Improving the behavior Reinforced Concrete frames made of UHPC using the metallic vertical shear link

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Abstract. This paper investigates the behaviour reinforced concrete frames of the Ultra High Performance Concert (UHPC) using the metallic vertical shear link. The behavior of the UHPC is analyzed such as the case of ultimate strength, its stiffness and dissipating energy. A metallic vertical eccentrically braced frame (VEBF) shear link with a shear mechanism is explored in the UHPC. Accordingly, improving the behavior of the RC frame with double VEBF is investigated. The proposed system is not easy fabrication and good seismic performance. But it can be easily replaced after a severe earthquake. Since the VEBF does not carry the gravity loads, its replacement does not affect the severability of the building during the repair. The finite element models are applied to investigate the behavior of moment resisting frame made of UHBC and conventional concrete strengthened with metal vertical shear link. The accuracy of the prosed results is compared with the reported experimental test. The numerical results indicated that adding the VEBF to the RC frame improved the behavior of the RC frame in elastic and inelastic zones. It enhanced the ultimate strength, stiffness, and energy absorption of the RC moment-resisting frame. Also, it prevents hinge formation over the main column.
Keywords: UHPC; Frame; Ultimate strength; Stiffness.

1 Introduction

The reinforced concrete (RC) buildings with moment resisting frame (MRF) system had shown a suitable performance in past earthquakes and experiential studies. Since dissipating energy in MRF relies on the hinge formations at two ends of the beams, they are damaged in severe earthquakes. Because the main frame carries the gravity loading, repairing the RC with the MRF system after the earthquake is complicated. Different ideas have been developed to improve the seismic behavior of existing and new RC buildings. The most impotent methods are classified into two approaches; a) adding new structural elements (shear walls or steel bracing) and b) locally strengthening the elements. The famous local strengthening method is jacketing the elements with concrete or steel, covering the element with FRP, and utilizing shape memory alloy. The use of steel bracing systems with concentrically braced frames (CBF) for seismic rehabilitation of RC moment frames offers some advantages such as: (a) a) minimal weight added to the structure; and (c) increasing the ultimate and stiffness. The application of steel bracing systems has been investigated experimentally and numerically in Ref [1]. Although it improves the ultimate strength and stiffness, it reduces the ductility of the system. The reduction of ductility is due to the buckling of the brace. So, utilizing the eccentrically braced frame (EBF) with short beam segments as active links has shown a suitable performance [2]. Shear links used in eccentrically braced frames constitute effective and inexpensive metallic passive energy dampers. Ductile yielding of members in shear represents an effective mechanism of energy dissipation in earthquake-resistant structural systems. The short shear link exhibit stables and ductile cyclic behavior without brittle failure before reaching a plastic rotation of 0.1 rad [3]. The idea of utilizing shear-yielding members as energy dissipation devices gave inspiration to the development of several structural systems such as metallic dampers to improve RC frame behavior [6], and innovative shear dampers on CBF [4]. Results indicated the capability of the metallic damper in enhancing the structural parameters of RC frames. Accordingly, since the ductile behavior of any system under seismic excitation, improving by metallic damper is proposed in this paper. Among the metallic damper, utilizing Vertical Shear Links (VEBF) are due to their simplicity in construction, ease of replacement after an earthquake, and suitable performance. the performance of the VEBF is related to the mechanism of the link. According to the AISC-341-16 [5], the inelastic response of a link is strongly influenced by the link length and the M_p/V_p ratio. Using plastic cross-sectional analysis, the plastic shear strength, V_p, of such a cross-section can be written as:

$$V_p = 0.6F_{yw}.t_w.(d - 2t_f) \tag{1}$$

where F_{yw} is the web yield strength, t_w is the web thickness, d is the web depth, and t_f is the flange thickness.

The plastic moment strength, M_p, of the cross-section can similarly be derived as:

$$M_p = F_{yf}.t_f.(b - 2t_w)(d - t_f) + F_{yw}.\frac{t_w.d^2}{2} \tag{2}$$

In this equation, F_{yf} is the flange yield strength, b is the flange width, and the other parameters are as previously defined. To impose the shear link

$$e \leq \frac{1.6M_P}{V_P} \tag{3}$$

Forcing the yielding to occur in, and to be confined to, ductile link elements is the primary goal of the eccentrically braced frame (EBF) design. Capacity-based design is utilized to realize this objective. In capacity-based design, while the links are sized for the load combinations specified by the code, the members outside of the links should be designed to resist the forces generated by the fully yielded and strain-hardened links.

In line with improving the RC frame by adding the VEBF, in recent years, utilizing Ultra-high performance concrete (UHPC) has been introduced as a novel construction that has realized rapid growth in construction. Compared to conventional concrete, the mechanical and durability properties are enhanced using UHPC which may reduce economical construction by reducing the cross-sections of structural members [6]. Lee [7] carried out a series of experimental research under seismic loading. Hung [8] investigated the cyclic flexural performance of UHPC experimentally. The results showed that UHPC beams reinforced with high-strength steel can show satisfactory cyclic flexural performance before failure. Besides, other researchers also studied the mechanical properties of UHPC columns or beams [9]. In summary, just a few investigations on the seismic behavior of UHPC columns are reported. In recent years, a lot of post-earthquake investigations [10] have confirmed that most of the conventional high-strength reinforced concrete columns, which were in areas strongly stricken by earthquakes, were seriously damaged in shear failure so that these columns could not resist seismic loading by utilizing their large deformation and corresponding energy dissipation efficiently. Gu [11] has figured out that the phenomenon described above is mainly attributed to the poor toughness and remarkably brittle nature of conventional high-strength concrete.

2 Numerical models

2.1 Models

To investigate the behavior of moment resisting frame (MRF) made of UHPC and conventional concrete strengthened with metal vertical shear link (VEBF), finite element (FE) models are analyzed. To do so, the first six double-shear links were designed according to the AISC-341-16 [5] to have a shear mechanism. To consider that they are acting together, they are analyzed. Then the optimum shear link was selected. Also, to add the VEBFs to the systems, first, a frame with conventional concrete is designed with ACI-341 [12] provision. The length and height of the model are, respectively, 5m and 3m. Then, by keeping all variables, its concrete is changed to the UHPC. To evaluate the effect of VEBF on the behavior of the MRFs, the VEBF is added to the system and their behavior is investigated. For each model, a name including two parts was designed. The first part represents the type of concrete; C for conventional concrete and U for UHPC. The second letter stands for VEBF the third part shows the section on VEBF. Also, the compressive strength of the conventional concrete and UHPC is 30MPa and 150MPa, respectively. Fig. 1 shows the schematic view of the FE model.

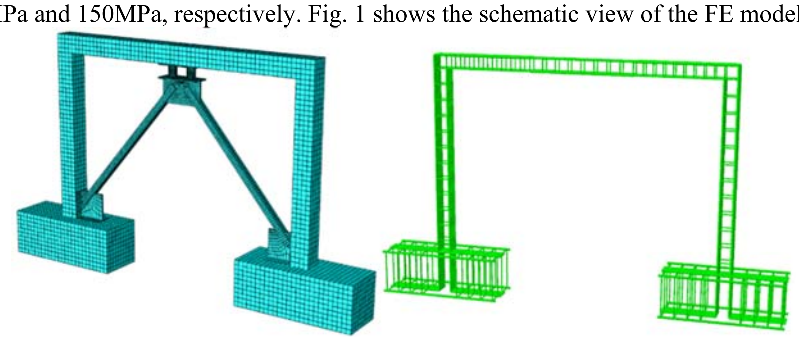


Figure 1: Schematic view of FE models

2.2 Verification of FE results

In this paper, ABAQUS software was employed to simulate the FE models. To ensure the accuracy of its results, an experimental test reported in Ref [13] was selected.

As shown in Fig. 2, the FE modeling has a good agreement with the test results. Therefore, in the next sections, other FE models are simulated by ensuring the accuracy of the ABAQUS results.

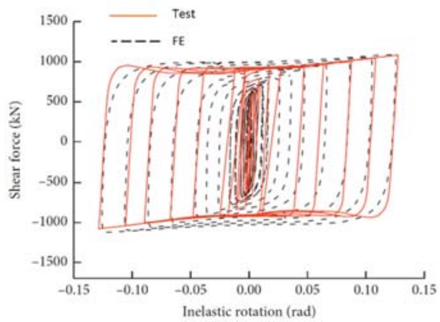


Figure 2: Comparing the FE results with the experimental test

3 Discussion and results

3.1 Bare double VEBF

In Fig. 3, the hysteresis curves of the shear links with different cross sections and lengths, e, are shown. According to the figure, the double shear links serve suitable hysteresis curves without any degradations. So, it is concluded that double-shear links act together as a ductile fuse. In the next sections, the shear links of IPE140 and IPE 120 with a length of 300mm (for simplicity in constructions) are added to the frame and their behavior is evaluated.

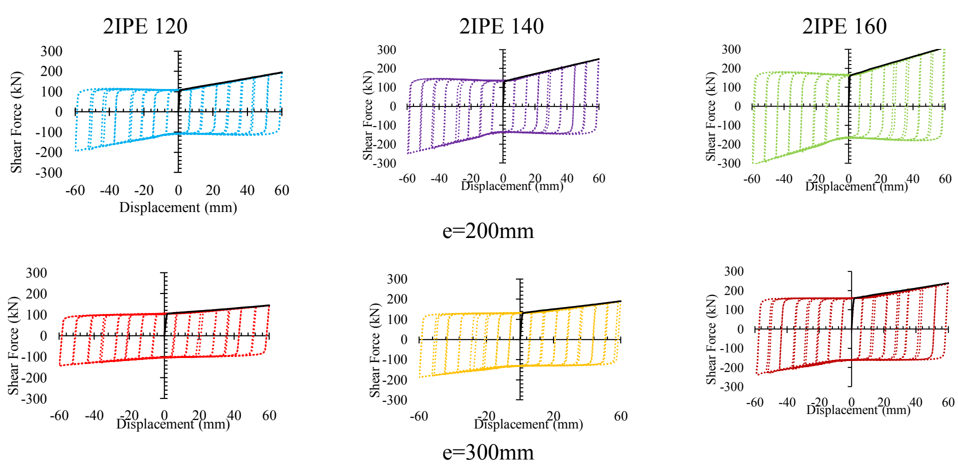


Figure 3. The hysteresis of double-shear links

3.2 Strengthen system

In Fig. 4, the hysteresis curves of FE models are compared. Referring to the figure, in all systems strengthened with VEBF, no degradation in hysteresis curves is seen. So, it causes stable hysteresis loops. Correspondingly, the VEBF improve the behavior of both frame with UHPC and conventional concrete in the case of stiffness, ultimate strength, and dissipating energy. Moreover, results indicate that the VEBF is more effective on the C-frame than the U-frame. It is due to the greater strength U-frame than the C-frame that causes a higher share of lateral loading. Also, comparing the cross-section of VEBF shows that it is affected the ultimate strength and dissipating energy but does not considerable effect on stiffness.

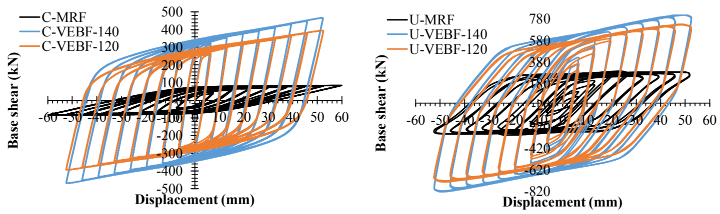


Figure 4. Comparing the behavior of structures strengthened with VEBs

3.3 The effect of concrete type on the behavior of the system

Fig. 5 reveals that by changing the conventional concrete to UHPC, the heresies behavior of systems with VEBFs is improved. It means that although adding the VEBF improves the behavior of the systems, utilizing the UHPC enhances the behavior of the system as well. Also, it is more effective on the ultimate strength and dissipating energy than stiffness as they considered in the next sections.

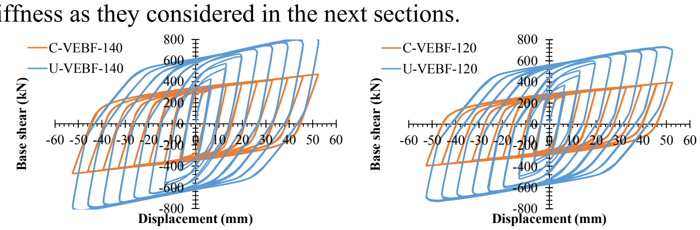


Figure 5. Comparing the behavior of different concrete

3.4 Comparing the structural parameters of the FE models

In Table 1, the ultimate strength, Fu, and stiffness, K, of FE models are listed. Comparing the results indicate that utilizing the UHPC instead of conventional concrete is more effective on the Fu than K. Also, it is more effective on the bare frame than the strengthened system. By changing the conventional concrete to UHPC for bare and strengthened systems the ultimate strength is enhanced 3.72 times and 2.14 times which is considerable. Also, the elastic stiffness is enhanced 1.28 times and 1.08 times. Also, by adding the VEBF to the frames the Fu and K for the conventional frame are, respectively, enhance by 4.29 to 5.13 and 7.63 to 8.55. Also, it enhances the Fu and K of UHPC by 2.47 to 2.78 times and 6.44 to 7.17 times, respectively.

Table 1. The ultimate strength and stiffness of the FE models

Model	Fu (kN)	K (kN)	U − models/C − models		VEB model/ frame	
			Fu	K	Fu	K
C-MRF	79.71	13.22				
C-VEBF-120	341.77	100.87			4.29	7.63
C-VEBF-140	409.07	112.99			5.13	8.55
U-MRF	296.23	16.94	3.72	1.28		
U-VEBF-120	730.36	109.02	2.14	1.08	2.47	6.44
U-VEBF-140	824.15	121.50	2.01	1.08	2.78	7.17

3.5 Energy dissipating

To assure acting the VEBF as a ductile fuse in these systems, the dissipating energy by the VEBF and frame is shown in Fig. 6. As shown in this system, the VEBF dissipate around 50% of the imposed seismic energy to the system. Therefore, it can be accounted as a ductile fuse to dissipate the imposed energy.

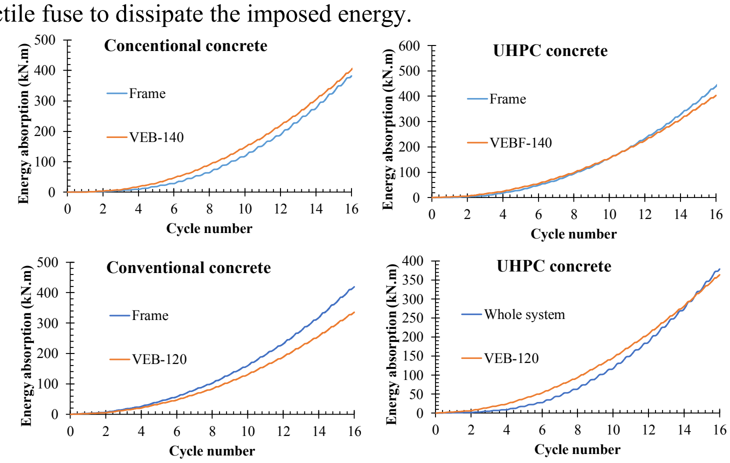


Fig. 6. Comparing the absorbed imposed energy by the system and VEBF

Referring to Fig. 7, the strengthened system with greater VBEF gives higher dissipating energy capability for both frame concrete types. Also, utilizing the UHPC instead of conventional concrete cause to increasing the energy dissipating around 2 times. This increase is a considerable advantage to the use of UHPC.

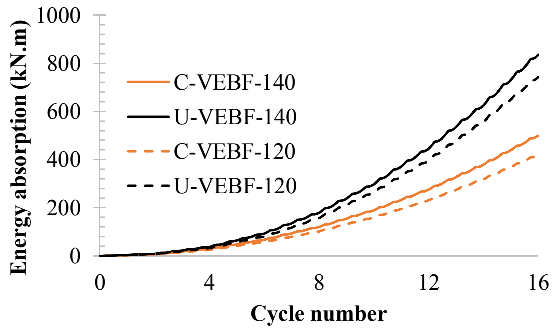
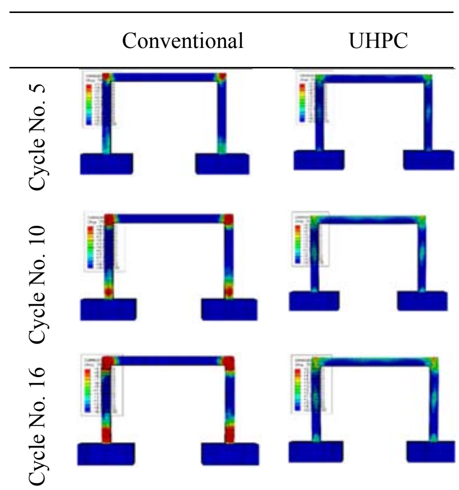


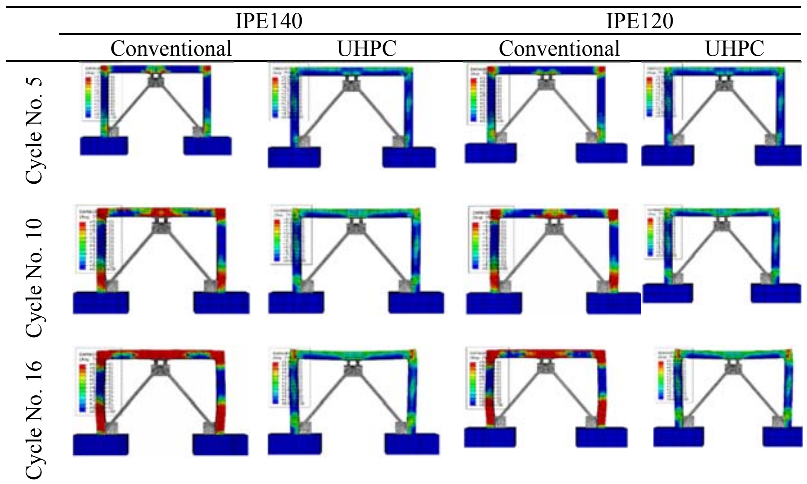
Fig. 7. Energy dissipating the strangled system

3.6 Damages statues of the FE models

The damages statue of the system with a bare frame and strengthened with VEBF are shown in Fig. 8 for both conventional and UHPC. As shown in these figures, using the UHPC the damages are completely prevented in the main frame and it is confined to the VEBFs. So, after a severe earthquake, it can be replaced easily. In a system with conventional concrete, the brae frame is fractured in cycle No. 16 however by strengthening with VEBF, they are not fractured. Although in the conventional concrete frame, the damages are reduced over the columns, they are completely prevented. Also, in this system, the VEBF with weaker VEBF results from lower damages in the beam.



(a). The system with a bare frame



(b). The system with a VEBF

Figure 8. Damages over the systems

4. Conclusions

In this paper, the improving behavior of the RC frame strengthened with double VEBF was investigated numerically. The results are summarized as follows:

- The VEBF improves the behavior of both frames made of UHPC or conventional concrete in the case of stiffness, ultimate strength, and dissipating energy.
- Moreover, results indicate that the VEBF is more effective on the C-frame than the U-frame. It is due to the greater strength U-frame than the C-frame that causes the higher share of lateral loading.
- Also, comparing the cross-section of VEBF shows that it is affected the ultimate strength and dissipating energy but does not considerable effect on stiffness.
- Using UHPC for bare and strengthened frames the ultimate strength is enhanced 3.72 times and 2.14 times which is considerable. Also, the elastic stiffness is enhanced 1.28 times and 1.08 times. Also, by adding the VEBF to the frames the Fu and K for the conventional frame are, respectively, enhance by 4.29 to 5.13 and 7.63 to 8.55. Also, it enhances the Fu and K of UHPC by 2.47 to 2.78 times and 6.44 to 7.17 times, respectively.
- Utilizing the UHPC instead of conventional concrete cause to increasing the energy dissipating around 2 times. This increase is a considerable advantage to the use of UHPC. Also, the VEBF dissipates around 50% of the imposed seismic energy to the system. Therefore, it can be accounted as a ductile fuse to dissipate the imposed energy.
- Using the UHPC the damages are prevented in the main frame and it is confined to the VEBFs although, in the conventional concrete frame with VEBF, the damages are reduced over the columns. Also, in this system, the VEBF with weaker VEBF results from lower damages in the beam.

References

[1] Haddad M, Shrive N., **2019**, Investigating the inelastic cyclic behavior of large-size steel wide-flange section braces, Construction and Building Materials, 199 (28): 92-105. https://doi.org/10.1016/j.conbuildmat.2018.12.016.

[2] Chen, L., Tremblay, R., Tirca, L. **2019**, Modular tied eccentrically braced frames for improved seismic response of tall buildings, Journal of Constructional Steel Research, 155: 370-384. https://doi.org/10.1016/j.jcsr.2019.01.005.

[3] Alshimmeri, A, Kontoni, D., Ghamari, A., **2021**, Improving the seismic performance of reinforced concrete frames using an innovative metallic shear damper, Computers and Concrete, 28 (3). https://doi.org/10.12989/cac.2021.28.3.000.

[4] Thongchom, C.; Bahrami, A.; Ghamari, A.; Benjeddou, O. **2022**, Performance Improvement of Innovative Shear Damper Using Diagonal Stiffeners for Concentrically Braced Frame Systems. Buildings. 2022, 12, 1794. https://doi.org/10.3390/buildings12111794.

[5] AISC. 2016, Seismic provisions for structural steel buildings." Standard ANSI/AISC 341-02, American Institute of Steel Construction, Inc., Chicago, IL.

[6] Tang, C. **2004**. High-performance concrete-past, present and future. In Proceedings of the International Symposium on UHPC, Kassel, Germany (pp. 3–9).

[7] Lee HL. **2007**, Shear strength and behavior of steel fiber reinforced concrete columns under seismic loading. Eng Struct,29(7):1253–62.

[8] Hung CC, Chueh CY. **2016**, Cyclic behavior of UHPFRC flexural members reinforced with high-strength steel rebar. Eng Struct 2016; 122:108–20.

[9] Dadmand, B., Pourbaba, M., Sadaghian, H., Mirmiran, A., **2020**, Experimental & numerical investigation of mechanical properties in steel fiber-reinforced UHPC, Computers and Concrete, 26 (5): 451-465 http://dx.doi.org/10.12989/cac.2020.26.5.451

[10] Wang Z. A, **2008**, preliminary report on the Great Wenchuan Earthquake. Earthq Eng Eng Vib, 7(2):225–34.

[11] Gu DS, Wu YF, Wu G, Wu Z. **2012**. Plastic hinge analysis of FRP confined circular concrete columns. Constr Build Mater, 27(1):223–33.

[12] ACI-341. **2016**, Seismic provisions for structural concrete structures, American Institute of Concrete, Inc., Chicago, IL.

[13] X. D. Ji, Q. F. Ma, Y. D. Wang, **2014**. Cyclic tests of replaceable shear links in steel coupling beams," Journal of Building Structures, 35 (6):. 1–10, 2014.