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CYCLIC BEHAVIOUR OF RC SHEAR WALL USING EMBEDDED CNC STEEL PLATE REINFORCEMENT TECHNIQUE

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Abstract

Using of new technique to reinforce concrete structures is needed to improve their strength against unexpected loads such as earthquake. The Computer Numerical Control (CNC) technique is one of the modern ways to configure the steel plate in any desired shape. RC shear wall is one of the important structural elements in the buildings. Reinforcing of concrete shear wall by embedded CNC steel plate instead of steel bars has been proposed in this study under cyclic loading. To implement the investigation of the new technique of reinforcement, a numerical simulation of the concrete shear wall specimen reinforced with ordinary steel bars under cyclic loading combined with vertical uniaxial load has been adopted from previous literatures. The numerical results have been verified with a selected experimental case results in term of hysteresis behaviour of the RC wall model. Then, the comparison in seismic behaviour of the ordinary and the proposed reinforcement technique of concrete shear wall model has been exhibited. Furthermore, three varied parameters have been inspected to explain the efficiency of the new technique. The parametric study includes reducing the thickness of steel CNC plate, cyclic loading path and steel yield strength. The results show significant enhancement of concrete wall strength by increasing the ultimate loading capacity when using embedded steel CNC plate technique by 173% with appropriate energy dissipation capacity. The new technique could be alternative process than traditional ways in the precast building construction industries to correspond the modern method of robot-based construction, as well to reduce the cost.

Keywords: CNC steel plate, Cyclic loading, New reinforcement technique, Seismic analysis, Shear wall.

1. Introduction

Reinforced concrete is one of the most widely used construction materials due to its strength and durability. However, it is also prone to cracking and corrosion over time, which can compromise its structural integrity. To overcome these issues, a new reinforcement technique using CNC steel plates has been suggested, which promise to improve the performance and longevity of concrete structures. CNC steel plate reinforcement involves cutting steel plates into precise shapes using a Computer Numerical Control machine with clean undistorted cutting edge. These plates are then embedded in concrete structures providing better mechanical fixing than manually which adding additional strength and ductility to the system. Compared to the traditional reinforcement methods such as rebars, CNC steel plate reinforcement offers several benefits, including high tensile strength, increased stiffness, and better crack resistance [1-6]. Moreover, the CNC process ensures precise fitting of the plate, reducing the risk of errors and material waste.

Several research delt with RC shear wall subjected to cyclic loading, such as Parulekar et al. [7] implemented experimental and numerical analysis of shear wall under monotonic and cyclic loading to evaluate the strength and deformation capacity. Their results showed that improving in lateral load resistance and the brittle shear failure mode. Some studies have investigated structural behaviour of composed reinforced concrete members with steel elements, such as Khalou and Dehkordi [1] studied experimentally the use of perforated steel plates for reinforcing concrete slabs and testing three specimens with perforated plates with three ordinary reinforced slabs. Their results displayed that the slabs with perforated plates gave improvement in cracking strength, ductility (40%), energy absorption and ultimate strength. The results indicate the potential for enhanced force transfer in various applications, especially for high-tensile composite materials. Likewise, Wu et al. [8] conducted seismic performance of steel and concrete composite shear walls with embedded steel truss chord and web brace subjected to reversed cyclic lateral load. They concluded that embedded truss with web brace increasing lateral load, energy dissipation and ductility while the embedded truss with cord enhanced the lateral load capacity.

Also, Wang et al. [4] reported the structural evaluation of corrugated steel plate concrete composite shear wall. They studied experimentally test and numerically simulation for different cases of steel plates (flat, horizontal corrugated and vertical corrugated) using ABAQUS software and the low frequency cyclic load was applied to implement the analysis. It was concluded that the section with vertical corrugated compared with flat plate exhibits enhancement in structural behaviour of stiffness (33%), energy dissipation ability (7%) and the ductility ratio (1.4%). Furthermore, Wang et al. [9] carried out experimental study on seismic behaviour of steel plate RC composite shear wall under cyclic loading. They used normal reinforcement with a steel plate embedded in the middle of the 16 wall specimens. It was concluded that the load capacity and ultimate displacement of shear wall with steel plate increased by 107% and 122%, respectively. And the thickness of steel plate is the major parameter of load capacity and ultimate displacement of the shear wall [9].

In addition, Al-Habbobi and Al-Wazni [5] investigated numerical response of a concrete slab reinforced with embedded CNC steel plate under blast load. They concluded that the model with embedded CNC steel plate reduced the maximum displacement by 12.1%. Also, Peyman and Eskandari [6] introduced experimental and numerical study of concrete slabs reinforced by perforated steel plates under blast loading. Their numerical model of rectangular concrete slab was analysed using ABAQUS software. They concluded that the proposed reinforcement technique reduced the maximum displacement of the concrete slab by up to 20%. As well as Li et al. [2] investigated, experimentally and numerically, the mechanical properties of perforated steel plate reinforced concrete through compression and pull-out tests. Their conclusion was that the compressive strength of the specimen with steel plate was increased 100% compared with plain concrete, as well the numerical simulation emphasizes the reliability of their experimental results.

Furthermore, Al-Zahid and Alwash [3] examined in their experimental study replaced the ordinary reinforcement with perforated steel plates for RC two-way slabs. They used four specimens of slabs using self-compacting concrete: three of them utilized perforated steel plates and one with ordinary steel bars keeping equal steel amount. They applied monotonic concentrated load on the specimens and the results revealed that the slabs with perforated plates showed a higher ultimate loading capacity by (43-76) % with less crack widths compared to the ordinary reinforcement. Therefore, the use of perforated steel plate reinforcement technique improves loading capacity and stiffness in RC slab under concentrated loads.

In this study, the numerical simulation to predict the behaviour of new technique for reinforcing a concrete wall is implemented. The process of model simulation adopted the experimental specimen of RC shear wall used in the study of Zhang et al. [10]. The nonlinear dynamic analysis using ABAQUS software is used to evaluate the seismic behaviour of shear wall reinforced with embedded CNC steel plate under cyclic loading.

2. Description of adopted RC shear wall

The reinforced concrete wall model with dimensions of 2300 mm in height, 850 mm in width and 125 mm in thickness is adopted in the present study, as shown in Figs. 1(a) and (b). The selected model was adopted by Zhang et al. [10] in their study to implement experimental investigation. They investigated the failure mechanism of RC wall under vertical and lateral loads for different boundary elements. The RC wall model was design according to China Code of specification of testing methods for earthquake resistant building (JGJ101-96, 1996) [11].

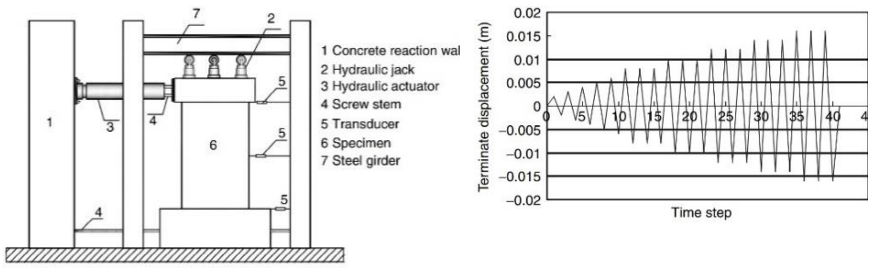
The supports of adopted model of the specimen were fixed in one edge of wall specimen. The reinforcement used in the model was two layers in two directions. The main reinforcement was 7-φ6 mm (6.53 mm) bar for each layer with equivalent longitudinal reinforcement ratio of 2.4% [10]. For stirrups, the reinforcement was φ6 mm bar at distance of 125 mm at the entire of the wall, as shown in Fig. 1(a). To represent the beam support rigidity, two masses of reinforced concrete were added, the first is on the top of the model, as shown in Fig. 1(b), with dimensions of (300×850×250) mm for height, width and thickness, respectively. The second mass is under the specimen with dimensions of (400×850×250) mm for height, width and thickness, respectively.

The material properties of concrete used in the wall model were compressive strength of 26.46 MPa (adopted as 26.5 MPa) and Young's Modulus of 33700 MPa. While the properties of φ6 mm steel bar were yielding strength of 392 MPa and Young's Modulus of 200600 MPa [10].

(a) Specimen details **(b) Experiment test**

Fig. 1. Adopted ordinary RC shear wall model [10].

The experimental RC wall specimen was subjected to axial force of 550 kN at top surface of wall, as shown in Fig. 2(a). Also, their model was subjected to lateral cyclic load by meaning of displacement control using hydraulic actuator, as shown in Figs. 2(a) and (b) [10].



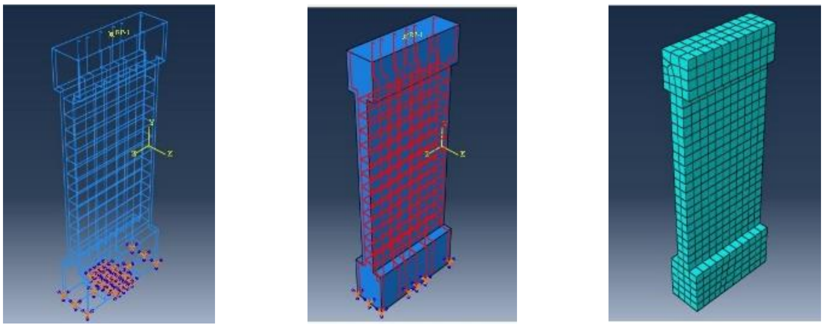
(a) Specimen test setup details **(b) Cyclic load diagram**

Fig. 2. Experimental test of RC shear wall model [10].

3. The FE model and verification process of RC wall

In the current study, the finite element (FE) model of the adopted experimental ordinary RC wall specimen was created using ABAQUS software, as shown in Fig. 3. The same geometry of the adopted wall specimen, material properties, reinforcement details and boundary condition were simulated in the FE model. The axial load was applied on the top surface of the model and the cyclic load was simulated laterally as lateral displacement subjected to the top surface of rigid concrete mass, as shown in Figs. 3(a) and (b). The FE model has been classified into two segments, the first simulates the concrete part and the second represents the steel reinforcement bars. The number of elements for both parts, the first and second part, are 1557, and the total number of nodes are 2079, as shown in Fig. 3(c).

The material modelling of RC part used in the FE model, in this research, is the concrete damage plasticity (CDP) model which has been adopted in ABAQUS explicit software to describe appropriate dynamic response of the structural RC wall under cyclic loading. The concrete damage plasticity model presumes that the two main failure mechanisms in concrete are the compressive crushing and the tensile cracking. In this material modelling, the appropriate tensile and compressive relationship of the reinforced concrete material, the cracking and crushing parameter and other parameters should be defined. For concrete material, the mass density is 2400 kg/m3 and damage plasticity parameter are listed in Table 1. The parameters values listed in the table are adopted in this study according to many trials during the calibration process as recommended in the previous studies [12, 13].



(a) Boundary conditions **(b) Reinforcement details** **(c) Meshing of FE model**

Fig. 3. Created FE model of adopted ordinary RC wall.

Table 1. Concrete damage plasticity parameters values.

Dilation angle	Viscosity	Fb_0/fc_0	K	Eccentricity
30	0.005	1.16	0.667	0.1

Belarbi and Hsu [14] explained the concrete behaviour in tension for both elastic and inelastic status, as shown in Fig. 4(a). They gave the stress-strain relationship of the tensile strength for the descending part by Eq. (1):

$$\sigma_t = \sigma_{t0}\left(\frac{\varepsilon_{t0}}{\varepsilon_t}\right)^{0.4} \tag{1}$$

where ε_{t0} is the maximum elastic tensile strain, ε_t is the inelastic strain, σ_{t0} is the maximum elastic tensile strength and σ_t is the tensile strength of inelastic strain.

Popovics [12] and Thorenfeldt et al. [13] represented the stress-strain relationship of the compressive behaviour for concrete material, as shown in Fig. 4(b) and it is given in Eq. (2):

$$\sigma_c = \frac{nE_c\varepsilon_c}{(n-1)+\left(\frac{\varepsilon_c}{\varepsilon_{cm}}\right)^{nk}} \tag{2}$$

The elastic modulus is estimated based on compressive strength f_{cm} as given in Eq. (3):

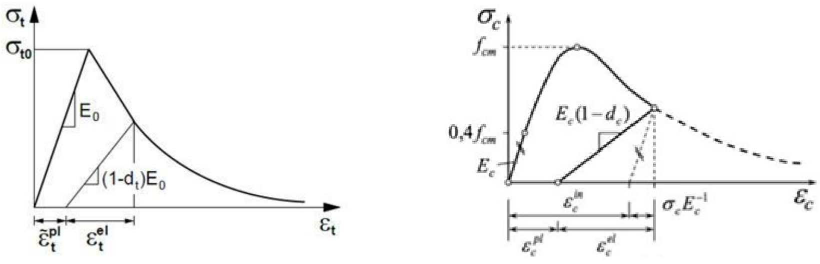
$$E_c = 3320\sqrt{f_{cm}} + 6900\text{MPa} \tag{3}$$

And n parameter in the Eq. (2) is determined by Eq. (4):

$$n = 0.8 + \left(\frac{f_{cm}}{17}\right) \tag{4}$$

The k parameter is extracted from the concrete strain $\varepsilon_c' = \frac{f_{cm}}{E_c}\left(\frac{n}{n-1}\right)$, and using Eq. (5):

$$k = \begin{Bmatrix} 0.67 + \left(\frac{f_{cm}}{62}\right) \rightarrow \frac{\varepsilon_c}{\varepsilon_c'} \rangle 1.0 \\ 1.0 \rightarrow \frac{\varepsilon_c}{\varepsilon_c'} \leq 1.0 \end{Bmatrix} \tag{5}$$



(a) Tensile relation [14] **(b) Compression relation [12, 13]**

Fig. 4. Concrete damage plasticity of material modelling.

The degradation in the modulus of elasticity, in the concrete damaged plasticity model, is simulated in reduction parameter of d, as written in Eq. (6) [15]:

$$E = (1 - d)E_0 \tag{6}$$

where E_0 is the intact elastic modulus. The stiffness reduction parameter, d is a stress state. The uniaxial reduction parameter for both compression and tension are written in Eqs. (7) and (8), respectively [15, 16]:

$$d_c = 1 - \frac{\frac{\sigma_c}{E_c}}{\varepsilon_c^{pl}\left(\frac{1}{b_c} - 1\right) + \frac{\sigma_c}{E_c}} \tag{7}$$

$$d_t = 1 - \frac{\frac{\sigma_t}{E_c}}{\varepsilon_t^{pl}\left(\frac{1}{b_t} - 1\right) + \frac{\sigma_t}{E_c}} \tag{8}$$

where b_c= 0.7 and b_t= 0.1 are extracted from the experimental test and the plastic strain is calculated by $\varepsilon_c^{pl} = b_c \varepsilon_c^{in}$.

For second part of steel reinforcement in the FE model, the elastic modulus and mass density are 200600 MPa and 7800 kg/m3, respectively [10]. The yield stress σ_y is equivalent to the value of 0.2% of the stress corresponding to the plastic strain in the stress-strain curve, as shown in Fig. 5 [17]. The strain value could be calculated as written in Eq. (9):

$$\varepsilon = \begin{Bmatrix} \frac{\sigma}{E_o} + 0.002\left(\frac{\sigma}{\sigma_{0.2}}\right)^n for \cdot \sigma \leq \sigma_{0.2} \\ \frac{\sigma - \sigma_{0.2}}{E_{0.2}} + \varepsilon_u\left(\frac{\sigma - \sigma_{0.2}}{\sigma_u - \sigma_{0.2}}\right)^m + \varepsilon_{0.2} \cdot for \cdot \sigma \rangle \sigma_{0.2} \end{Bmatrix} \tag{9}$$

Using the stress-strain relationship and trial and error can estimate the value of $\boldsymbol{n}$ and $\boldsymbol{m}$ by Eqs. (10) and (11):

$$n = \frac{ln(20)}{ln\left(\frac{\sigma_{0.2}}{\sigma_{0.01}}\right)} \tag{10}$$

$$m = 1 + 3.5\frac{\sigma_{0.2}}{\sigma_u} \tag{11}$$

where σ_u is the ultimate tensile strength.

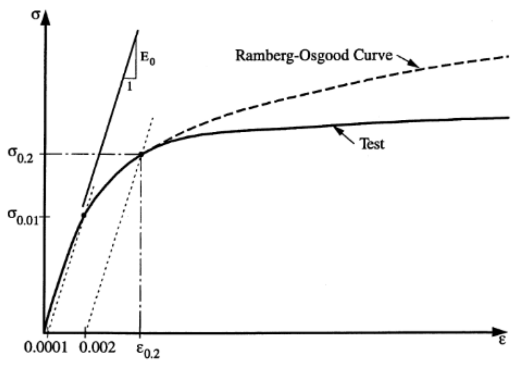


Fig. 5. Steel stress-strain relationship [17].

The modulus of elasticity of 0.2 stress is given in Eq. (12):

$$E_{0.2} = \frac{E_0}{1+\frac{0.002n}{e}} \tag{12}$$

where e is the nondimensional stress, $e = \frac{\sigma_{0.2}}{E_0}$. The strain at $\sigma_{0.2}$ is given in Eq. (13):

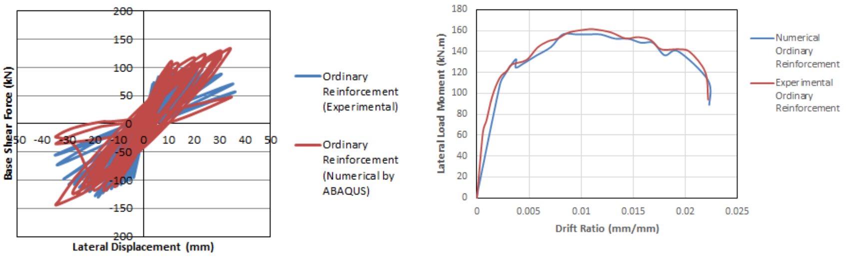
$$\varepsilon_{0.2} = \frac{\sigma_{0.2}}{E_0} + 0.002 \tag{13}$$

To verify the numerical analysis using ABAQUS software with the experimental test results of the adopted ordinary RC wall model [10], the comparison in hysteresis curve of cyclic response was implemented, as shown in Fig. 6(a). The hysteresis curve is the relation between the base shear forces in the vertical axis, produced from the applied cyclic load, and lateral displacement at the top point of the shear wall in the horizontal axis. The hysteresis curve shows the realistic structural behaviour presented the lateral displacement of the RC wall during exposed to the cyclic loading before the failure occurred, which is explained the continuous degradation in the stiffness of the RC wall due to initiation of concrete cracks and yielding the steel.

It is clear from figure that the numerical results coincide with the experimental by acceptable range of difference percent for both the maximum base shear forces and top point lateral displacement. The difference percent between the experimental and numerical results in the positive part are 7% and less than 1% in the elastic and plastic regions, respectively. Also, the comparison in the moment-curvature versus drift ratio between the numerical and experimental is inspired, as shown in Fig. 6(b). It is clear from Fig. 6(b), the match between the experimental and the numerical results and that verifies the adopted analysis procedures.

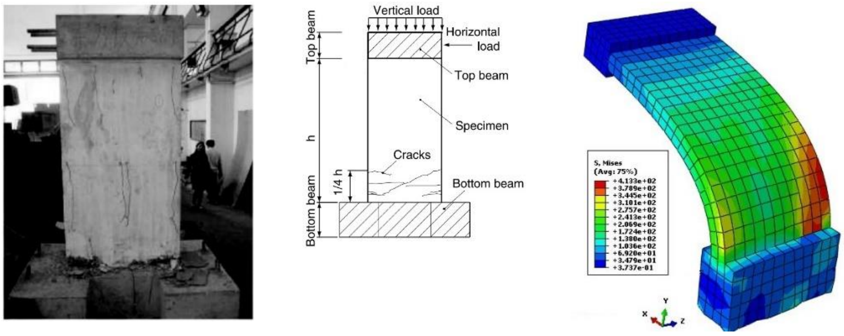
The comparison of crack pattern and failure mode between the experimental and numerical test is shown in Fig. 7. It is clear from Fig. 7 that the failure mode in the finite element model after completing the cyclic analysis is very close to the experimental test failure mode in its severity and location.

It is obvious, from the figures, excellent matching between the numerical and experimental results. Therefore, the numerical modelling could be utilized to carry out the objective of this research to study the proposed reinforcement technique by using embedded CNC steel plate instead of the ordinary reinforcement.



(a) Hysteresis behaviour **(b) Moment-curvature behaviour**

Fig. 6. Verification of FE model results with adopted experimental ordinary RC wall.



(a) Experimental test failure [10] **(b) Sketch of failure cracks [10]** **(c) Numerical model of Von-Mises failure**

Fig. 7. Comparison in failure mode between the experimental specimen and numerical model of RC shear wall.

4. Behaviour of the shear wall model using proposed reinforcement technique under cyclic load

The new technique of RC wall is modelled by substituting the ordinary reinforcement bar using embedded steel plate with openings cutting using CNC method. To increase the ductility of RC wall to withstand against such a cyclic load, a new technique should be conducted [1-3]. This means improve the structural member strength subjected to dynamic loading before failure occurred due to the high dissipation energy. As well, the minimize mistakes in the erection process during ordinary reinforcement works thereby the reduction of construction cost is more interested using the new reinforcement method. Also, the use of CNC steel plate improves the stiffness [1] of the RC wall model and decreasing the concentrated of tensile stress in the steel bar. Furthermore, it is valuable to improve the bonding and transfer forces between the concrete and reinforcement [1, 2] and then decreasing the slipping. Moreover, the new technique using embedded CNC steel plate is more durability comprised with the external strengthening way because it is protected from any external environment.

The material properties of the embedded CNC steel plate in this research have been assumed as same properties of ordinary reinforcement. The CNC technique is used to perforate the steel plate with specified openings shape and size. The geometry of the one-layer CNC steel plate used in the FE shear wall model is 2280 mm in height, 810 mm in width and 6.53 mm in thickness which is equivalent to one-layer of ordinary reinforcement bars in the specimen, as shown in Fig. 1(a). The number and size of openings in the CNC steel plate are corresponded to the spacing of bars in the ordinary reinforcement layer. The circular shape of the opening was recommended due to the best structural performance [5].

In this study, the 90-circular shape opening with diameter size of 63.69 mm in the entire sectional area of CNC plate model are adopted, as shown in Fig. 8(a). The inertia moment of the cross-sectional area for two layers of ordinary steel reinforcement was calculated to be replaced by the equivalent two CNC steel plate layers in the new technique even for rigid concrete mass at the top and bottom of the model, as shown in Fig. 8(b). The element modelling of the CNC steel plate is represented in ABAQUS software as 3D solid element using C3D8R for concrete element and using C3D10 for CNC steel plate element. The number of elements and nodes for the entire FE shear wall model meshing, with 2-layer of reinforcement, are 10273 and 22972, respectively, as shown in Fig. 8(c).

(a) One layer of CNC plate **(b) Two layers of CNC plate** **(c) Meshing model of CNC plate**

Fig. 8. Creating FE model of new RC wall model with CNC steel plate.

The same protocol of lateral cyclic load, as shown in Fig. 2(b), and axial vertical load are applied to the RC shear wall model with alternative reinforcement method. The numerical analyses of FE model using CNC steel plate are implemented and the results are extracted.

The comparison in the hysteresis behaviour of FE model between the ordinary and new technique is shown in Fig. 9. It is clear from Fig. 9 that the model with proposed technique gives high loading capacity at the same lateral maximum displacement with increasing ratio of 173% which is agree with previous studies [1-3]. Although the same maximum displacement is reached of the proposed model, however it is more ductile than the ordinary reinforcement, as shown in Fig. 9. The changes in the maximum loading capacity of the proposed model resulted from the appropriate distribution of the reinforcement within the volume unit of concrete shear wall which enhancing bonding between reinforcement and concrete in the wall. The bonding type used in the FE model is defined in embedded element technique by ABAQUS software for both ordinary and proposed reinforcement. Therefore, the shear wall using CNC steel plate increases the comprehensive stiffness as well as the ductility, as shown in Fig. 9.

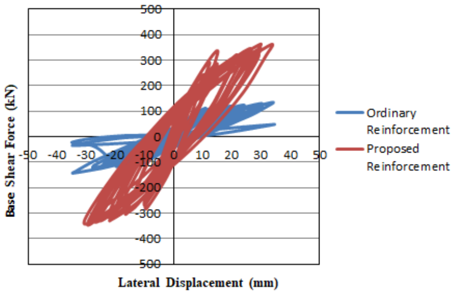


Fig. 9. Comparison in numerical results between ordinary and proposed technique reinforcement of shear concrete wall model under in-plane cyclic loading combined with vertical load.

5. Parametric study using new reinforcement technique.

In this research, three case studies of parameters are investigated to demonstrate the structural behaviour of the proposed model, such as the effect of changing the thickness of steel CNC plate, type of cyclic loading path and yield property of steel reinforcement on the concrete shear wall model with new reinforcement technique.

The first case study dealt with the thickness of steel CNC plate on the hysteresis behaviour of the RC wall. In this case, two new thicknesses of perforated steel plate are adopted as well as the original thickness of the plate (6.53 mm) as a reduction in thickness are 3.27 mm and 1.63 mm, as a reduction ratio by 50% and 75%. The results of the cyclic analysis in the mean of the hysteresis behaviour are shown in Fig. 10. It is obvious from figure that the decrease the thickness of plate the decrease the ultimate loading capacity of the shear wall compared to the original thickness (6.53 mm) by 16% and 32% for 3.27 mm and 1.63 mm reduction in the thickness, respectively. Furthermore, although the reduction in the thickness of steel CNC plate is implemented in the shear wall analysis to 3.27 mm and 1.63 mm, however the hysteresis behaviour has higher loading capacity compared with the ordinary reinforcement by 130% and 86%, respectively, as shown in Fig.10. This decreasing in the thickness of steel CNC plate which leads to the reduction in the weight of reinforcement thereby reducing the construction cost.

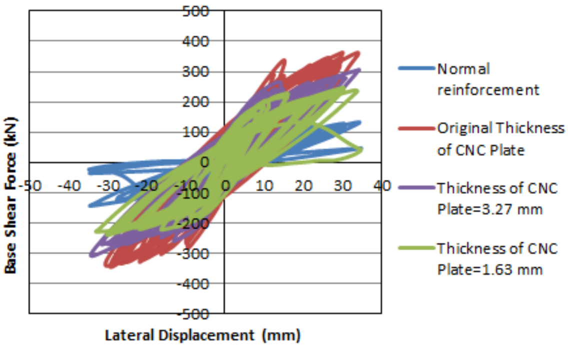


Fig. 10. The effect of thickness change of steel CNC plate on the hysteresis behaviour.

The second case study includes change cyclic loading path, in the mean of out-of-plane, is applied to the point at top surface of the concrete shear wall with new reinforcement technique combined with the vertical axial load. As well as the RC shear wall with the ordinary reinforcement was subjected to out-of-plane cyclic loading to carry out the comparison in hysteresis behaviour. The selection of loading path change is to inspect the loading capacity of the wall using the new technique in the plane of flexure. The result of the hysteresis behaviour of the concrete wall after implementing analysis of out-of-plane cyclic load is shown in the Fig. 11.

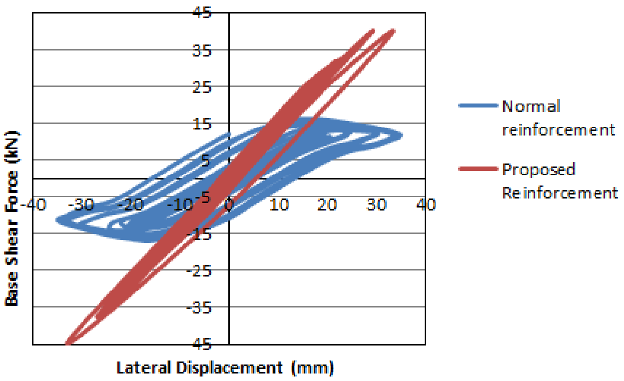


Fig. 11. Comparison between ordinary and proposed technique reinforcement in hysteresis behaviour for changing loading path to out-of-plane cyclic loading.

It is clear from figure that the flexural capacity of the proposed reinforcement increased compared with the ordinary reinforcement by 148%. Also, the enhancing ductility of the wall could be concluded due to reducing the degradation of the model material, as shown in Fig. 11. This enhancement of the behaviour comes from the efficient reinforcement in the new technique.

The third parameter is the change in yield strength of steel CNC plate used in the concrete shear wall to inspect its effect on the hysteresis behaviour. The chosen of yield strength values of steel plate is according to the industries standard specification and the availability in the market. In this study, two values of steel yielding are adopted of 235 MPa, 270 MPa as well to the adopted value of 392 MPa used in the concrete shear wall model. The comparison among the three-yielding strength of CNC plate with the ordinary reinforcement yielding strength of 392 MPa is implemented in this case. The hysteresis behaviour of applying the in-plane cyclic analysis combined with the vertical load on the shear wall model for four values of yielding strength are shown in the Fig. 12.

It is obvious from Fig.12, with the decreasing steel yield strength, the hysteresis exhibits excellent energy dissipation capacity with suitable stiffness and strength degradation under cyclic loading compared with ordinary reinforcement. The low reduction ratio in the loading capacity of using yield strength 235 MPa and 270 MPa with the adopted value are 12.8% and 13.3%, respectively, as shown in Fig.12. Thereby, the less effect of change yield strength is demonstrated because of durable and adequacy of proposed technique.

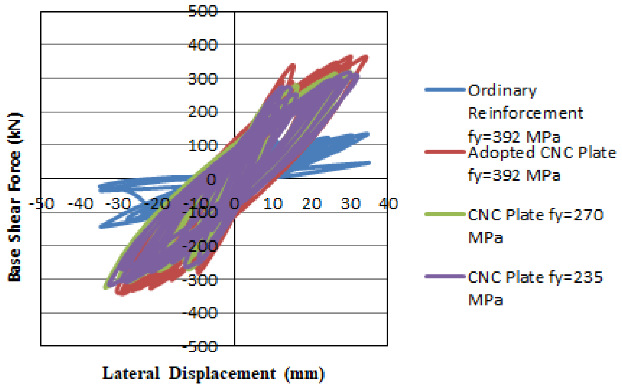


Fig. 12. The effect of changing yield strength of steel CNC plate on hysteresis behaviour.

Finally, the results of cyclic analyses of concrete shear wall model proves the efficiency and robust of using the proposed reinforcement technique as well as to word the simplest erection and cost reduction.

6. Conclusions

A proposed technique of using embedded CNC steel plate reinforcement has been inspected for a concrete shear wall model under cyclic loading. The verification of the numerical analysis process for the new reinforced concrete wall model has made by ABAQUS-software with the experimental results of the ordinary reinforced concrete wall specimen. Then many parameters have been studied, and the conclusions are listed.

- The validation procedures yield the excellent matching between the numerical and experimental results in hysteresis and curvature relationship.
- The proposed technique gives high load capacity at the same lateral maximum displacement by increasing ratio of 173% in the hysteresis behaviour and more ductile model than the ordinary reinforcement model.
- The thickness reduction of steel CNC plate, reinforcement weight, in the proposed wall model, in plate thickness 3.27 mm and 1.63 mm, caused decreasing the ultimate loading capacity by 16% and 32%, respectively. Furthermore, although the reduction in the thickness of steel CNC plate was implemented to 3.27 mm and 1.63 mm, however the hysteresis behaviour has higher loading capacity compared with the ordinary reinforcement by 130% and 86%, respectively.
- The investigation of loading path was carried out to study the flexural strength of the new method of embedded CNC steel plate reinforcement and the results showed that the flexural capacity increased compared with the ordinary reinforcement by 148%. Also, the improving ductility of the wall could be implicitly concluded due to reducing the degradation of the model material.
- The results of the yield strength changing of the new reinforcement method in the shear wall models subjected to cyclic load, using 235 MPa and 270 MPa

compared with 392 MPa, have low effect ratio in the loading capacity by 13.3% and 12.8%, respectively.

The new technique of CNC steel plate reinforcement offers a promising alternative to traditional reinforcement methods for improving the performance and durability of concrete structures such as shear wall. The precision and quality of CNC cutting ensure a precise fit and optimal distribution of reinforcement, leading to higher load-carrying capacity and energy dissipation. The proposed technique could be adopted instead of classical ways in the building construction which correspond to the robot-based construction method in the precast construction industries. Furthermore, numerical and experimental research are needed to explore the long-term behaviour and cost-effectiveness of this technique compared to traditional methods. Finally, the limitations of using this technique are the cost of steel plate configuration, experience workers and new specifications to be used.

Nomenclatures

b_c	Compression constant parameter
b_t	Tension constant parameter
d_c	Compression degradation variable of stiffness
d_t	Tension degradation variable of stiffness
E_c	Concrete Elastic Modulus, MPa
E_o	Steel Elastic Modulus in elastic region, MPa
Fb_0/fc_0	Ratio of the strength in the biaxial state to the strength in the uniaxial state.
f_{cm}	Maximum concrete compressive strength, MPa
K	Shape factor controls the dependence of the yield surface on the value of the intermediate principal stresses.
k	Concrete strain parameter calculated from Eq. (5)
n	Constant parameter calculated from Eq. (10)

Greek Symbols

ε_c	Inelastic strain produced by compression stress
ε_{cm}	Strain at the maximum compressive strength
ε_c^{pl}	Compressive plastic strain
ε_t	Inelastic strain produced by tensile stress
ε_{t0}	Maximum elastic tensile strain
ε_t^{pl}	Tensile plastic strain
$\sigma_{0.2}$	Yield stress of the steel equivalent to the value of 0.2%, MPa
σ_c	Compressive strength of concrete material, MPa
σ_t	Tensile strength of concrete material, MPa
σ_{t0}	Maximum elastic tensile strength, MPa
σ_u	Ultimate stress, MPa
σ_y	Yield stress of steel reinforced material, MPa

Abbreviations

CDP	Concrete Damage Plasticity
CNC	Computer Numerical Control
RC	Reinforced Concrete

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