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Nonlinear behavior of RC frames strengthened with steel curb and prop

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Steel jacketing.

Abstract. Using steel curbs and props is an appropriate method for strengthening the moment resisting reinforced concrete frames. In this paper, RC frames which were strengthened using steel prop and curb only, in combination with beam's revival steel sheets and column jacketing are investigated using numerical modeling. After verifying the models, local and global behaviors of these frames, such as displacement, ultimate strength, ductility factor and reduction factor, were studied. Analytical results show that ultimate lateral load of strengthened frames using the prop with sectional area of 1.2, 2.0 and 3.5 cm^2, has grown up to 2.0, 2.66 and 3.3 times of the ordinary frame, respectively. According to the results, when the prop's area increases, the ductility factor and the reduction factor of frames will decrease. The effects of column jacketing and beam revival sheet are opposite each other; while column jacketing increases the strength of the frame, the beam's revival decreases it, and when column jacketing increases ductility, the beam's revival decreases it.

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1. Introduction

Reinforced Concrete (RC) structural frames that were built prior to the 1970s generally do not meet current design code requirements and may behave in a non-ductile manner. Controlling lateral and horizontal displacement of structure is one of the main problems in Moment Resistant Reinforced Concrete (MRRC) frames. Deleting beam's hanger which causes reduction in the beam's height, this problem will be seen more. Moreover, this height reduction leads to increase of beam deflection, unobserving of code's precepts which cause creation and development of cracks in number and width during service. As panel zone is one of the most important parts of a structure which plays basic role in transferring loads from columns to the foundation, height reduction of beams, reduces beam-column-joint area, shear weakness of panel zone and global infirmity of the structure in seismic loadings. In recent years, for solving the first two mentioned problems in RC frames, several methods and technics were presented such as using bracing systems [1-3], and using masonry and shear walls [4,5]. Also for removal of the third problem, different methods have been used for strengthening, such as using FRP and CFRP sheets [6-10] or placing steel jacket in connections [11,12]. One of the usable methods for solving all three mentioned problems is to use steel curb and prop alone, or its combination with beams revival by steel sheets and column jacketing by steel sheets and profiles [13-15]. In some studies about some strengthening methods, the ductility factor and reduction factor have been investigated [16-19]. In these researches, RC members were the subject of the study, not a whole frame.

Recent earthquakes have demonstrated that the beam-column joint safety is an important factor for keeping the integrity of the entire structure. In some countries, steel bracing systems have been used for the rehabilitation of non-ductile RC buildings. Said and

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Nehdi (2008) proposed beam-column joint rehabilitation technique using local steel brace members [13]. They made two full-scale specimens representing a standard joint and a rehabilitated joint and tested under reversed cyclic load. Their behavior was compared to that of a non-rehabilitated specimen. They showed that the rehabilitation technique was successful in enhancing the overall performance of the deficient joint and upgrading it towards a close to current standard performance [13].

The technique of using these steel elements, called steel prop and curb in beam-column connections is usable for local and global strengthening of RC frames. Sharbatdar et al. (2012) experimentally studied the cyclic behavior of damaged exterior RC beam-column joint retrofitted using this technique [14,15]. The main idea of this technique was using a compressive member which acts as a resistant arm. So it reduces the moment and shear in panel zone. In their study, four half-scale RC joints were tested under cyclic loading; two control specimens were loaded up to their ultimate strength and the test was followed by retrofitting of these damaged specimens as new specimens and they were tested again under the same loading pattern. The experiments showed that the reduction of beam height caused increasing in deflection of joint beam, decreasing of ductility and also decreasing in bearing capacity and energy absorption. The ultimate load of the frame was increased and its rigidity decreased. Also the energy absorption was enhanced and the cracks were minimized due to a new lateral loading in the beam-column joint region in this upgrading method [14,15].

One of main shortages of available studies about using steel prop and curb in RC frames is that in these researches, only local behavior of connections were investigated and not global behavior of frame. To cover this shortage, in the present study, an RC frame has been strengthened in four general ways (curb and prop, curb and prop and revival sheet between beam's two curb, curb and prop and column jacketing in the bottom of column's curb region, combination of three mentioned method) with three different prop's sectional areas. After modeling and verifying performance of the model, local and global behavior of these frames was investigated; displacement, ultimate strength, ductility factor and reduction factor of frames were calculated and studied.

2. Analytical model

Two main concrete failure mechanisms are cracking under tension and crushing under compression [20]. For simulations of concrete in ABAQUS, according to its brittle behavior, Concrete Damage Plasticity (CDP) model was used [20].

Table 1. Suggested parameters of CDP model under compound stress.

Viscosity parameter	k_c	Eccentricity (ϵ)	Ψ	f_{b0}/f_{c0}
0.0024	0.6667	0.1	36	1.16

In concrete, according to the modifications, the failure surface in the deviatoric cross section needs not to be a circle and it is governed by parameter K_c. It is highly recommended to assume $K_c = 2/3$.

The shapes of the plane's meridians change in the stress space. This shape is adjusted through eccentricity (plastic potential eccentricity). Parameter eccentricity (ϵ) can be calculated as a ratio of tensile strength to compressive strength [21]. The CDP model recommends to assume $\epsilon = 0.1$.

σ_{b0}/σ_{c0} (f_{b0}/f_{c0}) is the ratio of the strength in the biaxial state to the strength in the uniaxial state. The ABAQUS user's manual specifies default $f_{b0}/f_{c0} = 1.16$. Another parameter characterizing the performance of concrete under compound stress is dilation angle, i.e. the angle of inclination of the failure surface towards the hydrostatic axis, measured in the meridional plane.

The other parameters describing performance of concrete are determined for uniaxial stress. Table 1 shows the model's parameters characterizing its performance under compound stress.

For modeling of concrete 20-node solid element, C3D20R has been used, which is a cubic element with 20 nodes. Each node has 6 degrees of freedom; 3 translational and 3 rotational degrees of freedom [22]. For modeling of reinforcements, Truss elements, T3D2 were used.

Another material used and modeled in this study is steel. Also for modeling steel curb and prop and external steel sheets, 8-node shell element, S8R5 was used.

To verify the performance of elements and behavior of models in program (ABAQUS), an RC frame, which had been tested by Hemati (2012), in structural lab of Semnan University, was used [23]. Details of this one bay frame are shown in Figure 1.

Properties of concrete and steel (reinforcement) used in this frame (by Hemati (2012)) are presented in Tables 2 and 3, respectively.

Yield stress for prop and curb and all steel sheets and profiles used in this study has been assumed to 300 MPa and their modulus of elasticity 200×10^3 MPa. Different mesh sizes were used for calibration of the

Table 2. Concrete properties used in simulations based on experimental model of Hemati (2012) [23].

Poisson's ratio (ν)	E_c (MPa)	f'_c (MPa)
0.2	30000	34.49

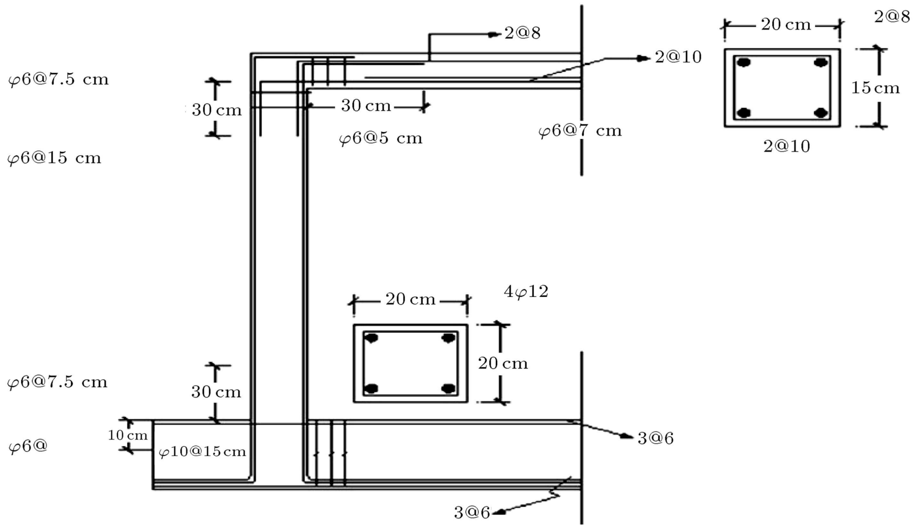

Figure 1. Details of the experimental frame tested by Hemati (2012) [23].

Table 3. Reinforcement properties used in simulations based on experimental model of Hemati (2012) [23].

Poisson's ratio (ν)	E_s^t (MPa)	E_s (MPa)	ε_y	ε_u	f_y (MPa)
0.3	6200	200000	0.002	0.15	400

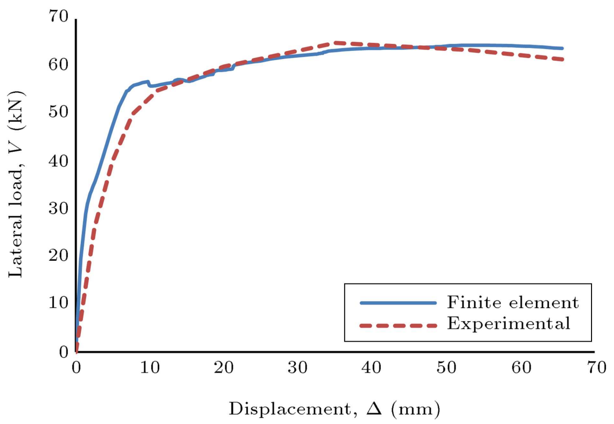

Figure 2. Verification of numerical (FE) model with experimental model.

frame and ultimately, 60 × 60 mm^2 mesh sizes were chosen (for concrete) for the accuracy of results. Force-displacement diagram of the experimental and finite element (numerical) models are presented in Figure 2.

Observing the situation of experimental and numerical frame at ultimate displacement, location of cracks and plastic hinges can be investigated. In Figure 3, the location of plastic hinges and maximum strains and tensile damage in numerical model can be observed, which have a good coincidence with results of the experimental model (Figure 4).

In Figure 3, direction of cracks shows direction of maximum plastic strains in concrete and also shows

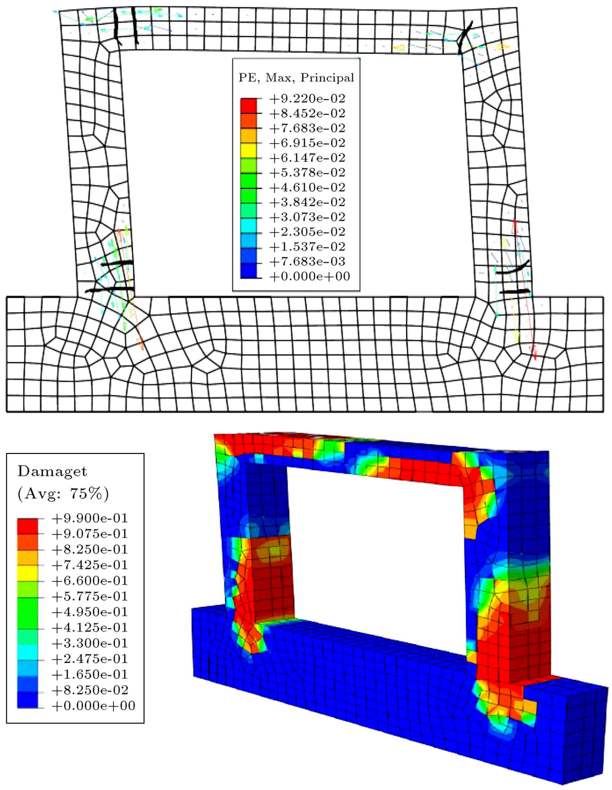

Figure 3. Location of cracks, maximum plastic strains and tensile damage in numerical model.

that they are tensile or compressive. Directions of cracks are perpendicular to the directions of plastic strains. Directions of cracks are shown with black lines.

3. Modeling and results

In this Study, for investigating effects of curb and prop, beam's revival sheet and column steel jacketing, 12 frames were modeled in 4 general forms (curb and

Figure 4. Location of cracks and tensile cracks pattern in experimental model [23].

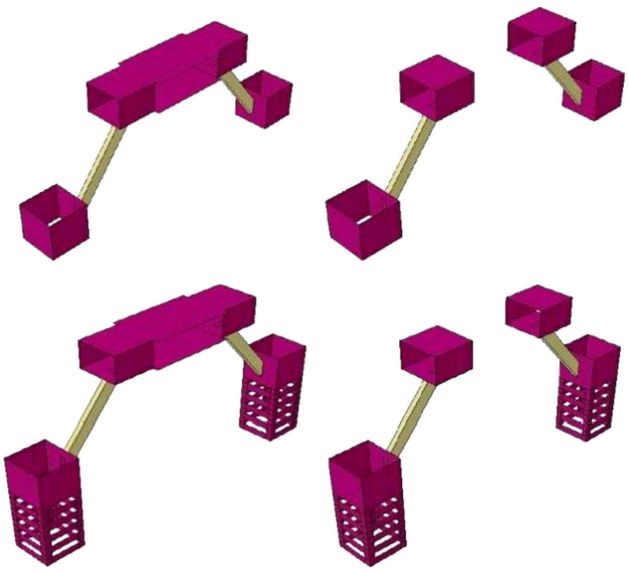

Figure 5. Four general strengthening forms used in this study.

prop, curb and prop and revival sheet between beam's two curb, curb and prop and column jacketing in the bottom of column's curb and combination of three mentioned method). In Figure 5, these 4 general mentioned forms are shown.

Three different sectional areas were used for props. Hence, totally 12 frames were modeled and analyzed. Geometrical properties of props are presented in Table 4.

The length of curb in beams and columns was 200 mm and the distance between their center to the edge of beam and column was 300 and 400 mm, respectively. Dimension of the sheet used between beam's two curb was $400 \times 250 \times 5$ mm. Angle sections

Table 4. Geometrical properties of props.

Number	Shape of prop's section	Prop's length (cm)	Prop's area (cm^2)
1	BOX $20 \times 10 \times 2$	50	1.2
2	BOX $30 \times 20 \times 2$	50	2.0
3	BOX $60 \times 30 \times 2$	50	3.5

used for jacketing in the bottom of column's curb was $L30 \times 30 \times 5$ mm. Between these angles, five $200 \times 40 \times 5$ mm sheets were placed with 70 mm center-to-center distance, so angles did not buckle.

Models used in this study were named in this way: the first part of the name (letters) shows strengthening method and the second part (digits) shows sectional area of the prop.

If the frame is strengthened with curb and prop only, it is named as P-C; if the frame is strengthened with curb and prop and revival sheet between beam's two curb, it is named as P-C-B; if the frame is strengthened with curb and prop and column jacketing in the bottom of column's curb, it is named as P-C-C; and if the frame has been strengthened with total mentioned method, it has been named as T. For example, P-C-1.2, P-C-B-2, P-C-C-3.5 and T-3.5, respectively, refer to the frame strengthened with only curb and the prop with sectional area of 1.2 cm^2, the frame strengthened with curb and prop the prop with sectional area of 2.0 cm^2 and revival sheet between beam's two curb, the frame strengthened with curb and the prop with sectional area of 3.5 cm^2 and column jacketing in the bottom of column's curb, and the frame strengthened with total mentioned method with the prop with sectional area of 3.5 cm^2. Also the reference frame which was not strengthened was named as ordinary frame.

In this study, ultimate displacement of numerical models were applied as the same ultimate displacement of experimental model which was 65.61 mm. Force-displacement diagrams for the ordinary frame and frames P-C, P-C-B, P-C-C and T are presented in Figures 6 to 8 for the prop with sectional area of 1.2, 2.0 and 3.5 cm^2, respectively.

As observed in Figures 6 to 8, stiffness of strengthened models has grown significantly compared to the ordinary frame. Strength of strengthened models has grown up to 2 times of the ordinary frame, in the frames using the prop with sectional area of 1.2 cm^2. Also strength of strengthened models, using the prop with sectional area of 2.0 and 3.5 cm^2, has grown up to 2.66 and 3.3 times of the ordinary frame, respectively.

Figure 9 shows the distribution of tensile damage in frames using the prop with sectional area of 1.2 cm^2.

According to Figure 9, using column jacketing decreases the tensile damage in frames and transmigrates

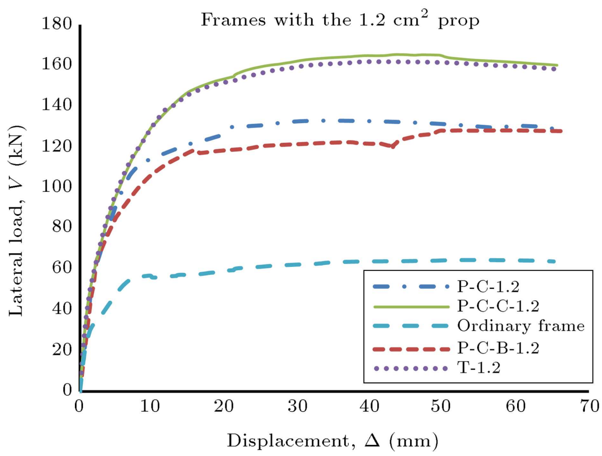

Figure 6. Force-displacement diagrams for all frames with the 1.2 cm^2 prop.

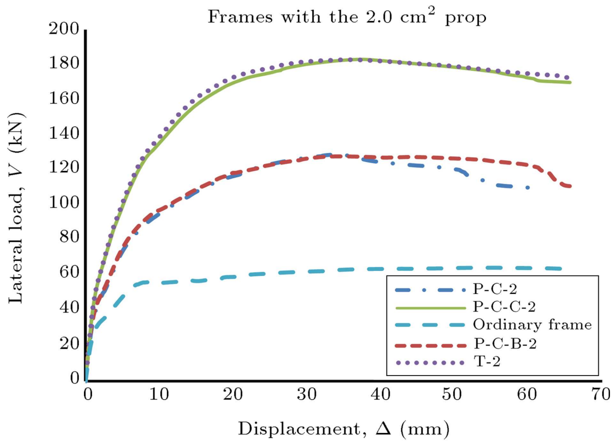

Figure 7. Force-displacement diagrams for all frames with the 2.0 cm^2 prop.

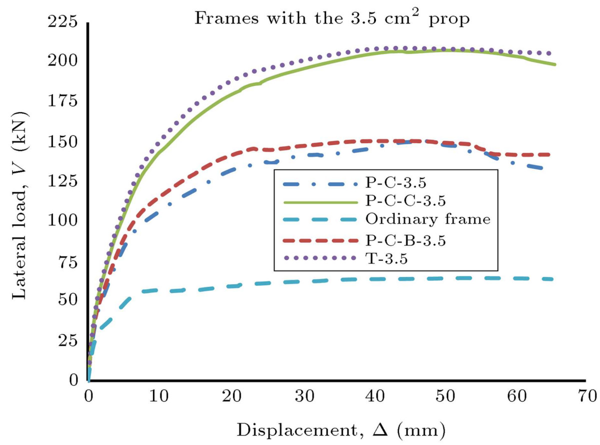

Figure 8. Force-displacement diagrams for all frames with the 3.5 cm^2 prop.

the failure to the foundation. Also using revival sheet between beam's two curbs, the tensile damage in beam region will increase and plastic hinge will be transmigrated to the edge of connection of beam to the column.

Critical displacement, corresponding to inelastic buckling of compressive prop (Δ_{cr}), and its corresponding frame force (P_{frame}) are presented in Table 5.

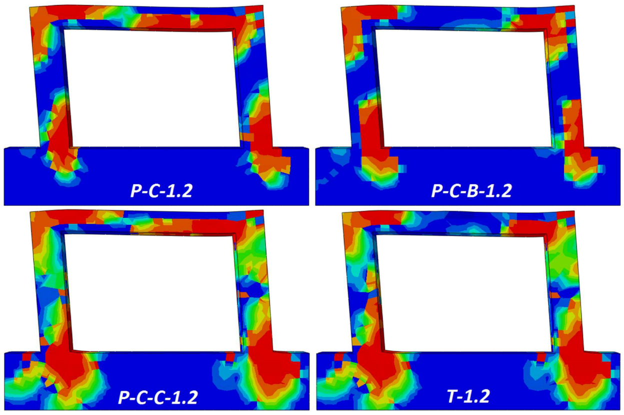

Figure 9. The distribution of tensile damage in frames using the prop with sectional area of 1.2 cm^2.

Table 5. Critical displacement, corresponding to inelastic buckling of the prop and its corresponding prop's force.

Frame	Δ_{cr} (mm)	P_{frame} (kN)
Ordinary frame	0	0
P-C-1.2	15.87	112.61
P-C-B-1.2	9.87	107.58
P-C-C-1.2	17.80	149.80
T-1.2	11.77	138.35
P-C-2	34.28	128.88
P-C-B-2	29.92	126.60
P-C-C-2	36.24	182.97
T-2	31.92	182.37
P-C-3.5	52.73	146.88
P-C-B-3.5	30.95	147.70
P-C-C-3.5	56.98	205.74
T-3.5	46.20	108.67

Using revival sheet between beam's two curbs, inelastic buckling of compressive prop occurs in lower displacement. Results showed that using revival sheet causes to more force absorption in props, and this leads to sooner inelastic behavior and energy absorption in props. Hence, during lateral loadings such as earthquake, firstly props will absorb force, yield and then buckle. Thereupon, props will be the first members of the frame which fails because of force and energy absorption. This means that in these frames, props play the role of the first defensive line and props act as fuse in these frames.

On the other hand, using revival sheet between beam's two curbs has no meaningful effect on the ultimate strength of the frame. In these frames, force-displacement diagram does not decline significantly at the end of diagram. In fact, using revival sheet affects inelastic buckling of props and changes the load carrying mechanism of the frame.

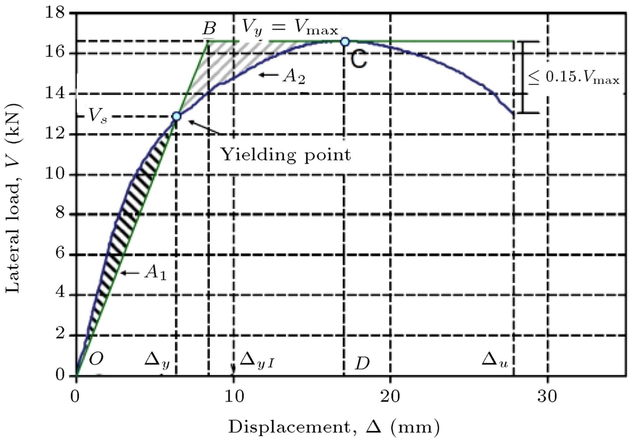

Figure 10. Definition of ultimate and ideal yield displacement (based on the balance of energy) [23].

Table 6. Ductility factor for the ordinary and strengthened frames.

	Prop's area	$\boldsymbol{\Delta_{yI}}$	$\boldsymbol{\Delta_u}$	$\boldsymbol{\mu}$
Ordinary frame	0.0	10.21	65.61	6.43
P-C-1.2	1.2	9.90	65.61	6.63
P-C-B-1.2	1.2	10.80	65.61	6.08
P-C-C-1.2	1.2	9.90	65.61	6.63
T-1.2	1.2	9.70	65.61	6.77
P-C-2	2.0	13.85	61.59	4.45
P-C-B-2	2.0	12.94	65.61	5.07
P-C-C-2	2.0	14.16	65.61	4.63
T-2	2.0	12.77	65.61	5.14
P-C-3.5	3.5	17.01	65.61	3.86
P-C-B-3.5	3.5	13.16	65.61	4.99
P-C-C-3.5	3.5	17.15	65.61	3.83
T-3.5	3.5	15.47	65.61	4.24

4. Ductility

Ductility is an essential property of structures, because it guarantees safety of structures when subjected to accidental, blast, or seismic loads. Displacement ductility (μ_Δ) of a structural frame is obtained from the idealization of the force-displacement diagram. The ductility factor μ is obtained as the ratio between the ultimate displacement (Δ_u) and the yielding displacement (Δ_{yI}); $\mu_\Delta = \Delta_u/\Delta_{yI}$. Determination of such values in the response diagram depends on the used method.

Figure 10 represents the method of calculating displacement ductility (μ_Δ) of a frame which has been used in this study for idealizing the diagrams obtained from models. This bi-linear diagram is defined in terms of two characteristic points: The effective yielding displacement (Δ_{yI}), which denotes the change between elastic and plastic behavior, and the ultimate displacement (Δ_u). Based on the suggestion of Lam et al. [24], in this method the, idealization of the force-displacement diagrams is performed by an energy balance between the model diagrams and the ideal diagram up to ultimate load (Figure 10), i.e. the area below the model curve is equal to the area below the ideal elastic-plastic curve. The effective yielding displacement is obtained (Δ_{yI}) by matching area A1 to area A2. This method is named as "Method Based on Balance of Energy" (MBBE) [24].

Idealized diagrams of the ordinary and strengthened frames are presented in Figure 11. In all these diagrams, vertical axis expresses the lateral load, V (kN), and horizontal axis expresses the displacement, Δ (mm).

Yield displacement (Δ_{yI}), ultimate displacement (Δ_u) and ductility factor (μ) for all frames are presented in Table 6. Ductility factors for the ordinary and strengthened frames are shown in Figure 12.

According to Figures 6 to 8, when the prop's area increases, the strength of frames will increase and according to Figures 12 and 13, when the prop's area increases, the ductility of frames will decrease. As observed in Table 6 and Figure 12, strengthening frames using steel curb and prop, with the 1.2 cm^2 prop, the ductility factor of the frame does not change sensibly; it increases less than 5%. Strengthening frames using steel curb and prop, with the 2.0 and 3.5 cm^2 prop, the ductility factor of the frames decrease up to 30 and 40%, respectively.

Figure 12 shows that when the prop's area increases, use of revival sheet between beam's two curb will improve ductility of the frame. In comparison with the same frame without beam's revival sheet using beam's revival sheet, with the 1.2, 2.0 and 3.5 cm^2 prop, the ductility factor of the frames increase up to -8, +14 and +30%, respectively. As a result, when area of the prop increases, the additive effect of using beam's revival sheet on the ductility factor of the frame increases too.

Also Figure 12 shows that when the prop's area increases, the effect of column jacketing on ductility of the frame is little. In comparison with the same frame without column jacketing, using column jacketing, in combination with the 1.2, 2.0 and 3.5 cm^2 prop, the ductility factor of the frames increase up to -0.2, +5 and -1%, respectively. As a result, using column jacketing, in combination with the prop, has the best effect on the ductility factor, when area of the prop is 2.0 cm^2.

It is obvious that the effects of column jacketing and beam revival sheet are opposite each other; while one increases the strength of the frame, the other decreases it, and when one increases ductility, the other decreases it.

The ductility factors for strengthened frames versus the prop's area are shown in Figure 13.

According to Figure 13, in all methods of strengthening, when area of the prop increases, the ductility factor decreases. This problem shows it-

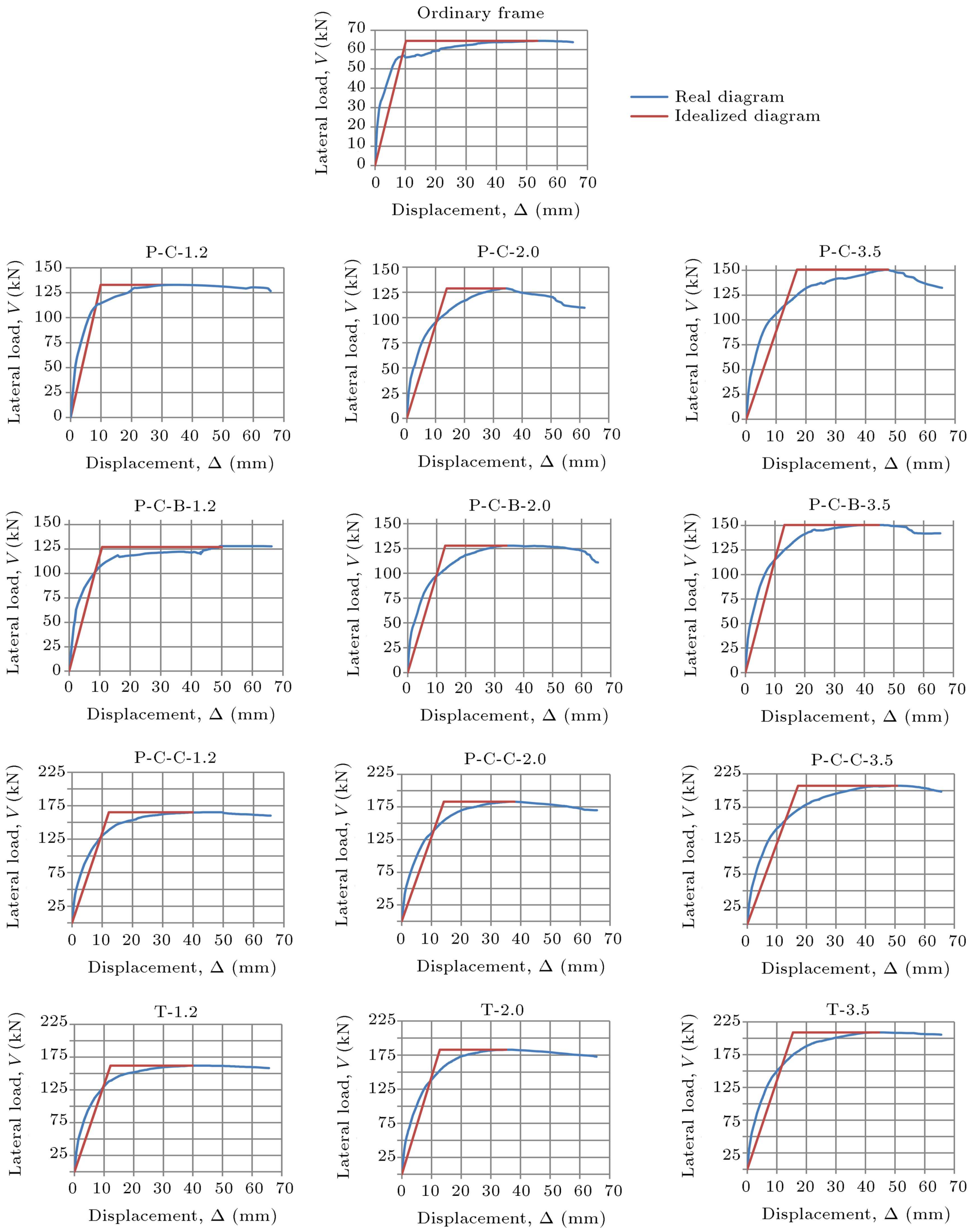

Figure 11. Idealized diagrams of the ordinary and strengthened frames.

self more, when T (all mentioned methods together) method of strengthening is used.

5. Reduction factor

In forced-based seismic design procedures, reduction factor, R (or R_w) refers to other terms including response modification factor (UBC code [25] and NEHRP provisions [26]), is a force reduction factor used to reduce the linear elastic response spectra to the inelastic response spectra [27]. In other words, reduction factor is the ratio of the strength required to maintain the structure elastic to the inelastic design strength of the structure. Reduction factor is generally expressed in the following form [28,29] using three components:

$$R = R_\mu \times \Omega \times Y, \tag{1}$$

where, R_μ is the ductility-dependent component also known as the ductility reduction factor, Ω is the

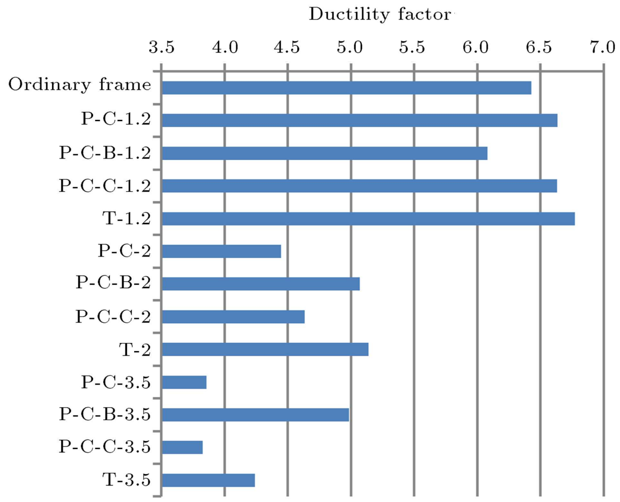

Figure 12. Ductility factor for the ordinary and strengthened frames.

overstrength factor, and Y is termed the allowable stress factor [28,29]. For structures designed using an ultimate strength method, the allowable stress factor, Y, becomes unity and the reduction factor is reduced to:

$$R = R_\mu \times \Omega. \tag{2}$$

Nassar and Krawinkler (1991) presented a relation for R_μ in the following form [30]:

$$R_\mu = [c(\mu - 1) + 1]^{1/c}, \tag{3}$$

where c is a coefficient which depends on some parameters, such as period of the structure and post-yield stiffness [30]. Overstrneght factor Ω is calculated using Eq. (5):

$$\Omega = V_y/V_s = V_{\max}/V_s, \tag{4}$$

where V_y and V_s correspond to the idealized yield strength and the first significant yield strength, respectively (Figure 10).

Table 7. Overstrength factor and reduction factor for the ordinary and strengthened frames.

	Prop's area	V_y	V_s	R_μ	Ω	R
Ordinary frame	0.0	64.52	56.63	3.44	1.139	3.92
P-C-1.2	1.2	132.94	111.73	3.50	1.190	4.17
P-C-B-1.2	1.2	127.25	101.59	3.34	1.253	4.18
P-C-C-1.2	1.2	165.34	128.00	3.50	1.292	4.52
T-1.2	1.2	161.87	128.62	3.54	1.259	4.46
P-C-2	2.0	128.90	96.32	2.81	1.338	3.76
P-C-B-2	2.0	127.89	96.99	3.02	1.319	3.99
P-C-C-2	2.0	183.07	138.96	2.88	1.317	3.79
T-2	2.0	182.90	136.31	3.05	1.342	4.09
P-C-3.5	3.5	150.54	114.92	2.60	1.310	3.39
P-C-B-3.5	3.5	150.52	116.37	3.00	1.293	3.87
P-C-C-3.5	3.5	207.40	155.41	2.58	1.335	3.44
T-3.5	3.5	208.80	158.25	2.74	1.319	3.61

In this study, by using equations above, overstrength factor and reduction factor for strengthened frames have been obtained. In Table 7, overstrength factor, ductility reduction factor and reduction factor for the ordinary and strengthened frames are presented.

According to Table 7, using steel curb and prop for strengthening of a frame, overstrength factor will grow over a unit and become more than one. On the other hand, by using this method, the reduction factor of the frame will decrease, especially when the prop's area increases. In this method, overstrength factor of the frame will face an increase from 5% in the model P-C-1.2 up to 18% in the model T-2.O overstrength factor of the ordinary frame is 1.139. When strengthening the frame using steel curb and prop, with the 1.2 cm^2 prop, the overstrength factor of the frame increases up to 13% and reaches 1.292. Strengthening frames using steel curb and prop, with the 2.0 and 3.5 cm^2 prop, the overstrength factor of the frames increase up to 18 and 17%, respectively.

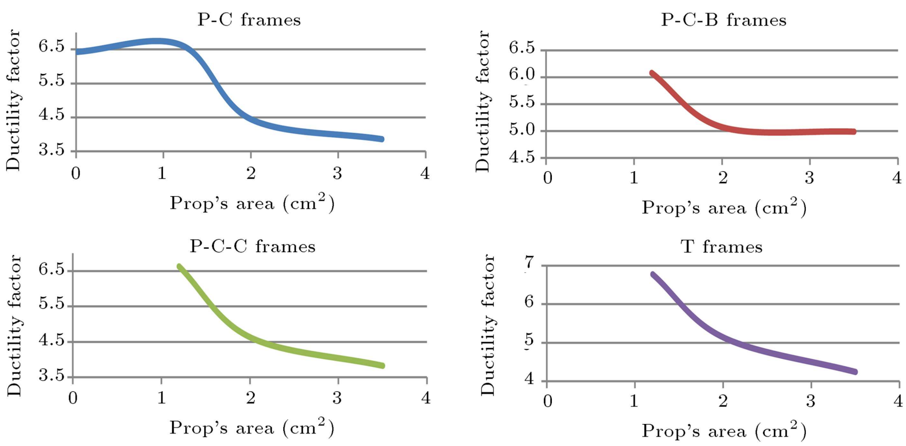

Figure 13. Ductility factor for strengthened frames vs. the prop's area.

Table 7 shows that when the prop's area increases, using revival sheet between beam's two curbs will increase overstrength of the frame. In comparison with the same frame without beam's revival sheet, using beam's revival sheet, with the 1.2, 2.0 and 3.5 cm^2 prop, the overstrength factor of the frames increase up to 5.3, -1.5 and -1.3%, respectively. As a result, when the area of the prop increases, using beam's revival sheet on the overstrength factor of the frame has decreasing effect.

Also Table 7 shows that when the prop's area increases, the effect of column jacketing on overstrength of the frame is little. In comparison with the same frame without column jacketing, using column jacketing, in combination with the 1.2, 2.0 and 3.5 cm^2 prop, the ductility factor of the frames increase up to 8.6, -1.5 and 2%, respectively. As a result, using column jacketing, in combination with the prop has the best effect the overstrength factor when area of the prop is 1.2 cm^2.

Reduction factor for the ordinary and strengthened frames is shown in Figure 14. As observed in Table 7 and Figure 14, when strengthening the frames using steel curb and prop, with the 1.2 cm^2 prop, the reduction factor of the frame increases up to 15%. Strengthening the frames using steel curb and prop, with the 2.0 and 3.5 cm^2 prop, the reduction factor of the frames decreases up to 4 and 13%, respectively.

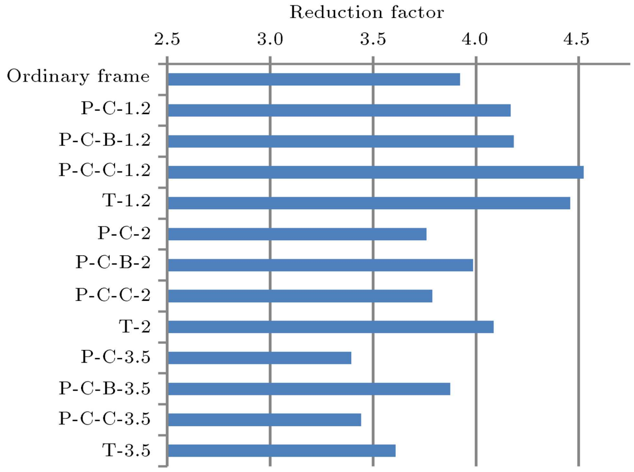

Figure 14. Reduction factor for the ordinary and strengthened frames.

Figure 14 shows that when the prop's area increases, using revival sheet between beam's two curbs will improve behavior of the frame. In comparison with the same frame without beam's revival sheet, using beam's revival sheet with the 1.2, 2.0 and 3.5 cm^2 prop, the reduction factor of the frames increases up to 0.4, 6 and 14%, respectively. As a result, when the area of the prop increases, the additive effect of using beam's revival sheet on the reduction factor of the frame increases too.

Also Figure 14 shows that when the prop's area increases, the effect of column jacketing on behavior of the frame decreases a little. In comparison with the same frame without column jacketing, using column jacketing, in combination with the 1.2, 2.0 and 3.5 cm^2 prop, the reduction factor of the frames increase up to 8.5, 0.7 and 1.4%, respectively. As a result, using column jacketing, in combination with the prop has the best effect when the area of the prop is 1.2 cm^2.

Strengthening an RC frame with curb and 1.2 cm^2 prop, its reduction factor will improve, especially when using column jacketing. But when the prop's area increases, reduction factor decreases. This is because when the prop area increases, the frame behaves more brittle. When it is necessary to increase the prop's area, it is suggested to use beam revival sheet. The reduction factors for strengthened frames versus the prop's area are shown in Figure 15.

According to Figure 15, in all methods of strengthening, when area of the prop increases, the ductility factor decreases. This problem shows itself

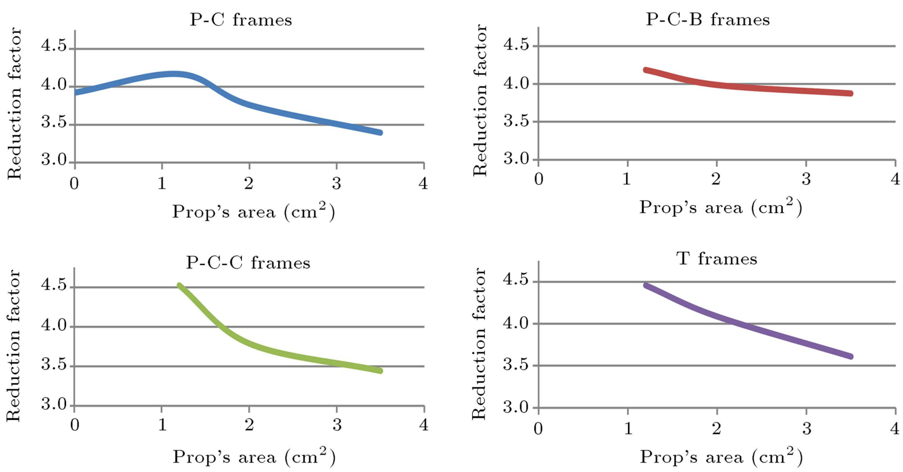

Figure 15. Reduction factor for strengthened frames vs. the prop's area.

more when P-C-C (curb and prop with column jacketing) method of strengthening is used.

6. Conclusion

In the present study, using numerical method, an RC frame was strengthened using steel prop and curb alone, and steel prop and curb in combination with beam's revival steel sheets and column jacketing. After verifying performance of the program (ABAQUS), the most important parameters of the frame behavior, such as displacement, ultimate strength, ductility factor and reduction factor, were investigated. The main results can be summarized as:

1. Strength of strengthened models using the prop with sectional area of 1.2, 2.0 and 3.5 cm^2 has grown up to 2.0, 2.66 and 3.3 times of the ordinary frame, respectively.
2. Using revival sheet between beam's two curbs has no meaningful effect on the ultimate strength of the frame, but it affects the inelastic buckling of props and changes the load carrying mechanism of the frame.
3. When the prop's area increases, the strength of frames will increase and the ductility factor of frames will decrease.
4. The effects of column jacketing and beam revival sheet are opposite each other; while column jacketing increases the strength of the frame, the beam's revival decreases it, and when column jacketing increases ductility, the beam's revival decreases it.
5. Using steel curb and prop for strengthening a frame, overstrength factor will grow over 1.0 and become bigger than a unit. On the other hand, by using this method, the reduction factor of the frame will decrease, especially when the prop's area increases. The overstrength factor of the frame faces an increase from 5 to 18%.

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