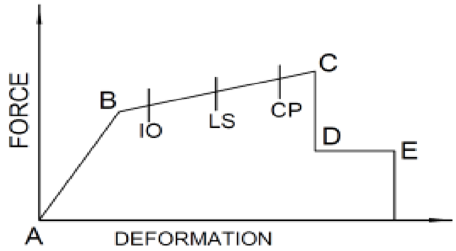


Fig 7 Generalized force deformation curve

Table-5 shows the values of the base shear and lateral displacement at performance point evaluated from the static pushover analysis.

TABLE 5 PERFORMANCE POINT

Base Shear (kN)	**Displacement (m)**
807.6	0.085

TABLE 6 TOTAL AREA UNDER CURVE

X Axis (m)	Value of Y Axis (kN)	Area under curve
0	0	41.06
0.1	821.25	82.89
0.2	836.60	83.68
0.3	837.01	81.87

0.4	800.48	77.07
0.5	741.1	43.34
0.56	703.88	
	Summation	409.93

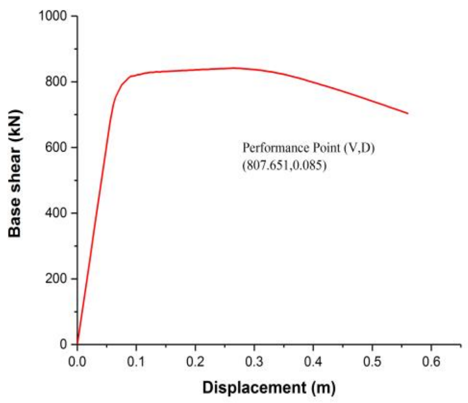


Fig 8 Capacity curve for 4 storey RC frame

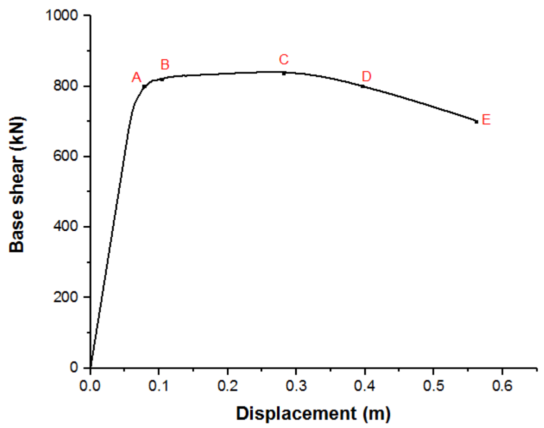


Fig 9 Performance point on capacity curve

The damage estimated at each step of pushover analysis using different damage methods which are presented in table 6 for 4 storey RC frame.

TABLE 7 DAMAGE IN % FOR 4 STOREY RC FRAME

Method of damage	Damage at point				
	A	B	C	D	E
Method 1	0	2	22	33	100
Method 2	0	1	21	32	100
Method 3	0	1	20	30	100

V. CONCLUSIONS

A comparative study on seismic performance of 4-storey RC frame structure designed by conventional force based design approach as per IS 1893:2016 (Part-I) is carried out. The aim for this study is to evaluate damage indices of RC structure and seismic assessment of RC-frame building. The seismic damage assessment methods mentioned in this study are based on nonlinear static pushover analysis & it helps for quick assessment of the damage state of structure for any nonlinear deformation and it gives idea about the margin of safety left for the total collapse. The methods mentioned in this paper are based on energy concept considering deformations and strength degradation and method can be applied for flexure and shear failure case. These methods clearly gives information about distribution of the damage among the structure for any global damage state and intermediate damage state of the structure can be easily estimated by looking forward to the formation of plastic hinges. This methods may be useful for deciding the retrofitting pattern based on distribution of damage of the structure.

VI. REFERENCES

[1]. Helmut Krawinkler and G. D. P. K. Seneviratna, “Pros and cons of a pushover analysis of seismic performance evaluation.” Engineering Structures, Vol. 20, Nos 4-6, pp. 452-464, 1998.

[2]. A. Ghobarah, H. Abou-Elfath and Ashraf Biddah, “Response based damage assessment of structures”. Earthquake Engineering and Structure Dynamics, 28, 79-104 (1999).

[3]. Gupta B. and Kunnath S., “Adaptive Spectra based Pushover Procedure for Seismic

Evaluation of Structures", Earthquake Spectra, Vol. 16, (2), 2000, pp 367-390.
[4]. Anil K. Chopra and Rakesh K. Goel, "A modal pushover analysis procedure for estimating seismic demands for buildings." Earthquake Engineering and Structure Dynamics 2002, pp 561-582.
[5]. Kotanidis, C. and Doudoumis, I.N., "Energy-based approach of static pushover analysis". Proc. The 14th World Conference on Earthquake Engg. October 12-17, 2008, Beijing, China.
[6]. Mario E. & Daniel Padila, "A Damage Index for the Seismic Analysis of Reinforced Concrete Member", Journal of Earthquake Engineering, 13:364-383, 2009.
[7]. Sumit R. Thakur, Sudhir P. Patil and Dr. Keshav K. Sanagle, "Evaluation of Damage Index of High Rise Building Using Nonlinear Static Seismic Analysis." ISSN 2250-2459, Volume 2, Issue 10, October 2012.
[8]. YeongAe Heo and Sashi K. Kunnath, "Damage-Based Seismic Performance Evaluation of Reinforced Concrete Frames." IJCSM, Vol. 7, No. 3, pp 175-182, September 2013.
[9]. Lipika Halder and Santanu Paul, "Seismic Damage Evaluation of Gravity Load Designed Low Rise RC Building Using Non-Linear Static Method". 12th International Conference on Vibration Problems, ICOVP 2015, pp1373-1380.
[10]. Anthugari V. and Pradeep Kumar, "Expanded energy based damage assessment of RC structures: new damage assessment methods". Earthquake engineering research centre, IIIT Hyderabad, Vol. 43, No. 4, pp. 341-350, October-November 2016.
[11]. Federal Emergency Management Agency (FEMA), Prestandard and Commentary for Seismic Rehabilitation of Buildings, FEMA 356-2000, Washington D.C., USA.
[12]. Applied Technology Council (ATC), Seismic Evaluation and Retrofit of concrete Buildings, ATC 40-1996, California.
[13]. Indian Standard Code of Practice for Plain and Reinforced Concrete, IS 456-2000. Bureau of Indian Standard Standards, New Delhi.
[14]. Indian Standard Criteria for Earthquake Resistant Design of Structures Part 1: General Provision and Building, IS 1893-2016. Bureau of Indian Standard, New Delhi.
[15]. IS 1893 Part I, "Indian standard criteria for earthquake resistant design of structures", Part I: General provisions and buildings, Bureau of Indian standards, New Delhi, India, 2016.
[16]. IS 1893 Part II, "Indian standard criteria for earthquake resistant design of structures" Part II:Liquid retaining tanks, Bureau of Indian standards, New Delhi, India, 2014.
[17]. IS 13920: 2016, Ductile design and detailing of reinforced concrete structures to seismic forces-Code of practice (First revision).
[18]. IS 875: 2015, Indian standard code of practice for design loads (other than earthquake) for building and structures (Second revision)