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COMPARATIVE STUDY OF SEISMIC DESIGN GUIDELINES OF MAJOR NATIONAL BUILDING CODES FOR RC SHEAR WALLS

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Abstract

Multi-storey RC frame building with shear walls is preferred construction practice even in high seismic regions to meet the ever-increasing housing demand. Design codes worldwide exercise controls of different design parameters such as, design base shear, ductility capacity, ductility demand, and drift to ensure desired seismic performance. However, significant differences exist in basic provisions of various codes. Indian seismic design standards IS 1893 and ductile detailing guidelines IS 13920 have undergone major revisions in 2016. This manuscript compares important provisions related to the seismic design of RC buildings with shear walls in some of the national seismic building codes viz. ASCE 7, Eurocode 8, NZS 1170.5, IS 1893, and SBC-301. Code provisions regarding minimum horizontal and vertical reinforcement, boundary element requirements, minimum thickness, etc. are compared. Effect of modifications in the latest Indian seismic design codes on the seismic performance is examined by a comparative case study of high-rise RC buildings with shear walls situated in seismic zone IV and designed according to older and latest version of the IS 1893 and IS 13920. Pushover analysis has been performed to compare nonlinear responses of the RC shear wall building in terms of their lateral load capacity as well as displacement ductility. Sensitivity of seismic performance on the design parameters has also been evaluated.

Keywords: *design philosophy; RC shear wall; seismic design codes; design base shear; seismic performance*

1. Introduction

The urbanization and the land cost in urban areas lead the demand to construct buildings from mid to high rise buildings even in high seismic zones. Although, high rise buildings experience higher lateral forces due to wind and earthquakes due to higher flexibility, past earthquake damage surveys reveal the significance of shear walls in framed structure and their performance compared to moment resisting frames during moderate to severe intensity earthquakes[1]. The building systems with shear walls exhibit satisfactory performance in terms of no economic loss and causalities compared to buildings with only moment-resisting frames lead to severe structural damage/collapse of buildings during strong seismic events. Hence shear walls are incorporated for stability and improved performance under lateral loading [2]. Indian seismic design Standard similar to other design standards of the different countries is based on Force-Based Design (FBD) concept in which desired seismic performance of a building, designed according to the Indian seismic design Standards IS 1893 and IS 13920 is indirectly regulated by exercising control on various design parameters such as minimum design force, ductility demand, overstrength etc. [3]. Along with the strength, emphasis of the seismic design standard IS 13920 is enhancement of ductility by proper detailing and proportioning of members by facilitating plastic deformations in desirable ductile modes only [4].

This manuscript compares important provisions effecting seismic performance of RC buildings with shear walls in some of the national seismic building codes viz. ASCE 7, Eurocode 8, NZS 1170.5, IS 1893, and SBC-301. Code provisions regarding minimum horizontal and vertical reinforcement, boundary element requirements, minimum thickness, etc. are compared. Effect of modifications in the latest Indian seismic design codes on the seismic performance is examined by a comparative case study of high-rise RC buildings with shear walls situated in seismic zone IV and designed according to older and latest version of the IS 1893 and IS 13920. Pushover analysis has been performed to compare nonlinear responses of the RC shear wall building in terms of their lateral load capacity as well as displacement ductility. Sensitivity of seismic performance on the design parameters has also been evaluated.

2. Comparison of key provisions of seismic design codes for RC shear walls

This article presents a comparative study of selected major national codes by studying the different code provisions governing the seismic performance. The scope of the present study is limited to RC frame buildings with shear walls. The codes considered in the present study include the ASCE 7, Eurocode 8, NZS 1170.5, IS 1893, and SBC-301 along with their complimentary RC design codes, as these are currently the most advanced and widely applied codes. Table 1 summarizes the different code provisions of these considered major national codes for ensuring desired seismic performance.

2.1 Approximate fundamental period of RC shear wall buildings

The fundamental natural period of the building has its significance in the seismic design for calculating the seismic design base shear as base shear calculations involve the spectral acceleration coefficient. S_a/g varies with the time period of the building,therefore almost all countries seismic design codes have equations to determine the time period. Different country codes provide the formula for obtaining the fundamental period of shear wall buildings but some of the country codes provided formulas with an uncertainty that leads to issues in the design of buildings by the design engineers [5]. The fundamental period of the building depends on the building geometry, method of construction and the materials of the building. These equations mainly consider the effective cross-sectional area, the height of shear wall and the base plan area of the building. As the different countries are following different construction practices, construction material and design loads the period varies according to the building system. Table 2 briefly reviews the approximate fundamental period of RC shear wall buildings by IS 1893:2016 [6], Saudi Building Code 301:2007[7], Eurocode8 [8], NZS 1170.5:2004[9, 10], ASCE 7[11, 12]. Fig. 2 demonstrate the approximate fundamental period of 4-, 8-, and 12-story RC shear wall building with plan dimensions as shown in Fig. 1 along longitudinal and transverse direction, respectively. The equation for the fundamental period given in ASCE and Saudi building code considered the height of the shear wall in the building, the effective cross-section area of shear wall and a number of walls placed along the considered direction whereas other codes do not incorporate the height of shear wall parameter in the fundamental period equation.

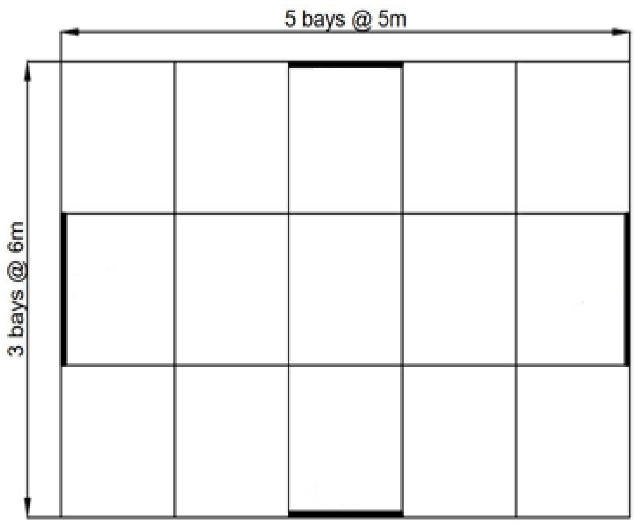
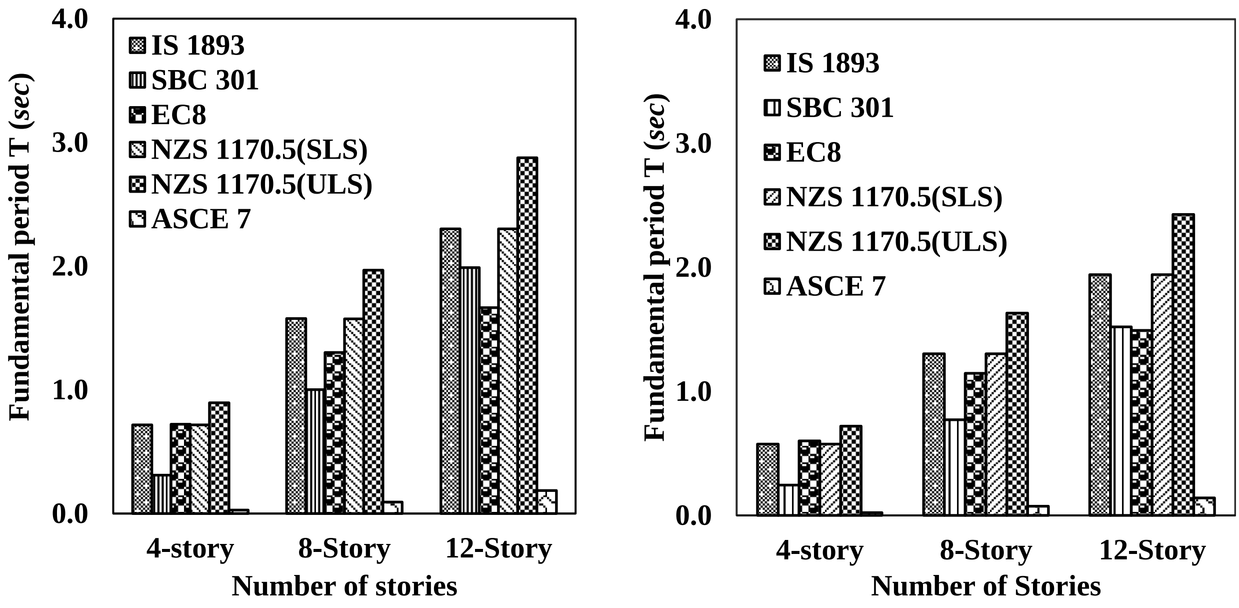


Fig. 1- Plan of the considered building

The fundamental natural period of building is one of the key parameters of the dynamic properties of the building. The seismic design of buildings depends on the calculation of the period of building for estimating the base shear corresponding to the spectral acceleration [13]. The seismic design base shear value and its distribution through its building height affect the design of building members. The design base shear is a function of the fundamental period, the seismic weight of the building, location of building and importance of the building. The fundamental period of buildings is not known before construction different country codes proposed formula for time period evolution. In many country codes the fundamental period of RC buildings with shear wall doesn't consider the effect of varying thickness of the shear wall through building height, openings in the shear wall although these will affect the building mass and stiffness which significantly affect the fundamental period.



(a) (b)

Fig. 2 - Comparison of fundamental time periods of RC shear wall buildings along (a) longitudinal direction; (b) transverse direction

2.2 Response reduction/behaviour factor of shear wall buildings

The seismic design reinforced concrete shear wall buildings consider response reduction/behavior factor in the base shear calculation to consider the effect of inelastic energy dissipation. Indian code specifies two categories of shear wall building systems namely ordinary shear wall and ductile shear wall. The ductile shear wall is designed and detailed as per the revised code guidelines. Based on the framing system response reduction factor values are shown in Fig. 3(a) for ordinary/special moment-resisting frames. Eurocode specifies three ductility classes namely low, medium and high ductility classes for different building frame systems are shown in Fig. 3(b). ASCE code defines the response modification factor for ordinary and special reinforced shear walls as shown in Fig. 3(c). Saudi building code defines response reduction factor values for ordinary and special shear wall with different building systems as shown in Fig. 3(d).

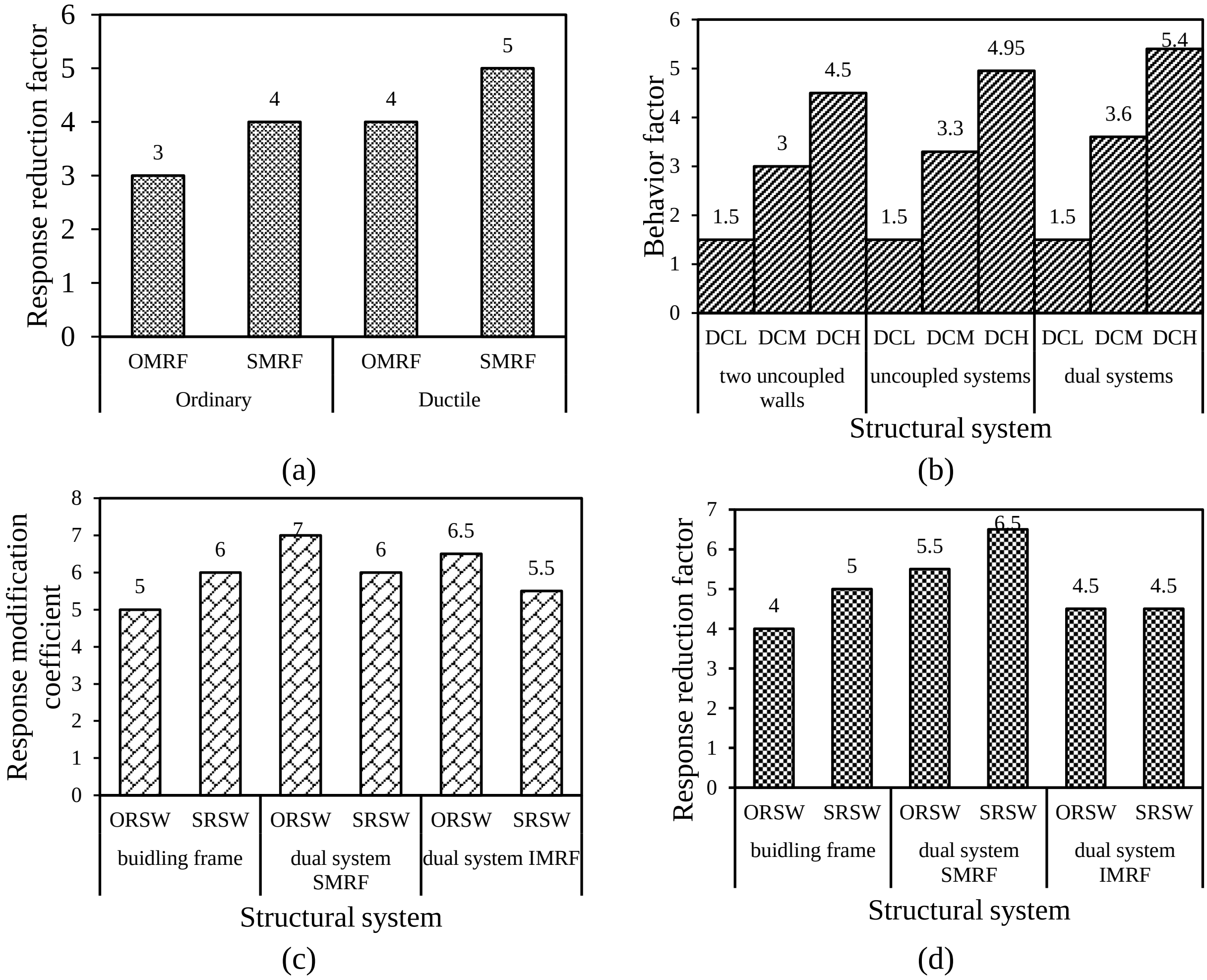


Fig. 3 - Response reduction/behavior factor of shear wall building systems (a) Indian code; (b) Euro code; (c) ASEC code; (d) Saudi code.

OMRF- Ordinary Moment Resisting Frame, SMRF- Special Moment Resisting Frame; DCL- Ductility Class Low; DCM- Ductility Class Medium; DCH- Ductility Class High; ORSW- Ordinary Reinforced Shear Wall; SRSW- Special Reinforced Shear Wall

3. Code provisions on shear wall

Reinforced concrete shear wall buildings are designed in various countries are based on the code provisions recommended by the respective country. The major country codes have different criteria for proving the shear wall thickness, classification of shear wall based on the aspect ratio of shear wall. Minimum horizontal and vertical reinforcement, number of reinforcement layers, the maximum diameter of reinforced bar and boundary element requirements.

3.1 Thickness

Reinforced shear wall thickness is based on the type of shear wall like whether shear wall is a planar shear wall or coupled shear wall. The Indian code states the minimum thickness of shear wall as 150 mm and for buildings with coupled shear walls in any seismic zones, the thickness is proposed as 300 mm. New Zealand code[14] states the minimum thickness of structural walls shall have equal to greater than 100 mm. Eurocode states the minimum thickness is provided as a maximum of the $1/20^{th}$ of clear storey height, 150 mm. Saudi code recommends to provide a minimum thickness of shear wall as 200 mm and the minimum length of shear wall shall be 0.4 times the length of the corresponding direction of the building.

3.2 Classification of shear wall

The shear walls are classified based on the aspect ratio of the shear wall as the behavior of shear wall depends on the aspect ratio like squat shear walls are shear dominant and slender shear wall are flexure dominant. Indian code classifies the shear walls as squat shear wall (aspect ratio less than 1), intermediate shear wall (aspect ratio is in between 1 and 2) and a slender shear wall (aspect ratio is greater than 2). Euro code states the shear wall classification as squat shear wall (aspect ratio less than 2) and slender primary seismic walls (aspect ratio greater than 2). Saudi code classifies shear walls as ordinary and special shear walls.

3.3 Rebar layers

The reinforced bars shall be provided in layers based on the thickness of the shear wall and shear stress demand in the wall. Indian code states that reinforcement shall be provided in two layers when the factored shear stress demand in the shear wall exceeds $0.25\sqrt{f_{ck}}$; f_{ck} is the characteristic compressive strength of concrete and when the wall thickness is more than 200mm. New Zealand code states the shear wall shall be provided with two layers parallel with the face of the wall when the basement wall thickness is greater than 250 mm and other wall thickness greater than 200 mm. Saudi code recommends that reinforcement shall be provided in two layers when in-plane factored shear force exceeds 1/6 $A_{cv}\sqrt{f_c'}$; f_c' is the specified compressive strength of concrete.

3.4 Maximum diameter of Rebar

The maximum diameter of the reinforced bar shall be proportioned to have a uniform reinforcement throughout the cross-section of the shear wall. Indian code recommends that the diameter of the rebar shall not exceed $1/10^{th}$ of the thickness of that portion of the shear wall. New Zealand code states the diameter of the rebar in the wall shall not exceed $1/7^{th}$ of the wall thickness.

3.5 Spacing of rebar

According to Indian code, the maximum spacing of the vertical or horizontal reinforcement shall not exceed the lesser of the $1/5^{th}$ horizontal length of the wall, 3 times the thickness of the web of the wall and 450 mm. Eurocode recommends that the distance between the adjacent vertical bars shall not exceed minimum of 3 times the wall thickness and 400 mm. Saudi code recommends the spacing of reinforcement in vertical and horizontal direction shall not exceed 300 mm.

3.6 Boundary element

The boundary elements are provided along the vertical boundaries of the wall to minimize the stresses in the wall. Indian code recommends that the boundary elements are to be provided when the extreme fibre compressive stress in the wall exceeds $0.2f_{ck}$ due to factored gravity loads and earthquake forces. The boundary elements may be discontinued at elevations where extreme compressive stress becomes less than $0.15f_{ck}$. Boundary elements shall be designed as columns with a minimum reinforcement of 0.8 percent and a maximum of 4 percent of the gross cross-section. New Zealand code states that the thickness of the boundary region of the wall section, extending over the lesser of the plastic hinge length or the full height of the first storey. Saudi code recommends the necessity of boundary element based on the compressive strain level with unfactored forces. The boundary element is to be provided when the compressive strain exceeds 0.002. The length of the boundary element shall be 3 times the thickness of shear wall. Eurocode recommends the length of the boundary element shall be smaller of 0.15 times the length of the wall, 1.5 times the width of the wall.

Table 1 - Comparison of key provisions of seismic design codes for RC shear walls

Design Parameter	**Seismic Design Standards**				
	Indian code [6]	**Saudi code** [7]	**Euro code** [8]	**New Zealand code**[9, 10]	**American code** [11]
Fundamental Natural Period	$T_a = \frac{0.075\, h^{0.75}}{\sqrt{A_w}}$ $T_a \geq \frac{0.09h}{\sqrt{d}}$ A_w is total effective area (m2) of walls in the first storey of the building given by $A_w = \sum_{i=1}^{N_w}\left[A_{wi}\left\{0.2 + \left(\frac{L_{wi}}{h}\right)\right\}^2\right]$ T_a =approximate fundamental natural period (*sec*) h= height of building (*m*) Awi=effective cross-sectional area of wall in first storey of building (m2) Lwi= length of structural wall i in first storey in the considered direction of lateral forces (*m*); d= base dimension of the building at plinth level along the considered direction of earthquake shaking (*m*); Nw=number of walls in considered direction of earthquake shaking. The value of $^{L_{wi}}/_{h}$ shall not exceed 0.9	$T_a = \frac{0.0062}{\sqrt{C_w}} h_n$ $C_W = \frac{100}{A_B}\sum_{i=1}^{n}\left(\frac{h_n}{h_i}\right)^2 \frac{A_i}{\left[1 + 0.83\left(\frac{h_i}{D_i}\right)^2\right]}$ h_n= the height above the base to the highest level of the structure (*m*) A_B= base area of the structure (*m2*) A_i= area of shear wall "i" (*m2*) D_i= length of shear wall "i" (*m*) n= number of shear walls in the building effective in resisting lateral forces in the direction under consideration	$T_1 = C_t H^{\frac{3}{4}}$ $C_t = \frac{0.075}{\sqrt{A_c}}$ $A_c = \sum\left[A_i\left(0.2 + \left(\frac{l_{wi}}{H}\right)^2\right)\right]$ *lwi/H* ≤0.9 where, *AC*=total effective area of the shear walls in the first storey of the building (*m2*) *Ai*=effective cross-sectional area of shear wall *i* in the direction considered in the first storey of the building (*m2*) *lwi*= the length of the shear wall i in the first storey in the direction parallel to the applied forces (*m*)	$T = 1.0 k_t {h_n}^{0.75}$ for the serviceability limit state $T = 1.25 k_t {h_n}^{0.75}$ for the ultimate limit state $k_t = \frac{0.075}{\sqrt{A_c}}$ $A_c = \sum A_i \left(0.2 + \frac{L_{wi}}{h_n}\right)^2$ A_c=total effective area of the shear walls in the first storey in the building (*m2*) h_n= height from the base of the structure to the uppermost seismic weight or mass (*m*) L_{wi} = length of structural wall I in first storey in the considered direction of lateral forces (*m*)	$T_a = \frac{0.00058}{\sqrt{C_W}} h_n$ $C_W = \frac{100}{A_B}\sum_{i=1}^{x} \frac{A_i}{\left[1 + 0.83\left(\frac{h_n}{D_i}\right)^2\right]}$ where, *AB*= base area of structure (*m2*) *Ai*= web area of shear wall *i* (*m2*) *Di*= length of shear wall (*m*) *x*= number of shear walls in the building effective in resisting lateral forces in the direction under consideration h_n = is the height above the base to the highest level of the structure (*m*)
Thickness	{ 150 *mm* 300 *mm* for coupled shear wall	200 *mm*	{ $\frac{1}{20}$ *th* of clear storey height 150 *mm*	100 *mm*	Greater of { 4 *inches* $\frac{1}{25}$ th lesser of unsupported length and unsupported height
Classification	{ squat shear wall Intermediate shear wall Slender shear wall	{ Ordinary shear wall Speial shear wall	{ Squat shear wall slender shear wall	{ Squat wall slender wall	{ ordinary structural wall special structural wall
Rebar layers	Two layers { shear stress exceeds $0.25\sqrt{f_{ck}}$ thickness exceeds 200 *mm*	Two layers when in-plane factored sear force exceeds 1/6 $A_{cv}\sqrt{f_c'}$; A_{cv} is total cross-sectional area.	Web reinforcement should have two curtains of bars with same bond strength.	Two layers when thickness exceeds 200 *mm*	At least two curtains of reinforcement shall be used if Vu exceeds 2Acv$\lambda\sqrt{f_c'}$; Acv is gross area of concrete section; f_c' is the specified compressive strength of concrete; λ is modification factor; Vu factored shear force.
Maximum diameter of rebar	Shall not exceed 1/10th of thickness	Shall not exceed 1/7th of thickness	Shall not exceed 1/8th of width of web.	Shall not exceed 1/7th of thickness	Shall not exceed 1/7th of thickness
Spacing of rebar	Shall not exceed { $\frac{1}{5}$ th length of wall 3 thickness of wall 450 *mm*	Shall not exceed 300 *mm*	Shall not exceed { 3 times thickness of wall 400 *mm*	Shall not exceed { 3 times thickness of wall 450 *mm*	Shall not exceed { $\frac{1}{5}$ th length of wall 3 thickness of wall 18 *inches*
Boundary element	When stress exceeds $0.2 f_{ck}$	Compressive strain exceeds 0.002	Smaller of { 0.15 times length of wall 1.5 *timeswidth of wall*	Full height of first storey	When stress exceeds $0.2 f_c'$
Openings in wall	Shear strength at critical section passing through openings shall be verified.	Additional reinforcement of 130 *mm2* shall be provided around the opening within a distance of 400 *mm*.	Random openings shall be avoided.	Additional reinforcement shall be provided at least 600 mm beyond the corners of the openings	Flexural and shear strength shall be verified at the sections passing through openings.
Coupling beam	Shall have at least 4 bars of 8 *mm* diameter with spacing not exceeding 100 *mm*.	Aspect ratio of coupling beam shall be less than 4. coupling beams shall be assumed not to exceed $\frac{5}{6} A_{cp}\sqrt{f_c'}$; where A_{cp} is the cross-sectional area of a horizontal wall segment or coupling beam.	Shall have diagonal reinforcement with side lengths at least equal to 0.5bw; where bw is the width of the web of a beam.	Coupling beams shall be avoided where Lnd/hb exceeds 4; where, hb is the overall depth of the beam, Lnd is clear span of beam.	Coupling beams with aspect ratio less than 2 and with Vu exceeds 4Acw$\lambda\sqrt{f_c'}$ shall be reinforced with two diagonally placed bars symmetrical about the midspan; Acw is area of coupling beam resisting shear.

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3.7 Openings in the wall

Shear wall constructed throughout building height will be effective compared to shear wall with openings as the openings in the wall reduce the strength of the wall so preferably construction of shear walls throughout yields better results. Shear wall placed at lift core and the outer periphery of wall may be having openings for serving floor access and windows respectively, in that case, it should be considered in the analysis, design and detailing of reinforcement at openings. Indian code recommends that when openings are provided in shear wall it should be verified for shear strength at a critical section passing through the openings and the additional reinforcement shall be provided which shall be equal to interrupted rebars and these rebars shall be continued to full storey height.

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3.8 Coupling beams

The shear walls located near to each other in the same plane can be connected by the coupling beam. The coupling beam shall be designed and special detailing is required for effectively transferring the earthquake-induced stresses. Indian code recommended that coupling beam design shall be checked for earthquake-induced stresses and at least 4 bars of 8 mm diameter should be provided along each diagonal. The longitudinal reinforcement provided in the coupling beam shall have confinement reinforcement with spacing not exceeding 100 mm and diagonal reinforcement shall be extended into the wall with 1.5 times the development length. Saudi code allows coupling only when the aspect ratio of the coupling beam is less than 4 and the shear strength of the coupling beam shall not exceed 5/6 $A_{cp}\sqrt{f_c'}$ and a minimum of 4 bars in each diagonal of coupling beam. A_{cp} is the cross-sectional area of a horizontal wall segment.

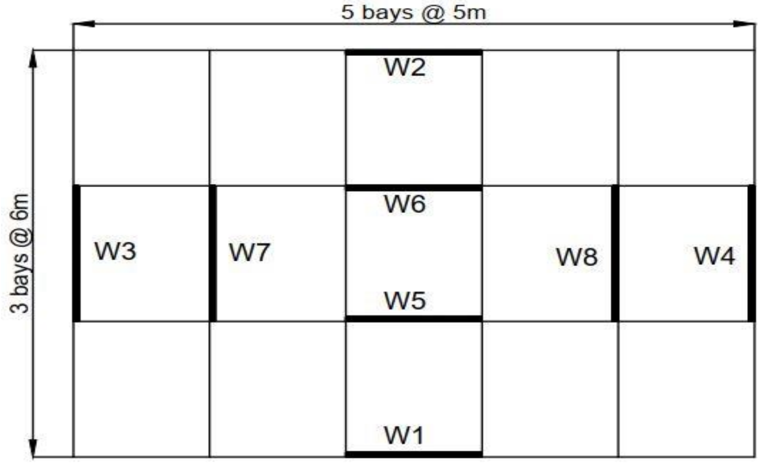


Fig. 4 - Plan of the Considered Building 2.

The time period of the two buildings (Fig.1 and Fig.4) with properties mentioned in the Table 2 is studied for comparison of the period of shear wall buildings according to the Saudi Building Code. The fundamental period is obtained from the model analysis by modelling the two-building model with the same material, loading and analysis method except that the shear walls in building 2-1 are continuous throughout building height whereas building 2-2 is having two of the shear walls along each direction are up to half the building only. The approximate fundamental period obtained from the expression given in the Saudi Building Code for building 2-1 along the longitudinal direction is 0.219 sec and the transverse direction is 0.173 sec. The fundamental period of the building 2-2 along the longitudinal direction is 0.091 sec and the transverse direction is 0.076 sec. The period values obtained for both the building represent the building 2-2 is stiffer than the building 2-1 but the building 2-1 is having shear wall throughout building height so the stiffness of this building should be higher than building 2-2. The model analysis results of the time period of building 2-1 along the longitudinal direction are 0.108 sec whereas building 2-2 period is 0.116 sec that represents that the lengthening the period of building 2-2 represents that it is less stiff than the building 2-1. The building with shear wall throughout its building height with uniform thickness will provide satisfactory results for the time period.

Table 2 Properties of the buildings

Building 2-1 Properties	**Building 2-2 Properties**
height = 12 m	height = 12 m
length shear wall @ longitudinal direction = 5 m length shear wall @ longitudinal direction = 6 m	length shear wall @ longitudinal direction = 5 m length shear wall @ longitudinal direction = 6 m
thickness of wall = 0.15 m	thickness of wall = 0.15 m
shear wall area @ longitudinal direction = 0.75 m^2 shear wall area @ longitudinal direction = 0.90 m^2	shear wall area @ longitudinal direction = 0.75 m^2 shear wall area @ longitudinal direction = 0.90 m^2
height of all the walls = 12	height of interior wall W5, W6, W7, and W8 = 6m

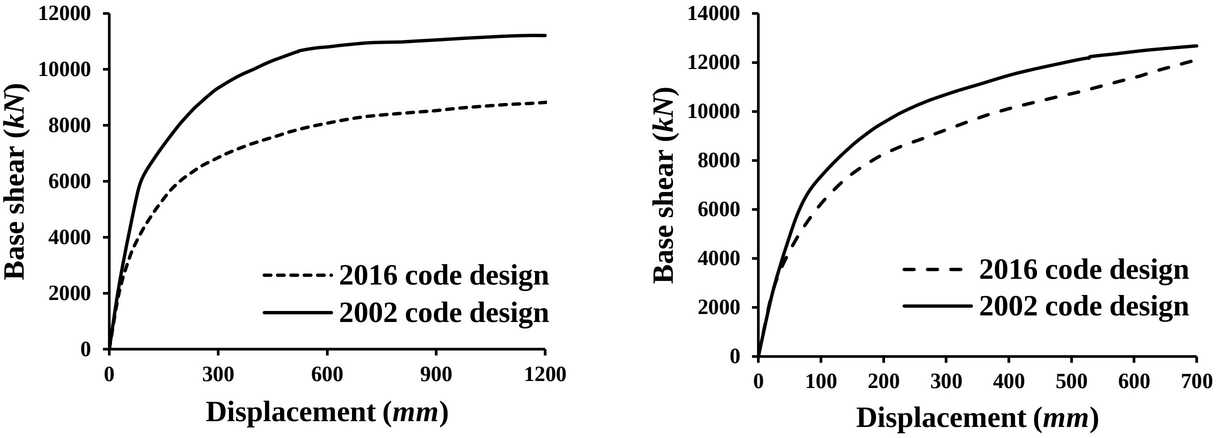
4. Analysis and design of considered buildings

Nonlinear static analysis is performed on the 8-storey building, each storey height is 3.3 m with plan dimension as shown in fig. 1, one of the building models modelling as per IS 1893:2002[15-17] and another building model is designed as per IS 1893:2016[18] using ETABS[19]. The beams and columns are modelled as line elements and shear wall is modelled as shell element. Shell model is widely used for finite element modelling of shear wall. The shear wall modelled in the considered is a planar shear wall with six degrees of freedom is considered in the analysis. The thickness of shear wall is 20 times the largest diameter of a reinforced bar in the beam that is parallel to the shear wall. The building is assumed to be located on medium soil in zone IV with peak ground acceleration of 0.24g as per Indian standards. Both building models are having the same dead and live loads as per IS 875(Part-1)[20] and IS 875(Part-2)[21] respectively. The exterior beams are having a wall with 230 mm thickness and interior beams are having a wall with thicknesses 115 mm. The slab is modelled as the rigid diaphragm.

5. Comparison of seismic performance of the buildings designed with revised and older Indian seismic standards

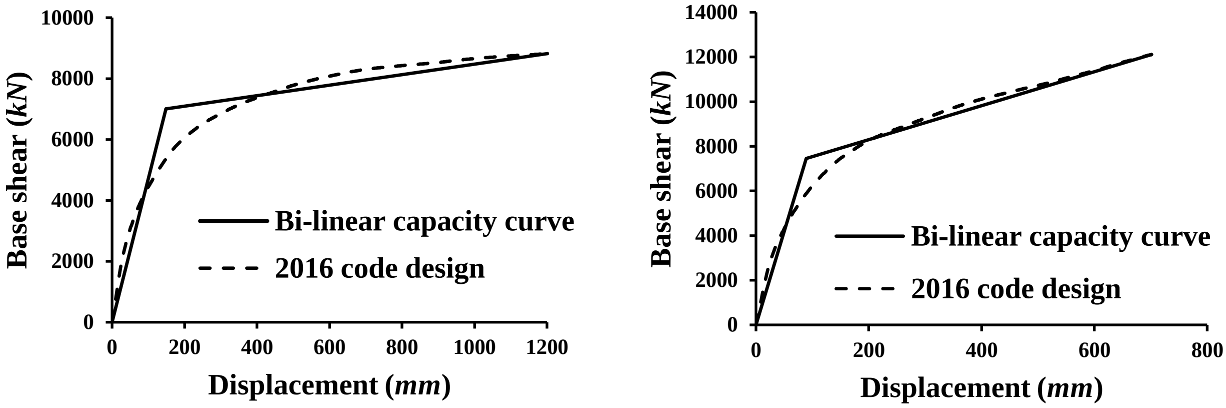
The capacity curves of the of RC shear wall building designed according to older and revised seismic design standards along longitudinal and transverse directions are shown in Figs. 5-7. It can be observed from the comparison of capacity curves of RC shear wall building designed according to older and revised seismic design standard that shear wall building designed according to older standard is showing higher yield and ultimate strength as compared to its revised counterpart. The yield and ultimate strength through bilinearization are found to be increased by 35% and 27% along longitudinal direction and 26% and 5% along transverse direction. The initial stiffness is found to be increased by 51% and 32% along the longitudinal direction and transverse direction respectively for the building designed according to the older standard as compared to its revised counterpart. The design base shear of the building designed as per older design code is found to be

117% higher along the longitudinal direction and 72% higher along transverse direction compared to the revised code. The displacement ductility of the building designed as per revised designed code is found to be 12% higher along the longitudinal direction and 8% along the transverse direction compared to the older design code. Hence the building designed according to older code leads to higher design base shear resulting higher seismic performance in terms of strength and stiffness.



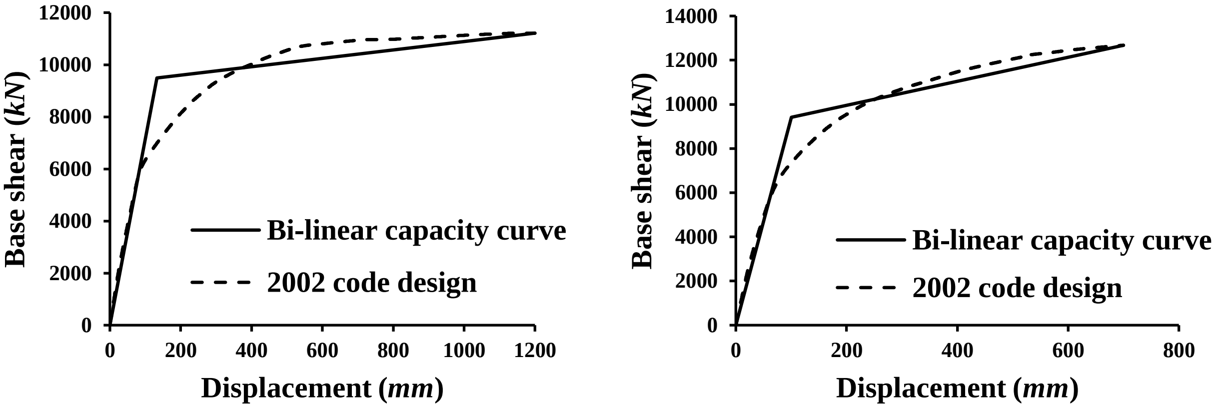
(a) (b)

Fig. 5 – Comparison of capacity curve of high-rise shear walled building along (a) longitudinal direction; (b) transverse direction



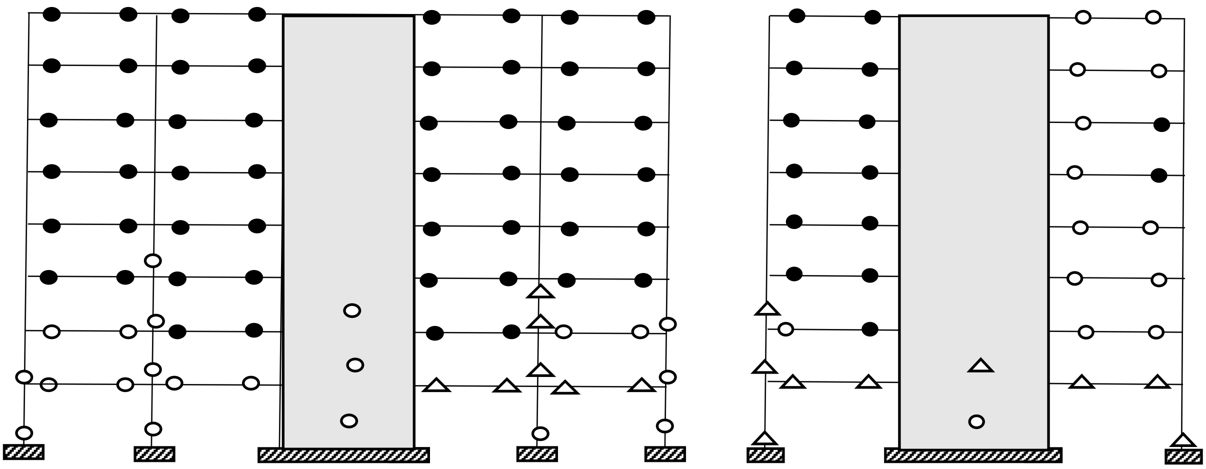
(a) (b)

Fig. 6 – Comparison of bi-linear capacity curve of high-rise shear wall building designed as per 2016 code along (a) longitudinal direction; (b) transverse direction



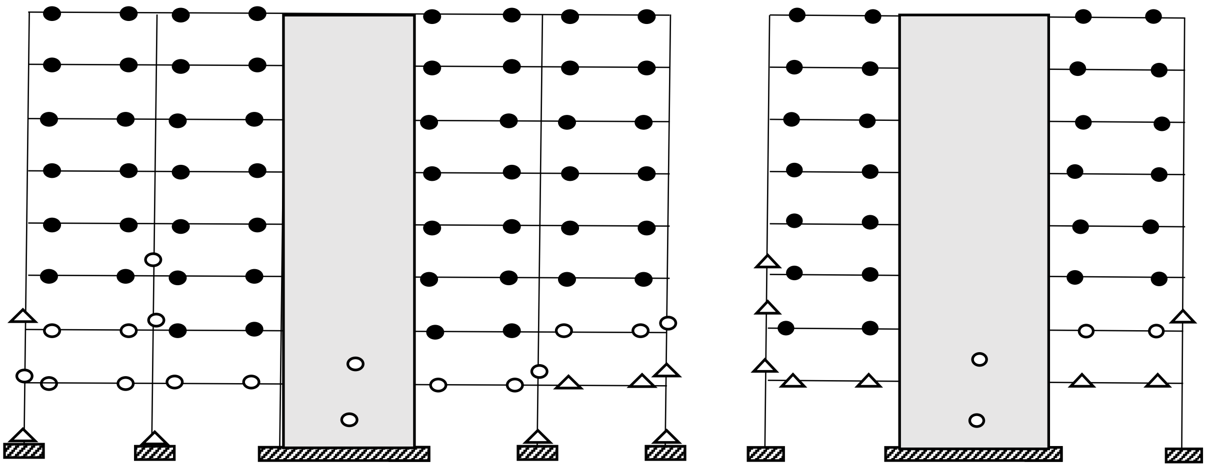
(a) (b)

Fig. 7 – Comparison of bi-linear capacity curve of high-rise shear wall building designed as per 2002 code along (a) longitudinal direction; (b) transverse direction



(a) (b)

Fig. 8 - Failure mechanism 2002 code design (a) longitudinal direction; (b) transverse direction



(a) (b)

Fig. 9 - Failure mechanism 2016 code design (a) longitudinal direction; (b) transverse direction

● Collapse prevention   O Life safety   Δ Immediate occupancy

6. Comparison of failure mechanism of shear wall buildings

The failure mechanism of the high-rise buildings designed as per older and revised Indian standard seismic design codes is shown in Fig.8 and Fig. 9 respectively. The failure mechanism representing the performance levels ranging from immediate occupancy , life safety and collapse prevention of the beams,columns and shear walls. It is observed that building designed as per older code, columns in the first and second floors are reaching life safety level after the collapse of 85% of the beams. Whereas the building designed as per the revised code, columns on the first floor reaching immediate occupancy level after the collapse of the 85% of the beams.

7. Conclusions

The revised Indian standard IS 1893 results in lower design base shear for shear wall buildings as compared to its older counterpart due to the higher time period values compared to older code. The seismic performance of the building designed as per older code shows higher initial stiffness, yield and ultimate force due to higher design base shear considered in the older code. However, the ultimate displacement remains identical for both the buildings designed as per older and latest versions. The failure mechanism of the older code designed building shows marginally better performance due to the higher design force considered. Hence the building designed according to older code leads to higher design base shear resulting in higher seismic performance in terms of strength and stiffness.

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