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Behavior of Column Reinforced UHPFRC Materials using Excentric Loading

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ABSTRACT

Column is part of reinforced concrete which has a function as a support. However, columns are often damaged by earthquakes. Damage to the column results in the need for treatment to improve the quality of the column. One way that can be done to repair the column is by providing a layer of UHPFRC reinforcement to the damaged column. UHPFRC is a concrete that has very high quality. Research on the UHPFRC continues today to get updates on the advantages of UHPFRC. In this study, the columns used were 4 samples. One sample is used as a control column which is tested by loading until it collapses and the remaining 3 samples will be reinforced with various variations of UHPFRC thicknesses of 10, 15 and 20 mm. The column is first given a load of 50% of the maximum load of the control column. The loading given to the column with eccentric loading is 175 mm. The results of laboratory tests carried out by compression testing showed that the reinforced column experienced an increase in maximum load compared to the control column. The maximum load on the control column (CC) is 17.79 kN, while the column with 10 mm thick UHPFRC (RT-C1) is 49.80 kN, the column with 15 mm thick UHPFRC is 59.60 kN and the column with 20 mm thick UHPFRC of 69.80 kN. The maximum load capacity increase in the reinforced column compared to the control column is RT-C1 55.63%; RT-C2 86.25% and RT-C3 118.13%. As a result of the load received on the column, resulting in shortening towards the vertical. The shortening that occurs in the control column (CC) is 17.79 mm; RT-C1 at 17.95mm; RT-C2 of 18.51 mm and RT-C3 of 19.84 mm. The results of this study indicate that UHPFRC can be used as a reinforcement material for reinforced concrete columns.

Keywords: column; UHPFRC; reinforcement; maximum load; shortening.

INTRUDUCTION

The planned building must have a good safety factor for users. So that before being built, the building must be designed in such a way in terms of durability and strength. In Indonesia, the types of natural disasters that often occur, such as earthquakes, volcanic eruptions, landslides, floods and so on. Buildings are most often damaged by earthquakes because Indonesia is a region that has a high probability of experiencing an earthquake. So it is not uncommon for buildings that have been hit by an earthquake to suffer damage. Damage that occurs in buildings is often seen in the upper structure, such as beams, columns and plates. However, the damage that most affects the safety of building users is the column. Meanwhile, the column has a very important role in the building, where the column has a function as a vertical load support and continues it to the foundation. Therefore it is urgently needed handling that can be done to repair the column damaged by the earthquake.

Damage to the column can be repaired one of them with the jacketing method. Jacketing can be done by coating the concrete with steel plates (steel jacketing), coating all sides of the concrete with a mixture of fiber reinforced concrete or coating the concrete with a layer of reinforced concrete with carbon fiber (Altun, 2004; Al-Sherrawi and Salman, 2015). The method chosen in column retrofitting is the concrete jacketing method. The concrete jacketing method is a method in which concrete is given additional or thickened dimensions by adding a fiber mixture to improve the quality of reinforced concrete which has decreased in quality due to the load received. There are several types of fibers that are used as additives to concrete mixes. The addition of this fiber is usually used to improve the tensile strength of concrete. Types of concrete with added fiber include Fiber

Reinforced Concrete (FRC), High Performance Concrete (HPC) and Ultra High Performance Fiber Reinforced Concrete (UHPFRC) and have begun to be widely used to meet sustainable infrastructure needs (Randl et al., 2014; Al -Osta, 2018; Zhang, Li, et al., 2020; Paschalis, 2021). Research on the UHPFRC continues today. Because UHPFRC has an advantage in terms of high tensile strength. Column repairs carried out in this study used UHPFRC as a reinforcement material to increase the capacity of reinforced concrete columns that had been damaged by the earthquake. So that in this study the focus was on finding out about the impact of the thickness of the UHPFRC layer on the reinforcement of reinforced concrete columns.

UPHFRC is a new generation of concrete which has the characteristics of a very dense material with high compressive strength. We encounter this very lively concrete as the application of concrete technology which is growing in the world of construction. This is evidenced by the increasing strength compared to conventional normal concrete. The properties of UHPFRC are increased by reducing the amount of water usage, using aggregate with a certain grain size, using high-quality silica fume and allowing the use of steel fiber (Graybeal, 2006; Tayeh et al., 2012). The difference between UHPFRC and conventional normal concrete in terms of mix design is the amount and grain size of the binder material, the use of fiber and the use of large amounts of superplasticizer. By using a finer aggregate grain size, the composition of the UHPFRC material is much denser than conventional normal concrete. Reducing the use of water which is replaced by the use of a large amount of superplasticizer to obtain the required workability, makes superplasticizer one of the characteristics of the UHPFRC. The UHPFRC is composed of very fine nano-sized materials, which makes it very densely packed and uses a very low amount of water. UHPFRC is UHPC with the addition of fiber, where this fiber has a very significant function of improving mechanical properties.

UHPFRC studies have studied a lot of mechanical properties (Máca, et al. 2013; Shafieifar et al. 2017; Mishra and Singh, 2019); strain and tensile (Nöldgen et al. 2013. Good bond strength between the reinforcement material and the media is very important in structural reinforcement work. As a reinforcement material, at an early age UHPFRC provides high bond strength and interacts strongly with the surface of the media, seen from failures that occur mostly on the media substrate (Tayeh, Abu Bakar and Megat Johari, 2012). The results of the flexural strength test also prove and confirm that UHPFRC can be connected and strongly bonded with the media. The bond strength between the concrete media and UHPFRC is stronger than the breaking strength and the roughness of the media substrate, indicated by the absence of damage to the bond but occurring in the media (Bassam A. Tayeh, Bakar, et al., 2013). From the various methods of gluing the layers performed, the best method was obtained by the sand blasting method (Tayeh, Abu Bakar, et al., 2013a) UHPFRC can be attached with very good quality in composite structures making it an excellent material for strengthening concrete structures based on the results of rapid chloride permeability testing and electron microscope image examination (Tayeh, Abu Bakar and Megat Johari, 2013).

The development of the use of UHPC has been carried out in many countries in America and Europe, as well as several countries in Asia. Until now the use of UHPC in structures has not been used as a complete building structure, its general use is in bridge structures and facades in building structures. The bridge structures developed include pedestrian bridges, bicycle bridges, railroad bridges and public traffic bridges. Here are some UHPFRC applications that have been implemented in the construction world. In 1990 at the museum in Lausanne, Switzerland. The museum is named "The Olympic Museum", in this museum the use of UHPC is applied to beams made in the form of prefabricated panels. After that, in 2013 in France, there is a museum that uses UHPC to support parts of building structures such as brackets, columns and facades. The museum is named “Mecum Marseille, France”. Mucem stands for Museum of European and Mediterranean Civilizations”. In the same year 2013 in Paris, the stadium building was constructed using roof panels made of UHPC. The stadium was named "Jean Bouin Stadium". In 2014 in France, there were buildings using UHPC as Cladding Panels. The building was named "Foundation Louis Vuitton, France" and is still growing today.

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RESEARCH METHODS

Materials and Mix Design

Mix Design for conventional concrete or normal concrete using reference from ACI 211.1-91 (A. Committee, 2002; Dixon et al., 1991). Experiments on several normal concrete mixes using coarse aggregate (gravel) with a maximum size of 9.5 mm; fine aggregate (river sand) with a fineness modulus of 2.4; ordinary portland cement with type I (OPC), and a water/cement ratio of 0.54. Based on the results of the fresh nature test, the slump value is 11.5 cm. The workability of fresh mixes is good without segregation. The normal compressive strength of concrete at 28 days is 28.8 MPa. While the mix design for the UHPFRC mixture refers to Tayeh et al. (2012, 2013). The material used for the UHPFRC mixture consists of type I OPC, silica fume, mining sand, micro steel fiber (steel fiber). water, superplasticizers. Normal concrete mixture (NSC) and UPHFRC were mixed using the appropriate mixture according to the proportions in table 1. In this study, the steel fibers used for the UHPFRC mixture had a diameter of 0.2 mm, a length of 10 mm, and a tensile strength of 2500 MPa. Mine sand used has a size of 100 – 1180 µm and to ensure the adequacy of the workability of the fresh UHPFRC mix a flowability test was carried out using a flow table according to ASTM C 1437 (ASTM, 2007, p. 1437) and Ahlborn et al. (2008). The test results show that the average diameter of fresh mixed UHPFRC is 215 mm at 20 strokes, which means that UHPFRC meets the flow classification requirements of UHPFRC fresh mix which is at the liquid limit so that it can be called self-compacting concrete, as stated in Table 2. UHPFRC also has compressive and flexural strengths of 141.8 and 22.8 MPa, respectivelyTable 1. Mix Design of Normal Concrete (NSC) and UHPFRC.

Tabel 1. Mix Design dari beton normal dan UHPFRC

Material	NSC	UHPFRC
	kg/m3	kg/m3
OPC	300	768
Steel Fiber	-	157
Minning Sand	-	1140
Silica Fume	-	192
Water	162	144
Coarse Aggregate	700	-
Fine Aggregate	1050	-
Superplasticizer	-	40

Table 2. Flow Classification of Fresh UHPFRC Mixtures

Flow Classification	Case I	Case II	Case III
	Stiff	Fluid	Very Fluid
Average measurement after 20 beats	<200 mm	200-250 mm	>250 mm

Source: (Graybeal, 2006; MDOT, 2008; Tayeh, 2013)

Preparation of Test Objects, Loading, and Column Testing

The dimensions of the reinforced concrete columns used in this study were 100x100x1000 mm, with dimensions of 8 mm diameter reinforcement and 6 mm diameter of stirrup reinforcement. Dimensional details and column reinforcement can be seen in Figure 3.21. Reinforcement of reinforced concrete columns is carried out by the jacketing method, which is carried out by providing a layer of UHPFRC to the damaged column on the side of the perimeter of the reinforced concrete column. In this study using an eccentric loading of 175 mm. The specimens are made of 4 reinforced concrete columns. One column is used as a control column which is compressed until it collapses. While the other 3 reinforced concrete columns were tested in compression with an initial loading of 50% of the maximum load of the control column, after that they were reinforced with variations in the thickness of the UHPFRC layers of 10, 15 and 20 mm, after which they were again tested until they collapsed. Details of the variations of the test object can be seen in figure 1 below.

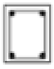
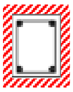
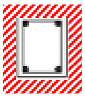
Num	Type	UHPFRC Reinforcement Type	Thickness Layer *UHPFRC* (mm)	Dimensions (mm)	Main Rebar Diameter (mm)	Distance of stirrup reinforcement (mm)
1		Control Column (CC)	-	100 X 100	4Ø8	D6-100
2		Retrofit Column 1 (RT-C1)	10	120 X 120	4Ø8	D6-100
3		Retrofit Column 2 (RT-C2)	15	130 X 130	4Ø8	D6-100
4		Retrofit Column 3 (RT-C3)	20	140 X 140	4Ø8	D6-100

Figure 1. Variation of Sample

Each reinforced concrete column is tested with a simple clamp-free support. To measure the deformation of a reinforced concrete column with eccentric loading, an LVDT is installed directly above the column to be tested. So that LVDT can read column deformation towards the vertical which is called shortening. Load cells are placed according to the specified eccentricity distance to determine the amount of loading that can be received by reinforced concrete columns. LVDT and load cells are connected to the data logger. The loading of each column is carried out in stages using a hydraulic jack. The data for the relationship between the load received by the column and the deformation that occurs is stored on a PC available in the laboratory, and the load deformation data is exported in MS Excel format.

Reinforced Concrete Column Repair with UHPFRC

Repair of reinforced concrete columns with UHPFRC in the study used the sandblasting method to increase the bonding power between the old concrete and UHPFRC as a strengthening material.

RESULTS AND DISCUSSION

The UHPFRC coating applied to reinforced concrete column specimens placed on the circumference of the column. The data that comes out of the results of the compression test on the column specimen is in the form of loads and deformations in the vertical direction (shortening). The loads that occur during the test are the initial load, maximum load and collapse load. The initial load is the initial loading that the column receives to give the condition of the damage that occurs. As a result of the initial load, deformation appears in a vertical direction which is called initial shortening. The initial load and initial shortening that occurs in the column specimens coated with UHPFRC can be seen in Figure 2 below.

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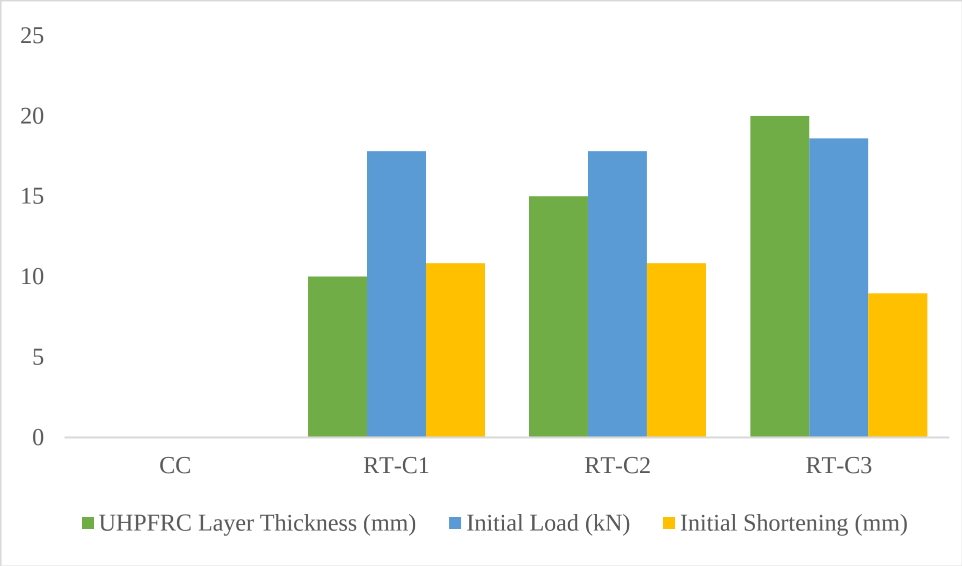

Figure 2. Graph of load & initial shortening column

The loading is given to the compressive strength test equipment by using a hydraulic jack which is operated manually which results in an initial load value of 50% of the maximum load of the control column test object given to the column test object to be given a layer of UHPFRC reinforcement cannot be set at the same number for each test object, but can only be in a range of values that are close to it. The graph in Figure 1 above shows that there is a slight difference in the magnitude of the initial load that occurs on each test object. The initial load given should be 16 kN which is obtained from 50% of the maximum load which is worth 32 kN, which is the maximum load value obtained from testing the control column test object. The magnitude of the initial load that occurs in each column is 17.8; 17.8; and 18.6 kN. Giving this initial load causes an initial shortening that occurs in all reinforced concrete column specimens. The value of the shortening that occurs sequentially is 10.84; 10.84; and 8.96mm. The magnitude of the load received by the specimen and also the initial shortening that occurs in the column specimen, causes damage to each reinforced concrete column specimen.

After the reinforced concrete column specimen is in a condition of damage due to the initial load it receives, after that the column specimen is given a layer of UHPFRC which functions as reinforcement. After the reinforcement process is complete, the compressive strength test is carried out again on the column specimens that have been strengthened by UHPFRC by applying loads until the column collapses. The compressive strength test produces the maximum load that can be carried by each test object. The magnitude of the maximum load generated on each reinforced concrete column test object with various variations of UHPFRC layer thickness can be seen in Figure 3 below.

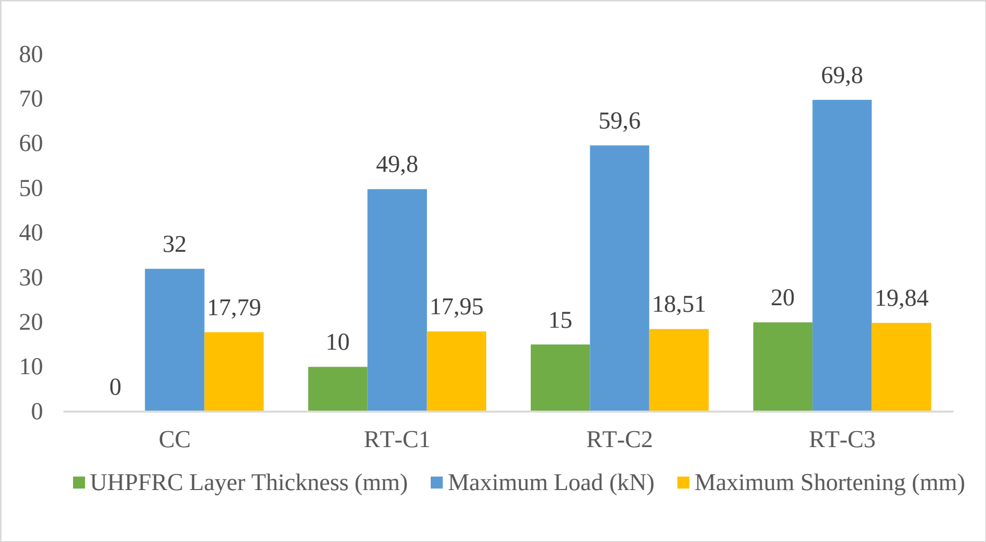

Figure 3. Graph of maximum load & shortening column

The thicker the reinforcement layer is given, the greater the maximum load will be. The strength of the UHPFRC provides enormous support to existing reinforced columns. The magnitude of the effect of the UHPFRC reinforcement layer on the column is very visible from the results of the compressive strength of the column above (Figure 4.11). The reason this happened was the influence of the given UHPFRC reinforcement layer (Nursyamsi, et al; 2022; C.-I. Lu., et al; 2023; X. Yang., et al; 2023). It is shown that the superior strength of the UHPFRC contributes to the new strength of the existing reinforced columns. Where the results show that the thicker the reinforcement layer given to the column results in an increase in the maximum load that can be accepted by the column. This is in line with the larger total dimensions of reinforced concrete columns that have been coated with a layer of UHPFRC reinforcement. Reinforced concrete column specimens with variations in the thickness of the 20 mm UHPFRC reinforcement produced the greatest maximum load on the RT-C3 column, which was 69.8 kN. The smallest maximum load obtained when testing reinforced concrete column specimens with variations in the thickness of the UHPFRC reinforcement of 10 mm occurred in the RT-C1 column, which was 49.8 kN. And for the UHPFRC layer thickness of 15 mm on the RT-C2 column specimen, it produces a maximum load of 59.6 kN. Overall, the resulting maximum load is greater than the maximum load obtained by the control column which is 32 kN. In the control column there is a shortening when the maximum load is 17.79 mm. In direct proportion to the maximum load, the specimen with the thickest UHPFRC reinforcement layer experienced the greatest shortening as well. In general, the shortening that occurs is greater as the thickness of the UHPFRC reinforcement layer is given, as shown in the graph in Figure 2 above, but the entire column test object experiences a greater shortening than the shortening produced by the control column which is 17.79 mm . The shortening that occurs on the specimens RT-C1, RT-C2, and RT-C3 respectively is 17.95; 18.51; and 19.84 mm as shown in Figure 4.11 above. In addition to the initial load and maximum load, the compressive strength test on the column specimen also produces a collapse load. The collapse load values obtained for the control column and UHPFRC reinforced column test specimens can be seen in Figure 4 below.

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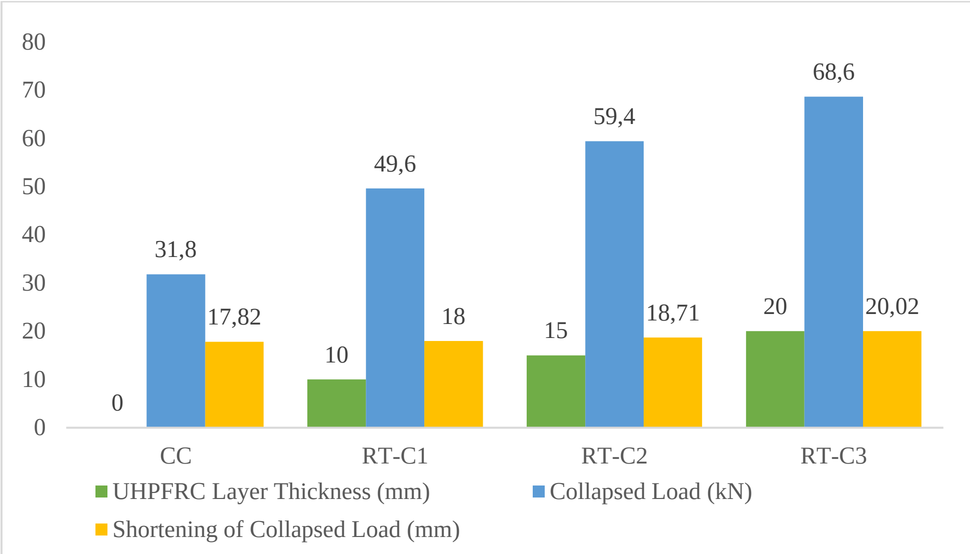
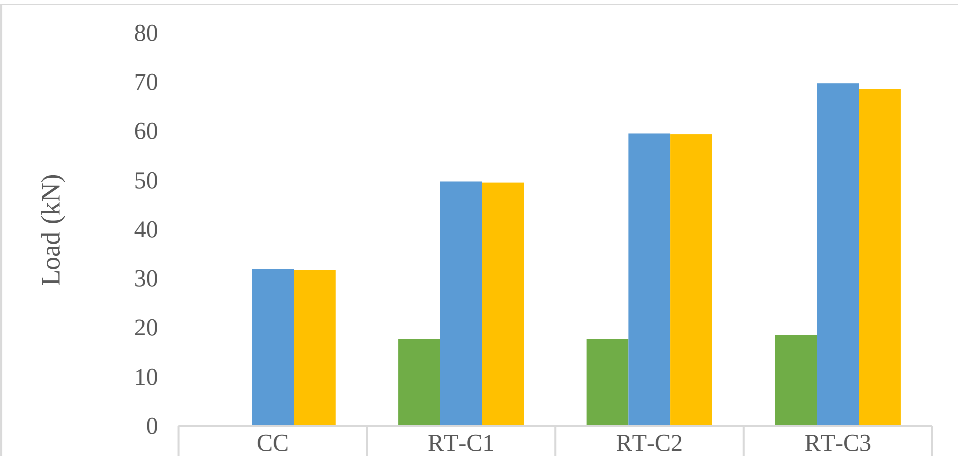


Figure 4. Graph of collapsing load and shortening column

Figure 5 shows a comparison of the load and shortening results that occur on all UHPFRC reinforcement test objects with the control column test objects, from the beginning to the end of the given loading. In the figure it can be seen that the load that occurs increases in line with the thickness of the layer of UHPFRC reinforcement given. Correspondingly, the value of shortening in the column is also getting bigger along with the increasing load that can be carried by each test object.



	CC	RT-C1	RT-C2	RT-C3
Initial	0	17,8	17,8	18,6
Maximum	32	49,8	59,6	69,8
Collapsed	31,8	49,6	59,4	68,6

Figure 5. Graph of the comparison of the results of the load that occurs on each UHPFRC reinforced concrete column test object

The increase in maximum load capacity that occurs in each test object compared to the control column with a variation of RT-C1 layer thickness of 10 mm; RT-C2 15mm; and RT-C3 20 mm respectively by 55.63%; 86.25% and 118.13%. The thicker the UHPFRC layer given to the reinforced concrete column specimen, the greater the maximum load obtained, shown in Figure 6 below.

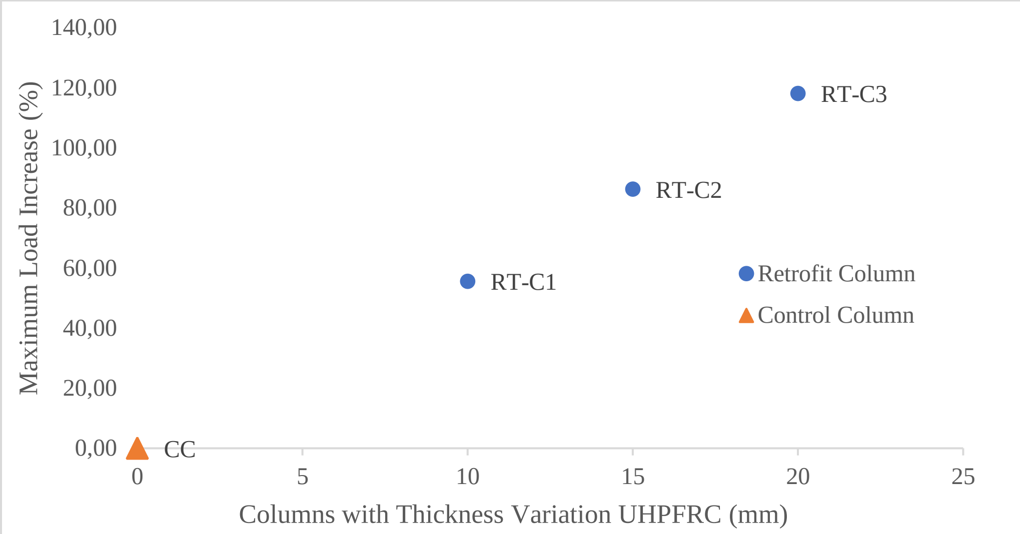


Figure 6. Graph of increasing column maximum load capacity

Table of maximum load comparison of the UHPFRC column test object to the control column can be seen in the following table 3 below.

Table 3. Comparison of Maximum Load Result of UHPFRC Reinforcement Column to Control Column

Num	Type	UHPFRC Layer Thickness	Dimention	Max Load	Increase in Maximum Load Capacity of the Control Column
		(mm)	(mm)	(kN)	(%)
1	CC-0	0	100 x 100 x 1000	32,00	0,00
2	RCS-1	10	120 x 120 x 1000	49,80	55,63
3	RCS-2	15	130 x 130 x 1000	59,60	86,25
4	RCS-3	20	140 x 140 x 1000	69,80	118,13

Then due to the maximum load that occurs, it causes shortening. Where the greater the load received by the column in line with the greater the value of the shortening that occurs in the column. Can be seen in the figure 6 and tables 5.

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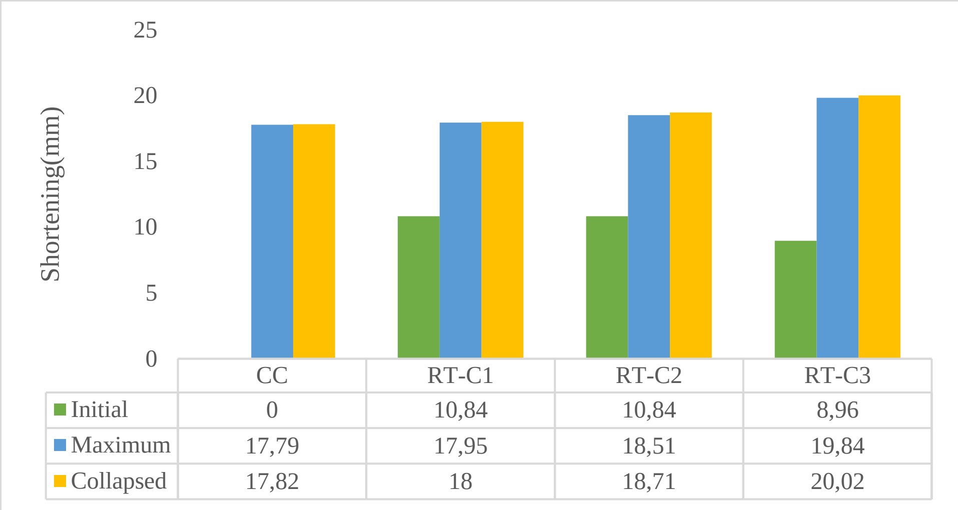

Figure 7. Graph of the results of the shortening that occurs in each column test object

Table 4. Comparison of Maximum Shortening Results of the UHPFRC Column to the Control Column

Num	Type	UHPFRC Layer Thickness	Dimention	Shortening	Increased in Maximum Shortening Capacity of the Control Column
		(mm)	(mm)	(mm)	(%)
1	CC-0	0	100 x 100 x 1000	17,79	0,00
2	RCS-1	10	120 x 120 x 1000	17,95	0,90
3	RCS-2	15	130 x 130 x 1000	18,51	4,05
4	RCS-3	20	140 x 140 x 1000	19,84	11,52

CONCLUSION

From the results of research that has been carried out in the laboratory, it can be concluded that UHPFRC is effectively used as a reinforcement layer material. The results of the study showed that there was an increase in the maximum load capacity of all reinforced concrete columns that had been reinforced with UHPFRC layers compared to the control column. This happens because the UHPFRC contributes to the addition of strength to the column. The thicker the UHPFRC layer is given, the greater the maximum load that can be accepted by the reinforced column. This is directly proportional to the larger dimensions of the column due to the additional thickness of the UHPFRC layer. The increase in maximum load capacity in reinforced UHPFRC columns with a thickness of 10 mm (RT-C1), 15 mm thick (RT-C2) and 20 mm thick (RT-C3) respectively 55.63%; 86.25% and 118.13%. The thicker the UHPFRC layer.

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REFERENCES

ASTM C 1437-07 (2007) 'Standard Test Method for Flow of Hydraulic Cement Mortar', ASTM International, pp. 6–7.

Bagus Soebandono, Andreas Triwiyono, Muslikh, (2011).'Retrofitting of Reinforced Concrete Beam by Using Ferrocement Jacketing Method due to Cyclic Loading on Ultimate Load'. Jurnal Ilmiah Semesta Teknika, Vol.14, No.2, Pp.166-176.

Badan Standardisasi Nasional (2019) Persyaratan Beton Struktural Untuk Bangunan Gedung Dan Penjelasannya (ACI 318M-14 Dan ACI 318RM-14,MOD)- SNI 2847:2019, BSN.Jakarta.

Bassam A. Tayeh, Mohammed Abu Naja, Samir Shihada, and Mohammed Arafa., (2019).,'Repairing and Strengthening of Damaged RC Columns Using Thin Concrete Jacketing'., Advances in Civil Engineering., Volume 2019, Article ID 2987412, pp 16.

C. Wen et al,. (2022). 'Influence of fibers on the mechanical properties and durability of ultra-high-performance concrete: A review'. Journal of Building Engineering. Vol 52. 104370.

Chynoweth, G., Stankie, R.R., Allen, W.L., Anderson, R.R., Babcock, W.N., Barlow, P., Bartholomew, J.J., Bergemann, G.O., Bullock, R.E. & Constantino, F. J. (2001) 'Concrete Repair Guide', ACI Committee, 546(Reapproved), pp. 1–41.

C. Wen et al (2022). 'Influence of fibers on the mechanical properties and durability ofultra-high-performance concrete: A review'. Journal of Building Engineering. Vol 52. 104370.

Chun-ling Lu , Kang Ouyang a, Cheng Guo a, Qiang Wang, Hou-qiong Chen a, Wan-xu Zhu, Axial compressive performance of RC columns strengthened with prestressed CFRP fabric combined with UHPC jacket *Engineering Structures* 275 (2023) 115113.

Dipohusodo, Istimawan., 1996, Manajemen Proyek dan Struktur, Gramedia Pustaka Utama, Yogyakarta.

Graybeal, B. (2006) 'Material Property Characterization of Ultra-High Performance Concrete', Fhwa, (FHWA-HRT-06-103), p. 186.

Graybeal, B. A., Ph, D. and Asce, M. (2014) 'Flexural Behavior of an Ultrahigh-Performance Concrete I-Girder', Journal of Bridge Engineering, 0702(May), pp. 602–610.

Heri Khoeri (2020).'Pemilihan metode perbaikan dan perkuatan struktur akibat gempa (Studi kasus pada bank sulteng palu)', Jurnal Konstruksia. Volume 12 No. 1.

Huang, Y., Grunewald., S., Schlangen., E., dan Lukovic., M. 2022. 'Strengthening of concrete structures with ultra high performance fiber reinforced concrete (UHPFRC): A critical review', Construction and Building Materials. Elsevier Ltd. 336. 127398.

Hung, C. C., Chen, Y. T. and Yen, C. H. (2020) 'Workability, fiber distribution, and mechanical properties of UHPC with hooked end steel macro-fibers', Construction and Building Materials, 260.

José D. Ríos, Carlos Leiva, M.P. Ariza, Stanislav Seitl, Héctor Cifuentes. (2019). 'Analysis of the tensile fracture properties of ultra-high-strength fiber-reinforced concrete with different types of steel fibers by X-ray tomography', Material and Design. Elsevier Ltd. 165 – 107582.

Jack C McCormac., 2004, Desain Beton Bertulang, Penerbit Erlangga, Jakarta.

Kusumawardaningsih, Y. et al. (2015) 'Tensile Strength Behavior of UHPC and UHPFRC', Procedia Engineering. Elsevier B.V., 125, pp. 1081–1086.

Kaize Ma, Xiwang Cao , Jiaxin Song , Xiangyu Meng , Lei QiaoAxial compressive behavior of concrete-filled steel tubes with GFRP-confined UHPC cores, *Journal of Constructional Steel Research* 200 (2023) 107632.

Li, G., Xie, H. and Xiong, G. (2001) 'Transition zone studies of new-to-old concrete with different binders', Cement and Concrete Composites, 23(4–5), pp. 381–387.

pISSN 2302-4240
eISSN 2655-2086
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Li, J. et al. (2020) ‘Durability of ultra-high performance concrete – A review’, Construction and Building Materials.

Mishra, O. and Singh, S. P. (2019) ‘An overview of microstructural and material properties of ultra-high-performance concrete’, Journal of Sustainable Cement-Based Materials. Taylor & Francis, 8(2), pp. 97–143.

Martinola, G. et al. (2010) ‘Strengthening and repair of RC beams with fiber reinforced concrete’, Cement and Concrete Composites. Elsevier Ltd, 32(9), pp. 731–739.

Máca, P., Sovják, R., dan Varinik, T., (2013)., ‘Experimental Investigation of Mechanical Propertis’. Procedia Engineering. Elsevier Ltd. 65. pp 14-19.

Mohd Zahid, M. Z. A. et al. (2015) ‘UHPFRC as Repair Material for Fire-Damaged Reinforced Concrete Structure – A Review’, Applied Mechanics and Materials, 802, pp. 283–289.

Nursyamsi, Tarigan, J., B. H., et al. (2020) 'Ultra High Performance Fiber Reinforced Concrete an Alternative Material for Rehabilitation and Strengthening of Concrete Structures : A review’ Journal of Physics : Conferense Series 1529-052010.

Nawy, E. G., 1990, Beton Bertulang Suatu Pendekatan Dasar, Eresco, Bandung.

Nöldgen, M. et al. (2013) ‘Properties of Ultra High Performance Concrete (UHPC) in tension at high strain rates’, FraMCos - Proc. 8th International Conference on Fracture Mechanics of Concrete and Concrete Structures, pp. 988–1000.

Ren, G. M. et al. (2018) ‘Effects of steel fiber content and type on static mechanical properties of UHPCC’, Construction and Building Materials, 163, pp. 826–839.

Shafieifar, M., Farzad, M., dan Azizinamini., A. (2017) ‘Experimental and numerical study on mechanical properties of Ultra High Performance Concrete (UHPC)’, Construction and Building Materials. Elsevier Ltd, 156, pp. 402–411.

Shafieifar, M., Farzad, M. and Azizinamini, A. (2018) ‘A comparison of existing analytical methods to predict the flexural capacity of Ultra High Performance Concrete (UHPC) beams’, Construction and Building Materials. Elsevier Ltd, 172, pp. 10–18.

Tayeh, Bassam A., Abu Bakar, B. H., et al. (2013) ‘Evaluation of bond strength between normal concrete substrate and ultra high performance fiber concrete as a repair material’, Procedia Engineering. Elsevier B.V., 54(Farhat 2010), pp. 554–563.

Tayeh, B. A. et al. (2012) ‘Mechanical and permeability properties of the interface between normal concrete substrate and ultra high performance fiber concrete overlay’, Construction and Building Materials. Elsevier Ltd, 36, pp. 538–548.

Tayeh, Bassam A., Abu Bakar, B. H., et al. (2013a) ‘Evaluation of bond strength between normal concrete substrate and ultra high performance fiber concrete as a repair material’, Procedia Engineering. Elsevier B.V., 54(Farhat 2010), pp. 554–563.

Wille, K., El-Tawil, S. and Naaman, A. E. (2014) ‘Properties of strain hardening ultra high performance fiber reinforced concrete (UHP-FRC) under direct tensile loading’, Cement and Concrete Composites. Elsevier Ltd, 48, pp. 53–66.

Wang, Z. et al. (2019) ‘Experimental and numerical investigation of the interfacial properties of non-steam-cured UHPC-steel composite beams’, Construction and Building Materials. Elsevier Ltd, 195, pp. 323–339.

Wu, Z., Shi, C. and He, W. (2017) ‘Comparative study on flexural properties of ultra-high performance concrete with supplementary cementitious materials under different curing regimes’, Construction and Building Materials. Elsevier Ltd, 136, pp. 307–313.

Wille, K. and Parra-Montesinos, G. J. (2012) ‘Effect of beam size, casting method, and support conditions on flexural behavior of ultra-high-performance fiber-reinforced concrete’, ACI Materials Journal, 109(3), pp. 379–388.

Xu Yang , Bing Zhang , Ao Zhou , Huinan Wei , Tiejun Liu Axial compressive behaviour of corroded steel reinforced concrete columns retrofitted with a basalt fibre reinforced polymer-ultrahigh performance concrete jacket *Composite Structures* 304 (2023) 116447.

Yoo, D. Y., Banthia, N. and Yoon, Y. S. (2016) 'Predicting the flexural behavior of ultra-high-performance fiber-reinforced concrete', Cement and Concrete Composites. Elsevier Ltd, 74, pp. 71–87.