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## Analysis of Flanged Shear Wall Using Ansys Concrete Model

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### ABSTRACT

The frequent occurrence of the major earthquakes in the Indian subcontinent, and construction of tall buildings, especially over the last two decades demands for the construction of earthquake resistant buildings. Many of the tall buildings had collapsed in recent earthquakes and the reasons attributed were poor design and construction practices. The objective of this work is to discuss the possibilities of modeling reinforcement detailing of reinforced concrete models in practical use. To carry out the analytical investigations, the structure is modeled in a Finite Element software ANSYS. The specimens are modeled as (i) discrete model and (ii) smeared model. It reports the results of the analysis of the flanged shear wall with two different types of modeling under cyclic loading. The consequences of small changes in modeling are discussed and it is shown that satisfactory results are obtained from the two models.

**Keywords:** Shear Wall, Modeling, Cyclic loading, Smeared, Discrete.

### 1. Introduction

Earthquakes demonstrate vulnerability of various inadequate structures, every time they occur. The lessons taught from the aftermath of earthquakes and the research works being carried out in laboratories give better understanding about the performance of the structure and their components. Damage in reinforced concrete structures was mainly attributed to the inadequate detailing of reinforcement, lack of transverse steel and confinement of concrete in structural elements. Typical failures were brittle in nature, demonstrating inadequate capacity to dissipate and absorb inelastic energy. This necessitates a better understanding of the design and detailing of the reinforced concrete structures under various types of loading.

An extensive description of previous studies on the underlying theory and the application of the finite element method to the linear and nonlinear analysis of reinforced concrete structures is presented in excellent state-of-the-art reports by the American Society of Civil Engineers in 1982 [ASCE 1982]. The results from the FEA are significantly relied on the stress-strain relationship of the materials, failure criteria chosen, simulation of the crack of concrete and the interaction of the reinforcement and concrete. Because of these complexity in short- and long-term behavior of the constituent materials, the ANSYS finite element program introduces a three-dimensional element Solid65 which is capable of cracking and crushing and is then combined along with models of the interaction between the two constituents to describe the behavior of the composite reinforced concrete material. Although the Solid 65 can describe the reinforcing bars, this study uses an additional element, Link8, to

investigate the stress along the reinforcement because it is inconvenient to collect the smear rebar data from Solid 65.

## **2. Research Significance**

Antonio F. Barbosa et al (2000) presented a paper considering the practical application of nonlinear models in the analysis of reinforced concrete structures. The results of some analyses performed using the reinforced concrete model of the general-purpose finite element code ANSYS are presented and discussed. The differences observed in the response of the same reinforced concrete beam as some variations are made in a material model that is always basically the same are emphasized. The consequences of small changes in modeling are discussed and it is shown that satisfactory results may be obtained from relatively simple and limited models. He took a simply supported reinforced concrete beam subjected to uniformly distributed loading has been analyzed. P. Fanning (2001) did research on nonlinear models of reinforced concrete beams. The requirement to include the nonlinear response of reinforced concrete in capturing the ultimate response of ordinarily reinforced beams demands the use of the dedicated Solid65 element in ANSYS. The internal reinforcements were modeled using three dimensional spar elements with plasticity, Link8, embedded within the solid mesh. Finite element models of ordinarily reinforced concrete beams and post-tensioned concrete beams, developed in ANSYS using the concrete element (Solid 65) have accurately captured the nonlinear flexural response of these systems up to failure. Anthony J. Wolanski, B.S (2004) did research on the flexural behavior of reinforced and prestressed concrete beams using finite element analysis. The two beams that were selected for modeling were simply supported and loaded with two symmetrically placed concentrated transverse loads. Qi Zhang (2004) presented the application of finite element method for the numerical modeling of punching shear failure mode using ANSYS. The author investigated the behaviour of slab-column connections reinforced with Glass Fibre Reinforced Polymers (GFRPs). SOLID65 and LINK8 elements represented concrete and reinforcing steel bars respectively. A quarter of the full-size slab-column connections, with proper boundary conditions, were used in ANSYS for modeling. The author reported that the general behaviour of the finite element models represented by the load-deflection plots at centre show good agreement with the test data. However, the finite element models showed slightly higher stiffness than the test data in both the linear and nonlinear ranges.

## **3. Design and Detailing of Flanged Shear Wall**

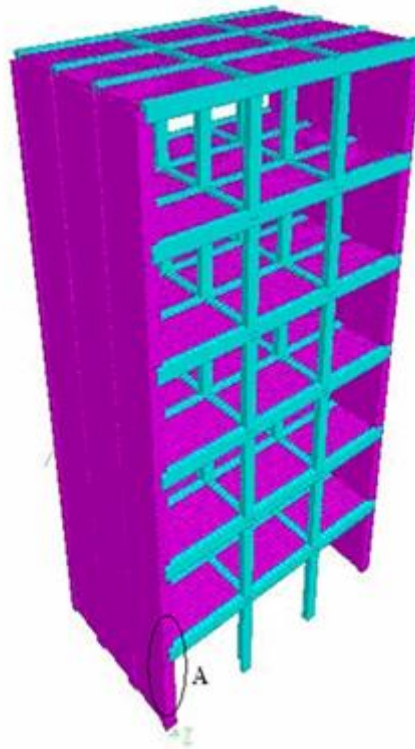
### **3.1 Structure and analytical model**

A six storey RC building in zone III on medium soil is analyzed using the software STAAD – PRO. The analytical model is shown in Figure 1. It is assumed that no parking floor for the building. Seismic analysis is performed using Equivalent lateral force method given in IS 1893:2002 and also by dynamic analysis.

#### **Description of Structure**

No of bays in X direction	=	3 m
No of bays in Y direction	=	3 m
Story height	=	3.5 m
Column size	=	0.45 m x 0.3 m

Beam size	=	0.3 m x 0.45 m
Density of concrete	=	25 kN/m <sup>3</sup>
Live load on roof	=	1.5 kN/m <sup>2</sup>
Live load on floors	=	3 kN/m <sup>2</sup>
Floor finish	=	1 kN/m <sup>2</sup>
Brick wall on peripheral beams	=	230 mm
Brick wall on internal beams	=	150 mm
Density of brick wall	=	20kN/m <sup>3</sup>



**Figure 1:** Analytical model

### **3.2 Computation of design forces**

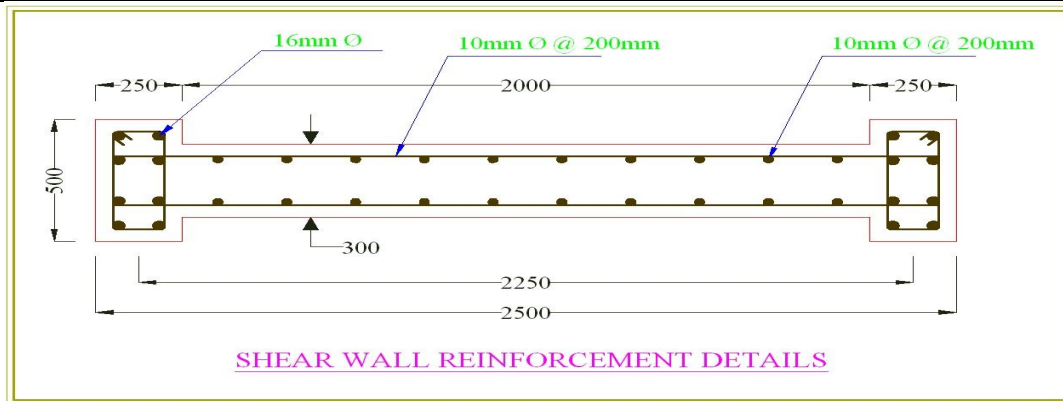
The shear forces, bending moments and axial forces at the bottom of the shear wall for the 13 load combinations (IS 1893(Part 1): 2002) are obtained. Seismic analysis is performed using Equivalent lateral force method and also by dynamic analysis.

### **3.3 Design of Flanged Shear Wall**

The design moment, shear and axial force at the base of the flanged shear wall for a length of 2.5 m obtained from the analysis are 4532.97 kN-m, 285.28 kN and 2038.74 kN respectively. The flanged shear wall is designed for these critical forces as per IS 13920:1993-Annexure I. Reinforcement details of shear wall are shown in Table 1 and Figure 2.

**Table 1:** Reinforcement details of flanged shear wall

Shear wall (Web)	Vertical bars	16 mm bars @ 200 mm c/c.
	Horizontal bars	10 mm bars @ 200 mm c/c.
	Lateral ties	8 mm bars @ 300 mm c/c.



**Figure 2:** Reinforcement details of shear wall

#### 4. Finite Element Modeling

The flanged shear wall is analysed using the finite element software ANSYS. The modeling has been carried out in two ways, (i) discrete modeling and (ii) smeared modeling. For discrete model, the smeared reinforcement capability of the Solid 65 element is turned off for the corresponding real constant. Here, Solid 65 element is used to model the concrete while Link 8 element is used to represent the reinforcement.

ANSYS provides a three-dimensional eight noded solid isoparametric element, SOLID65, to model the concrete. This element has eight nodes with three degrees of freedom at each node – translations in the nodal x, y and z directions. This element is capable of plastic deformation, cracking in three orthogonal directions and crushing. Link 8, three-dimensional spar element is a uniaxial tension-compression element with three degrees of freedom at each node – translations in the nodal x, y and z directions. Plasticity, creep, swelling, stress stiffening and large deflection capabilities are included.

##### 4.1 Sectional Properties (Real Constants)

For discrete model, since there is no rebar data, the real constants (volume ratio and orientation angle) are set to zero and the parameters to be considered for Link 8 element are cross sectional area and initial strain. The sectional properties adopted for discrete model are shown in Table 2.

**Table 2:** Real constants for steel reinforcement (Link 8 element)

Real Constant Set	Element Type	Particulars	Quantity
2	Link 8	Cross sectional Area (m <sup>2</sup> )	201x10 <sup>-6</sup>
	(Vertical reinforcement)	Initial Strain	0
3	Link 8	Cross sectional Area (m <sup>2</sup> )	113x10 <sup>-6</sup>

	(Horizontal reinforcement)	Initial Strain	0
4	Link 8	Cross sectional Area (m <sup>2</sup> )	50x10 <sup>-6</sup>
	(Shear reinforcement)	Initial Strain	0

For smeared model, parameters to be considered are material number, volume ratio, and orientation angles ( $\theta$  and  $\Phi$ ) in X and Y directions respectively. The rebars mentioned in Table 3, rebar1, 2 and 3 refer to vertical, horizontal and shear reinforcements. Volume ratio refers to the ratio of steel to concrete in the element.

**Table 3:** Real constants for concrete (Solid 65 element)

Real Constant Set	Element Type	Particulars	Constants		
			Real Constant for Rebar 1	Real constant for Rebar 2	Real Constant for Rebar 3
1	Solid 65	Material Number	2	2	2
		Volume Ratio	0.009	0.00785	0.00349
		Orientation Angle THETA 1	90	0	0
		Orientation Angle PHI 1	0	90	90

## 4.2 Material Properties

The material properties defined in the model are given in Table 4. For the reinforcing bars, the yield stress was obtained from the experimental test as  $f_y = 432$  MPa and the tangent modulus as 847 MPa. The concrete cube compressive strength  $f_{ck}$  determined from the experimental result is 44.22 MPa, 80% of which is used as the cylinder strength.

The multilinear isotropic material uses the Von Mises failure criterion along with the Willam and Warnke (1974) model to define the failure of the concrete.  $E_c$  is the modulus of elasticity of the concrete, and  $\nu$  is the Poisson's ratio. The characteristic strength of the concrete considered was 25 N/mm<sup>2</sup> and the Poisson's ratio was 0.3.

$$E_c = 5000 \sqrt{f_{ck}} = 2.5 \times 10^{10} \text{ N/m}^2$$

The multilinear isotropic stress-strain curve for the concrete under compressive uniaxial loading was obtained using (1a) and (1b) (Macgregor 1992).

$$f = \frac{E_C \varepsilon}{1 + (\varepsilon/\varepsilon_0)^2} \quad (1 \text{ a})$$

$$\varepsilon_0 = \frac{2f_{ck}}{E_C} \quad (1 \text{ b})$$

where,

$f$  = stress at any strain  $\varepsilon$ ,  $\varepsilon$  = strain at stress  $f$ ,  $\varepsilon_0$  = strain at the ultimate compressive strength.

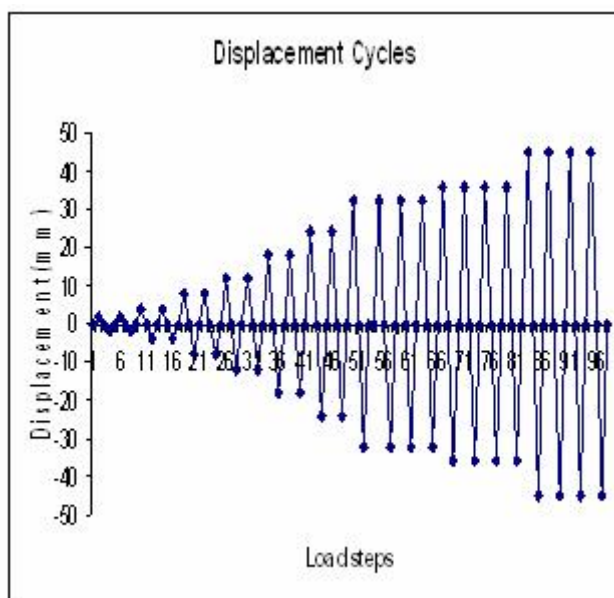
**Table 4:** Material properties (Anthony J. Wolanski, B.S, 2004)

Material Model No	Element Type	Material Properties		
1	Solid 65	Multi Linear Isotropic		
		Reference Point	Strain	Stress
		Point 1	0.00036	9.802 e6 N/m <sup>2</sup>
		Point 2	0.00060	15.396 e6 N/m <sup>2</sup>
		Point 3	0.00130	27.517 e6 N/m <sup>2</sup>
		Point 4	0.00190	32.103 e6 N/m <sup>2</sup>
		Point 5	0.00243	33.096 e6 N/m <sup>2</sup>
		<b>Concrete</b>		
		Shear transfer coefficients for an open crack		0.2
		Shear transfer coefficients for a closed crack		0.9
		Uniaxial tensile cracking stress		3.78 e6 N/m <sup>2</sup>
		Uniaxial crushing stress.		40 e6 N/m <sup>2</sup>
		Biaxial crushing stress		0
		Biaxial crushing stress		0
		Ambient Hydrostatic stress state.		0
Biaxial crushing stress under ambient hydrostatic stress state.		0		
Uniaxial crushing stress under ambient hydrostatic stress state.		0		
Stiffness multiplier for cracked tensile condition.		0		
2	Link 8	<b>Steel</b>		
		Linear Isotropic		
		Ex	2.1x10 <sup>11</sup> N/m <sup>2</sup>	
		PRXY	0.3	
		Bilinear Isotropic		
		Yield Stress	415x10 <sup>6</sup> N/m <sup>2</sup>	
Tang Modulus	20x10 <sup>6</sup> N/m <sup>2</sup>			

**5 Finite Element Analysis**

In ANSYS, the finite element models can be created either using command prompt line input or the Graphical User Interface (GUI). For the present study, the shear wall was modeled using Graphical User Interface. For carrying out the seismic analysis, the command prompt line input data was adopted. For carrying out the analysis, the command prompt line input data is adopted. The convergence criteria used for the analysis are displacement with the tolerance of 0.001.

The analysis has been carried out for the shear wall subjected to reversible cyclic loading. The axial load of 0.5 T is applied on top nodes of the shear wall. Lateral cyclic load is applied at the top nodes in plane with the shear wall. The displacement cycle adopted for the analysis is shown in Figure 3.



**Figure 3:** Displacement cycle

## 6. Numerical Results and Discussions

The modeling and analysis of flanged shear wall has been carried out with two different conditions, such as (i) shear wall with smeared reinforcement (ii) shear wall with discrete reinforcement subjected to in plane reversible cyclic loading. The observations from the analytical studies are briefly described.

### 6.1 Ultimate load and Moment carrying capacity

The ultimate load and moment carrying capacity for the two types of models are shown in Table 5. It can be observed that the ultimate load and moment are comparatively higher for the models with smeared reinforcement, however the variation is within agreeable limits of less than 10%.

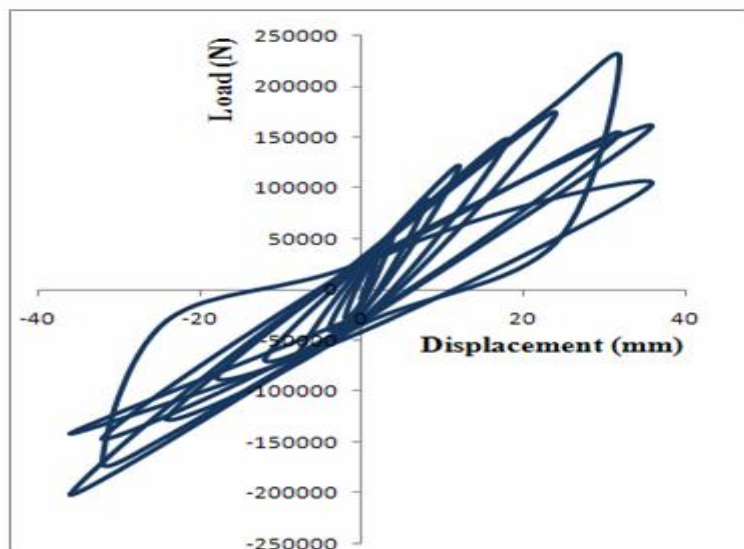
**Table 5:** Ultimate load carrying capacity of models

Description	Ultimate Load (kN)		
	Positive	Negative	Average

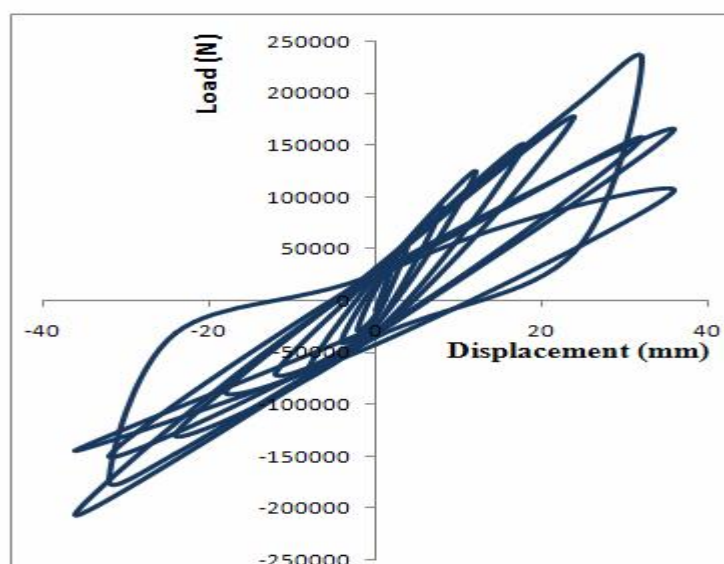
	direction	direction	( $P_u$ )
Shear wall with smeared reinforcement	233.347	235.875	234.611
Shear wall with discrete reinforcement	214.080	214.432	214.256

## 6.2 Displacement Analysis

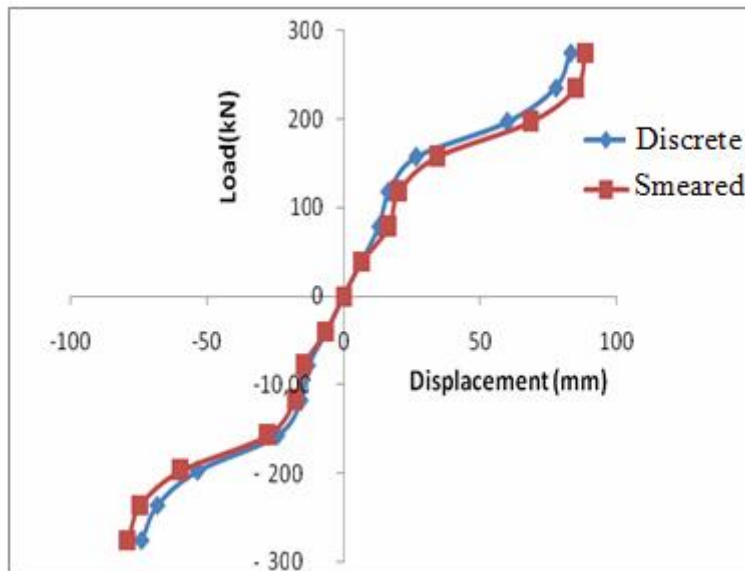
The load Vs displacement hysteretic loops for the models are shown in Figure 4 and Figure 5. For the smeared model, spindle-shaped hysteretic loops were observed with large energy dissipation capacity when compared to the discrete model. Here the ductility is increased without compromising the stiffness. The displacement envelope curve for both the models is shown in Figure 6.



**Figure 4:** Load Vs displacement curve for discrete model



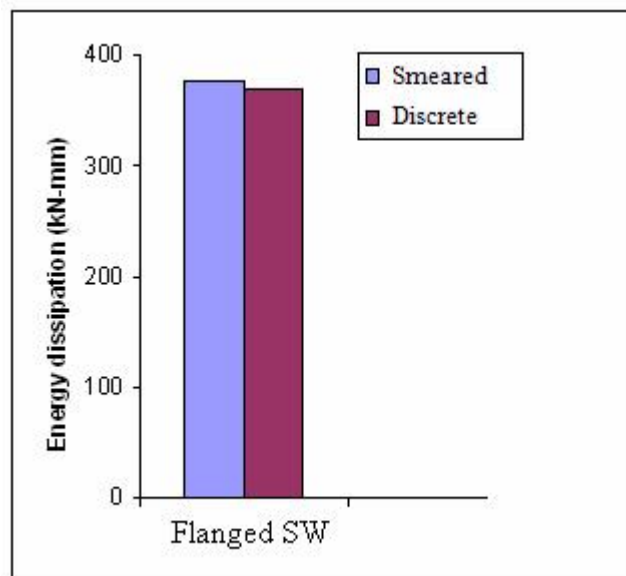
**Figure 5:** Load Vs displacement curve for smeared model



**Figure 6:** Load - displacement envelope curve for models

### 6.3 Energy Dissipation Capacity

The area enclosed by a hysteretic loop at a given cycle represents the energy dissipated by the specimen during that cycle (El-Amoury and Ghobarah 2002). Figure 7 shows the energy dissipated for each cycle of both the types of specimens. Smeared model exhibited higher energy dissipation than that of discrete model. But the variation is within 12.5%.



**Figure 7:** Comparison of cumulative energy dissipated

### 6.4 Displacement Ductility

Ductility is the capacity of the structure or a member to undergo deformation beyond yield without losing much of the load carrying capacity. The displacement ductility for the model

is calculated as per ASCE guidelines and is presented in Table 6. It can be observed that the displacement ductility is enhanced for smeared model than that of discrete model. But the variation is within 2.5%.

**Table 6:** Displacement ductility of models

Description of the specimen	Yield Displacement (mm)	Ultimate Displacement (mm)	Displacement ductility
Discrete Model	4.6	40	8.69
Smeared Model	4.5	40	8.88

## 7. Validation of Results

The equations for shear given in ACI 318 code (2002) were used to identify the shear failure of the RC shear wall. In ACI 318 code, for members subjected to additional axial compression force, the shear capacity of concrete is

$$V_c = \left( 1 + \frac{N_u}{14A_g} \right) \left( \frac{\sqrt{f_c'}}{6} \right) \text{ MPa}$$

where,  $N_u$  is the axial compression force and  $A_g$  is the area of the cross section.

The ultimate value of horizontal shear stress induced at the shear wall is almost equal or little higher than the ACI recommended values. It can be seen from Table 7 that the shear resisting capacity is more for the specimens detailed with smeared reinforcement than the discrete model.

**Table 7:** Comparison of ultimate shear stress

Designation of specimen	Analytical	$\frac{\tau_u}{\tau_{ACI}}$	
	Ultimate Load $P_u$ kN	Analytical	Theoretical (Equation 5.1)
Discrete Model	214.432	1.04	1.0
Smeared Model	235.875	1.08	1.0

## 7. Conclusions

In seismic zones, a structure can be subjected to strong ground motions, and, for economical design, a structure is considered to undergo deformations in the inelastic range; therefore, in addition to strength requirement, the structure should undergo these inelastic deformations

without failure. From the literature reviewed it is clear that paucity of information exists in the area of modeling of reinforced concrete structures. In the present study two types of models are analysed, (i) smeared model and (ii) discrete model. Both the models were analysed for cyclic loading. The analytical results are compared with the empirical relations in ACI 318 (2002). From the analytical results, following conclusions are drawn.

1. It is noticed that the smeared model exhibited higher ultimate strength compared to that of discrete model. There is 10 % increase in ultimate strength for smeared model than that of discrete model.
2. It is also observed that smeared model has higher average ductility than their counterparts (discrete model). The enhancement in deformation capacity for smeared model is 2.5 % than that of discrete model.
3. Spindle-shaped hysteretic loops are observed with large energy dissipation capacity for smeared model compared to discrete model. The enhancement in energy dissipation for smeared model is observed to be 7.5 % higher than that of discrete model.
4. Further, the ultimate shear capacities of both the models were observed to be matching with the empirical relation as per ACI 318.

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