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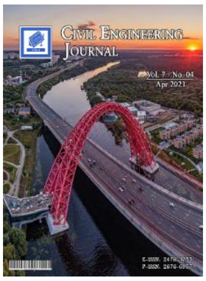

Performance of Retrofitted Square Reinforced Concrete Column using Wire Mesh and SCC Subjected to Cyclic Load

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Abstract

One way to restore or increase the strength of the structure against earthquakes is to use retrofit method and wire mesh is a material that has high prospects as retrofit material. The purpose of this study was to examine the use of wire mesh as a retrofit material on reinforced concrete columns burdened with cyclic loads. In this study, testing of 3 square column samples of reinforced concrete with dimensions of 300 × 300 mm. The first specimen is fully retrofit on the entire cross-section of the column, the second specimen is retrofitted on the plastic hinge area of the column and the third specimen is a control column without retrofit. In the first and second specimens were retrofitted with wire mesh size M6 using SCC which was then tested with a cyclic load using displacement control method based on the provisions stipulated in the Indonesian Standard SNI 7834:2012. From the test results and analysis results, it was found that the capacity and ductility of displacement in retrofit specimens increased significantly compared to specimens that were not retrofit. In addition, the decrease in stiffness in retrofit specimens was smaller than in non-retrofit specimens. As for the value of energy dissipation in fully retrofit specimens and in retrofit on the plastic hinge area is almost close. Based on these conditions, the use of wire mesh size M6 and SCC can be used as retrofit material on the column that is burdened with cyclic load.

Keywords: Retrofit; Wire Mesh; SCC; Strength, Ductility; Stiffness; Dissipation Energy.

1. Introduction

An earthquake is a potential energy release event from the earth's stomach that then radiates to the earth's surface in the form of earthquake waves caused by activity from the movement of tectonic plates that until today have not been predicted when it will happen, where it is located and how much energy will be released. Earthquakes cause thousands of people to die every year, either directly or indirectly. In addition, earthquakes not only cause damage to structures, but cause gas explosions, spark fires and in recent years, earthquakes have resulted in the loss of many lives in Japan, China and Indonesia [1]. The main problem that occurs due to earthquakes is the occurrence of damage and failure on building structures, especially those designed using building regulations in the 1970s because it has a low ductility in the column, making it very vulnerable to earthquakes and in recent decades various methods of

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strengthening and repairing columns have been developed to obtain columns that meet the requirements of strength, ductility and durability [2]. To increase the ductility of reinforced concrete columns can be achieved through the installation of repeating details properly and correctly, the use of confinement or the installation of jackets on the plastic hinge area of the column [3].

Retrofit installation on the column aims to increase the strength, deformability, ductility and stiffnes of the column, where since this method was developed various types of materials have been studied using various parameters and based on the material used this method can be classified based on the use of concrete jackets, steel jackets, ferrocement laminated jackets, and FRP confinement [4] and currently fiber reinforced polymer (FRP) composite is the most advanced material and promising as a material for retrofit on the structure because it has a high tensile capability, but also reveals exceptional properties such as high durability, stiffness, damping property, flexural strength, and resistance to corrosion, wear, impact, and fire [5]. In addition to the use of one type of material for retrofit, some researchers also use a combination of several materials such as using basalt and FRP as a confinement material on square columns of reinforced concrete with inadequate transverse reinforcement [6], the use of a combination of self-compacting concrete, CFRP filled and steel tubes on reinforced concrete square columns tested with constant cyclic and axial loads [7] and the use of NSM GFRP reinforcing and steel bars on columns modeled before the 1970s using plain bars and different lap splices [8].

In general, wire mesh is a material with specifications that vary widely around the world, this is because wire mesh is made from a variety of metal-based materials, with different shapes and dimensions depending on the importance of their use. From the results of Kumar and Vatel's research that the use of stainless steel wire mesh on circular columns tested with axial loads resulted in a significant increase in strength [9]. According to Kadir, et.al, that the use of wire mesh as a retrofit material is based on the consideration that wire mesh is also flexible enough in forming a confinement pattern and the installation of wire mesh with a certain number of layers can produce a significant amount of ductility value on a column that is burdened with cyclic load, and can increase the strength of the column shear [10].

In Indonesia wire mesh is a widely known construction material with the term woven iron with diameters ranging from 4 mm to 12 mm. Research on the use of wire mesh in this case woven iron is still very minimal and has not been done much. Therefore, in this study, experimental studies were conducted using wire mesh or woven iron diameter 6 mm (M6) combined with SCC as retrofit material on columns burdened with cyclic load. The parameters of the study consisted of strength, ductility, stiffness and energy dissipation capacity, with the hope that the use of wire mesh or woven iron can be used as an alternative retrofit material in lieu of retrofit materials from fiber to be applied to earthquake-prone building construction, especially remote areas in Indonesia. Furthermore, this paper describes experimental methods that include the dimensions of test specimens, setting up and testing methods, experimental results and analysis results that show that the use of a combination of wire mesh and SCC can be used as retrofit materials on columns. The flow of research conducted in this study is presented in Figure 1.

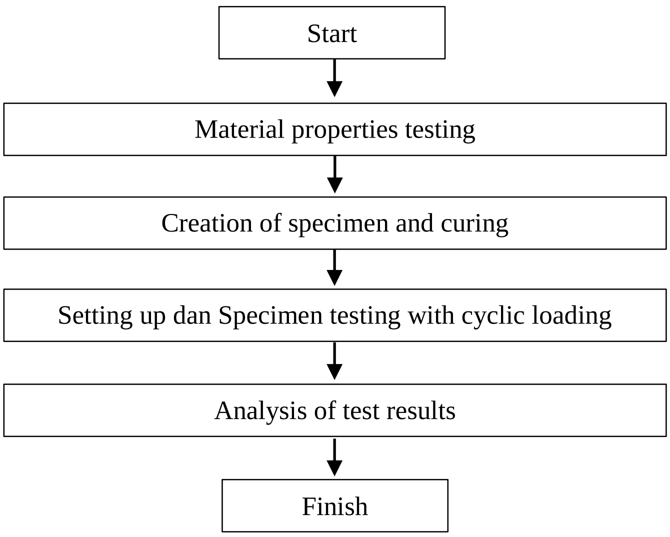

Figure 1. Research methodology flowchart

2. Experimental Methods

2.1. Specimen Test Dimensions

In this study, the test specimen used was a square column of reinforced concrete as many as 3 specimens consisting of a retrofited column filled with wire mesh and SCC along the column body (KR01), a column that was retrofitt with wire mesh and SCC in the plastic hinge area (KR02) and columns that were not retrofited with wire mesh and SCC

(KK). The three specimens of reinforced concrete columns are made of normal concrete with a quality (f'_c) of 25 MPa with the same dimensions. After the specimen is 14 days old, in specimens KR01 and KR02 are retrofit using wire mesh in the form of woven iron diameter 6 mm (M6) which has a grid dimension of 150×150 mm. The retrofit coating is 50 mm thick and uses a quality SCC (f'_c) of 25 MPa. For details of specimen dimensions and reinforcement used are presented in Figure 2 and Table 1.

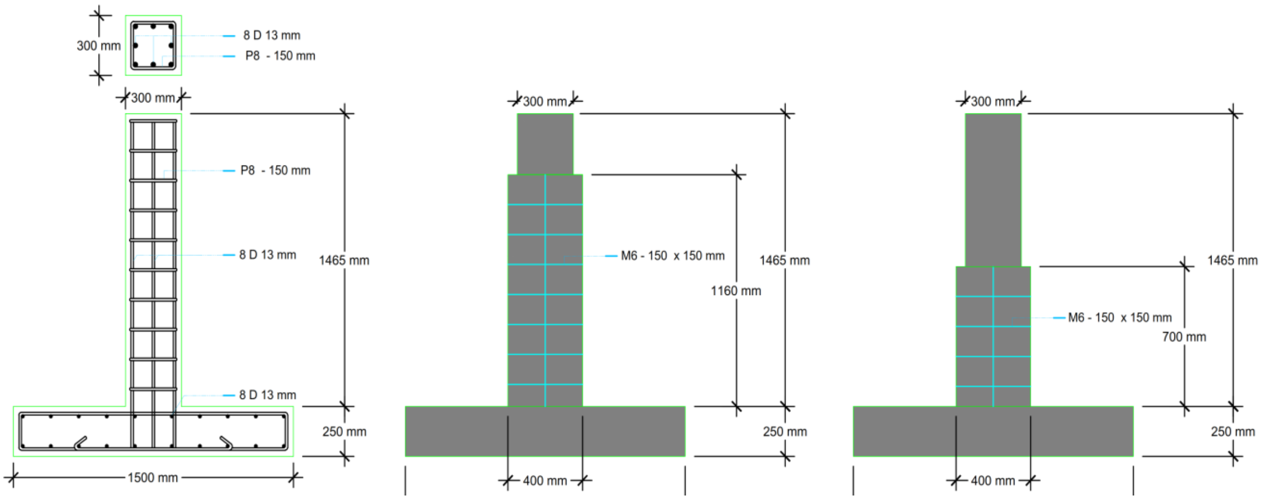

Figure 2. Detail specimens dimensions

Table 1. Specimen reinforcement

Specimen Test	Column Dimensions (mm)	Column Height (mm)	Column Reinforcement (mm)			f'c	A_{st}/A_g
			Longitudinal	Transverse	Retrofit	(MPa)	
KK	300 × 300	1465	8D13	∅8 - 150	-	25	0.0118
KR01	300 × 300	1465	8D13	∅8 - 150	M6	25	0.0118
KR02	300 × 300	1465	8D13	∅8 - 150	M6	25	0.0118

2.2. Setting Up and Testing Methods

Specimen testing is carried out after the specimen is 28 days old by placing the specimen in a predetermined position as shown in Figure 3.

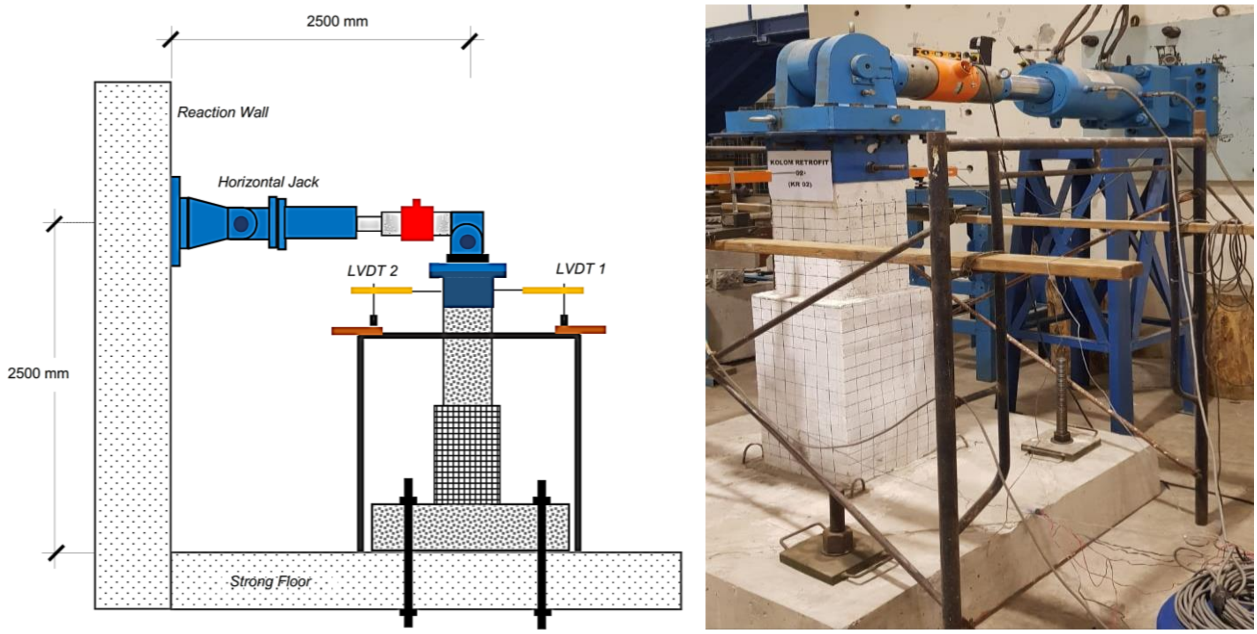

Figure 3. Testing setting up

The specimen was then tested with cyclic load based on displacement control method, where the amount of deformation given and the number of cycles is adjusted to the loading pattern referring to SNI 7834:2012 [11], as shown in Figure 4. During testing, three full cycles must be applied to each drift ratio, consisting of phase 1 which is the primary cycle and phases 2 and 3 which are stabilization cycles. During the test, data recorded on logger and computer data were taken, as well as visual observation of the cracks that occurred in the specimen.

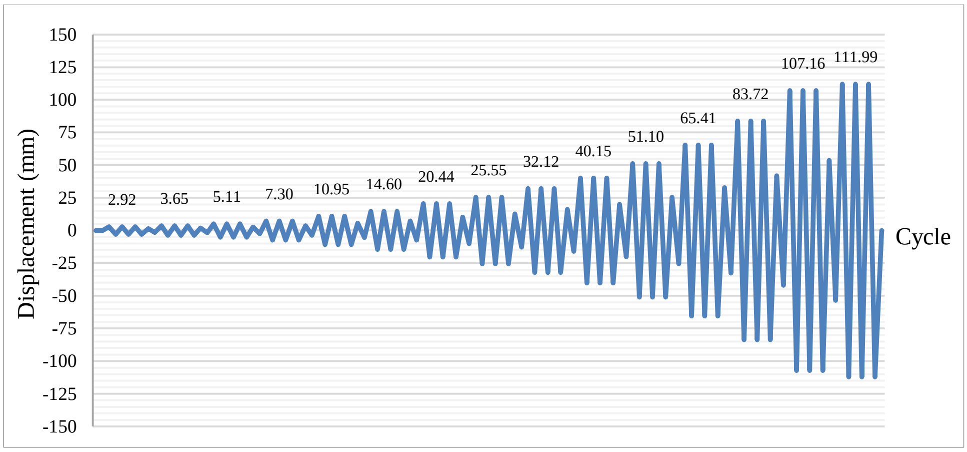

Figure 4. Loading pattern on specimen

3. Experimental Result and Discussion

3.1. Load, Drift Curve and Cracks

In KK specimens, the resulting hysteresis loops curve shape is not very fat and the decrease in stiffness is relatively insignificant as presented in Figure 5. At compressive loading, the KK test specimen curve experienced a significant increase in load up to a drift ratio of 2.2% and after that the curve experienced an insignificant increase result and tended to flatten to a drift ratio of 3.5%. While in the tensile loading, the KK specimen curve experienced a significant increase in load up to a drift ratio of 2.2% and after that the curve experienced an insignificant increase and tended to flatten to a drift ratio of 3.5% which is the minimum drift, without experiencing a decrease in strength in the specimen.

The relationship between load and deflection in retrofit column specimen KR01 due to working cyclic load is described in the form of hysteresis loops curve as presented in Figure 6. At compressive loading, the KR01 specimens curve experienced a significant increase in load to a drift ratio of 2.75% and after that the curve experienced an insignificant increase and tended to flatten to a drift ratio of 5.73%. In tensile loading, the KR01 specimen test curve experienced a significant increase in load up to a drift ratio of 3.5% and after that the curve experienced an insignificant increase and tended to flatten to a drift ratio of 5.73%.

The relationship between load and deflection in KR02 specimens due to working cyclic loads can be described in the form of hysteresis loops curves as presented in Figure 7. At compressive loading, the KR02 specimen curve experienced a significant increase in load to a drift ratio of 2.75% and after that the curve experienced an insignificant increase and tended to flatten to a drift ratio of 5.73%. In tensile loading, the KR02 test object curve experienced a significant increase in load up to a drift ratio of 3.5% and after that the curve experienced an insignificant increase and tended to flatten to a drift ratio of 5.73%.

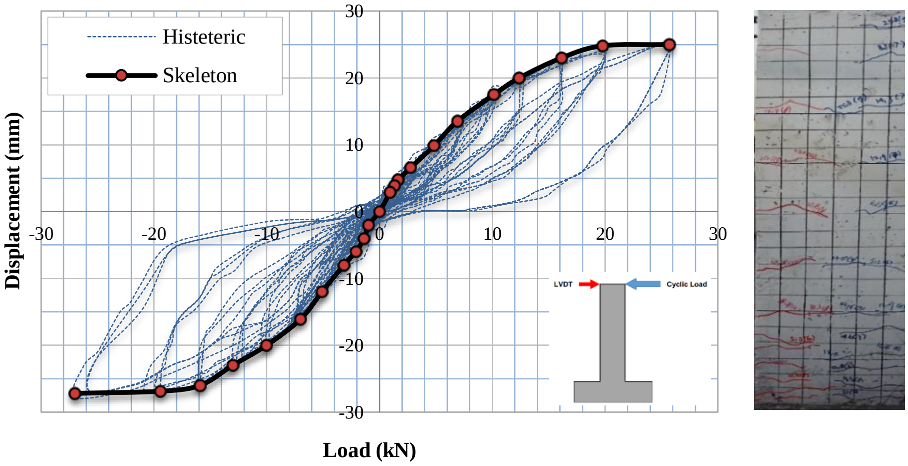

Figure 5. Hysteresis curve specimen KK

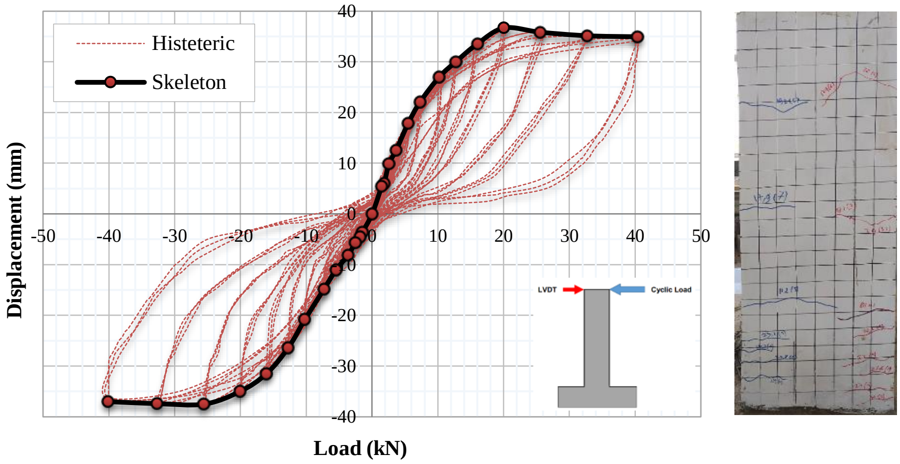

Figure 6. Hysteresis curve specimen KR01

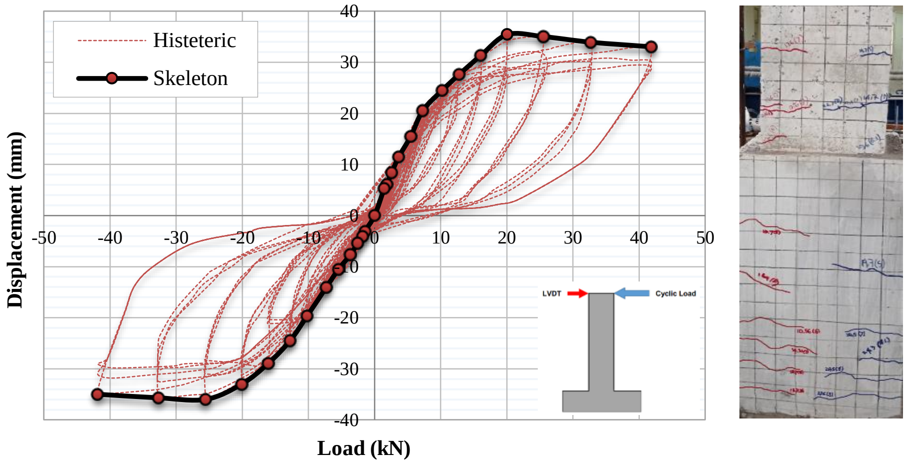

Figure 7. Hysteresis curve specimen KR02

As a result of the increase in cyclic load in the three specimens caused a gradual change in behavior from linear to non linear gradient behavior, thus exhibiting an inelastic behavior upon reaching the post yielding zone that automatically led to lateral stiffness changes in the specimen. Until the end of the test on compressive and tensile direction loading, the strength of KR01 and KR02 specimens has a higher strength compared to KK specimens and both specimens have not collapsed. In addition, all specimens meet the required minimum drift criteria of 3.5%.

In the first crack KK specimen occurred at a drift ratio of 0.75% due to a tensile load of 8,550 kN and subsequent cracks occurred due to a compressive load of 9,890 kN. The initial crack position is in the area of potential plastic hinge with a distance of 30 cm from the column legs. As a result of the increase in the number of cycles, the number of cracks continues to grow in the area of the column plastic hinge which then extends to the middle to the top of the specimen to a drift ratio of 1.75%. While until the end of testing at a drift ratio of 3.5% does not appear new cracks and only the addition of crack width.

In specimen KR01 the first crack occurred at a drift ratio of 0.75% due to a tensile load of 11,100 kN and the initial crack position was in the area of plastic hinge with a distance of 33 cm from the column legs. The subsequent crack occurred due to a compressive load of 17,850 kN and continued to increase in the area of the column plastic hinge which then spread to the center to the top of the specimen up to a deviation ratio of 1.75%. Until the end of testing at a drift ratio of 5.73% did not appear new cracks and the addition of the width of cracks that occurred was not as significant as in specimens KK.

In the KR02 specimen the first crack occurred at a drift ratio of 0.75% due to a tensile load of 10,560 kN and subsequent cracks occurred due to a compressive load of 15,525 kN. The initial crack position is in the area of the plastic hinge with a distance of 31 cm from the column legs. As a result of the increase in the number of cycles, the number of cracks continues to grow in the area of the column plastic hinge which then extends to the middle to the top of the specimen to a drift ratio of 1.75%. Until the end of the test at a drift ratio of 5.73% did not appear new cracks and the addition of crack width was not as significant as in KK specimens.

In the three specimens the crack pattern that occurs is almost the same, resulting in the same shear cracking pattern with the direction in which the cyclic load works. As for the addition of new cracks only to the drift ratio of 1.75%, where this is due to the mechanism of plastic hinge in the legs of the column has formed and longitudinal reinforcement attached to the area of plastic hinge has begun to yield.

3.2. Degradation of Strength in Specimens

For columns burdened with cyclic loads, SNI 7834:2012 [11] requires that the column should not experience strength degradation (D), where this condition can occur if the peak force (P_f) working is less than 75% of the maximum lateral load (E_{max}) in the same loading direction and the analysis results are presented in Table 2.

Table 2. Requirements for degradation of strength in specimens

Specimen Test	Lateral Force (kN)	E_{max} (kN)	$0,75.E_{max}$ (kN)	P_f (kN)	$D = 1 - P_f/E_{max}$ (%)	Requirements $P_f > 0,75.E_{max}$
KK	Compressive	24,98	18,735	24,80	0,721	OK
	Tensile	27,20	-20,400	26,88	1,176	OK
KR01	Compressive	36,64	27,480	34,90	4,749	OK
	Tensile	37,50	-28,125	37,00	1,333	OK
KR02	Compressive	35,40	26,550	33,00	6,780	OK
	Tensile	36,00	-27,000	35,00	2,778	OK

From the results of the analysis in Table 2 shows that all specimens meet the requirements of strength degradation, since the peak force value (P_f) in all specimens is greater than 75% of the maximum lateral load value that occurs.

3.3. Ductility

Ductility is the ability of the structure to formalize in elastically without experiencing a significant reduction in strength before it reaches collapse and the properties of structural ductility describe the amount of energy capable of being absorbed by the structure [12], where the value of displacement ductility occurs, can be expressed as a comparison between deflection at the time of ultimate condition (Δ_u) and deflection at the time of the first yield (Δ_u) occurred [13] and the results of ductility analysis on all specimens are shown in the Figure 8.

Figure 8. Displacement ductility value in specimens

Based on the results of the analysis, the value of displacement ductility in KK specimens due to compressive load of 2.074 and due to tensile load of 2.077. In the KR01 test specimen, due to the compressive load was 3.165 and the tensile load was 3.144. While in KR02 specimen, the value of displacement due to compressive load is 3.275 and due to tensile load of 3.275 and according to SNI 1726:2019 [14], that for the value of ductility more than 1.5 is included in the performance level of the partial ductility structure. If the value of displacement ductility in KR01 and KR02 specimens compared to the ductility value in KK specimens, then the value of displacement ductility in KR01 specimens increased by 52.6% due to compressive load and 51.4% due to tensile load. While the value of displacement ductility in KR02 specimens increased by 57.9% due to compressive load and 57.7% due to tensile load.

3.4. Stiffness

For structures experiencing cyclic loads, stiffness is defined as the slope of the line connecting the peaks of the maximum load in the positive and negative direction of the load curve and deflection [15], where the results of the analysis of the comparison of stiffness values in all specimens due to the compressive load are presented in Figure 9.a and tensile load are presented in Figure 9.b.

Due to the compressive load there was a decrease in stiffness in KK specimens by 32.15%, in KR01 specimens by 22.54% and in KR02 specimens by 21.74% at the end of loading. Meanwhile, due to the tensile load there was a decrease in stiffness in KK specimens by 52.15%, in KR01 specimens by 35.95% and in KR02 specimens by 39.89% at the end of loading.

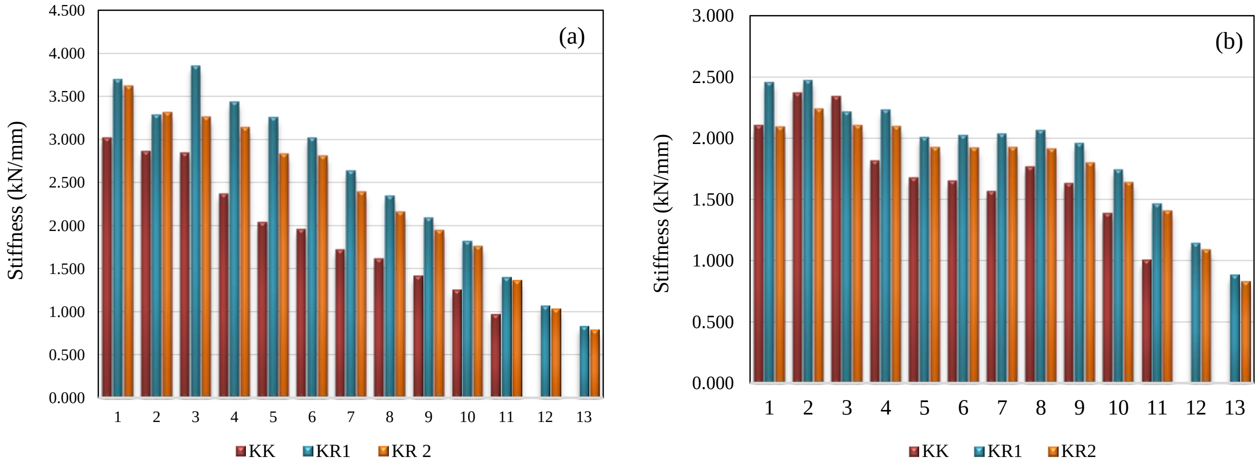

Figure 9. Stiffness of the specimen due to the (a) compressive load; and (b) tensile load

In addition, in specimens KR01 and KR02 the decrease in stiffness relatively did not occur, so it is likely that no pinching effect occurred and more led to more stable conditions with higher energy dissipation ability.

3.5. Initial Stiffness and Degradation of Stiffness

According to SNI 7834:2012 [11], that test specimen must meet the initial stiffness requirement, where the test specimen must reach the minimum lateral resistance value (E_n) before its drift ratio of 2% exceeds the value consistent with the permissible drift ratio limit. The results of the initial stiffness analysis are presented in Table 3. In addition, SNI 7834:2012 [11] requires that for structures or specimens designed against earthquakes must have sufficient stiffness degradation at the time of an earthquake or cyclic load. Test specimens are considered to have sufficient stiffness degradation, if the stiffness of the line connecting the intersection point -0.0035 to the drift ratio of +0.0035 is not less than 0.005 of the initial stiffness value (K_0) and the analysis results are presented in Table 4.

Tabel 3. Initial stiffness value of the specimen

Specimen Test	Cyclic Force	E_n (kN)	Δ_y (mm)	(h) (mm)	$r_1 = \Delta_y/h$ (%)	r_2 (%)	$r_1 < (1 + 0{,}02).r_2$ (%)
KK	Compressive	20,000	12,400	1460	0,849	3,5	Accepted
	Pull	23,000	13,000	1460	0,890	3,5	Accepted
KR01	Compressive	30,000	12,750	1460	0,873	3,5	Accepted
	Pull	26,400	12,760	1460	0,874	3,5	Accepted
KR02	Compressive	27,600	12,780	1460	0,875	3,5	Accepted
	Pull	24,500	12,780	1460	0,875	3,5	Accepted

Table 4. Requirements for degradation of stiffness in specimens

Specimen	Cyclic Force	(K_0) (kN/mm)	(K') (kN/mm)	Rasio $r_s = K'/K_0$	Requirements $r_s > 0{,}05$
KK	Compressive	3,021	2,964	0,981	Accepted
	Tensile	2,105	2,343	1,113	Accepted
KR01	Compressive	3,699	2,219	0,600	Accepted
	Tensile	2,459	2,219	0,902	Accepted
KR02	Compressive	3,627	2,109	0,582	Accepted
	Tensile	2,096	2,109	1,006	Accepted

In Table 3 the minimum lateral resistance value (E_n) is taken from the lateral force at the time of yielding (P_y) and the minimum lateral drift is taken from the drift value at the time of yielding (Δ_y). While the value of lateral resistance drift ratio (r_1) is a comparison between the value of drift at the time of yielding (Δ_y) and the height of the specimen (h) and r_2 is the minimum drift of 0.035 (%). From the results of the analysis, it can be concluded that all specimens meet the initial stiffness requirements, because the value of the lateral resistance drift ratio (r_1) is less than the requirements specified in SNI 7834:2012 [11]. From the results of the analysis in Table 4 showed that all specimens meet the requirements of stiffness degradation, where the r_s ratio value in all specimens is greater than 0.05.

3.6. Energy Dissipation

The main purpose of retrofit is to increase the capacity of structural elements, where capacity can increase in the event of an increase in energy dissipation capacity at the time of an earthquake, without a significant decrease in strength. Energy dissipation capacity is an important parameter for planned structures with earthquake loads that have long earthquake re-periods and energy dissipation values in a single cycle (E_D) can be calculated based on the area (A) of the relationship between lateral force occurring, with deformation in the form of a closing curve called hysteresis loops [16]. For energy dissipation and accumulative energy dissipation values on all specimens are used values from the first cycle which is the primary cycle, as presented in Figure 10.a and Figure 10.b.

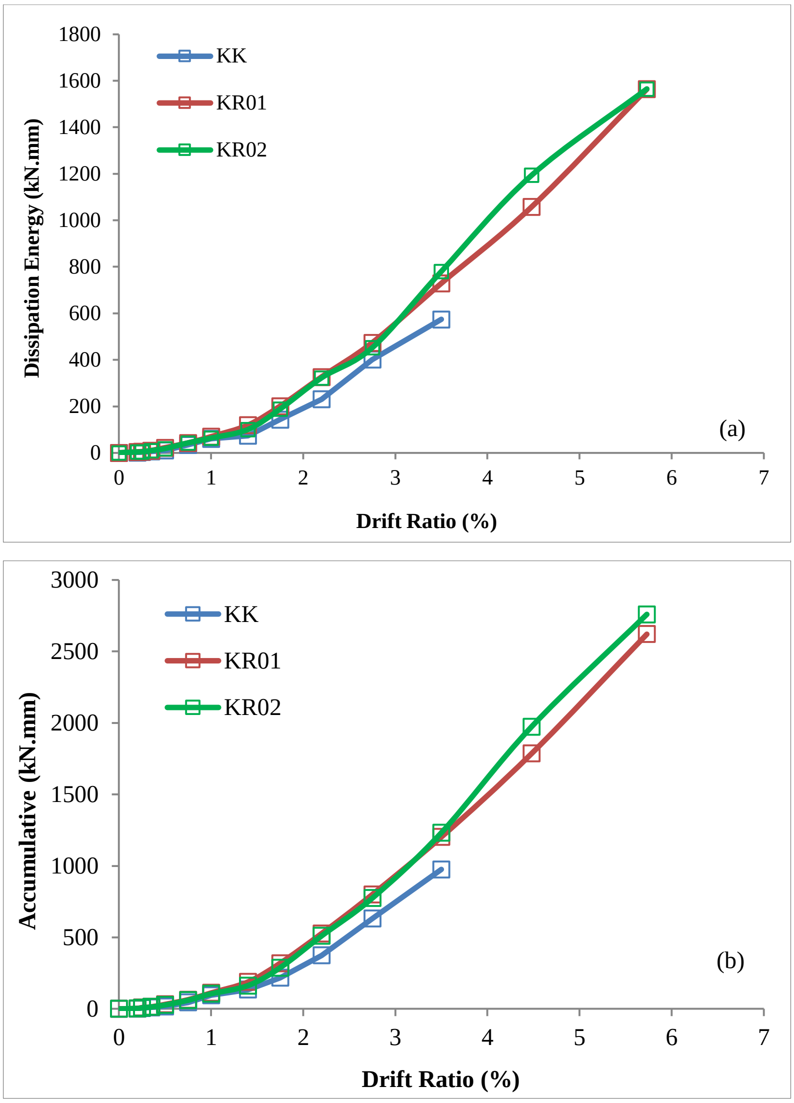

Figure 10. (a) Dissipation energy; and (b) Accumulative dissipation energy

From the energy dissipation comparison graph in Figure 10.a, it appears that the energy dissipation value in KR01 and KR02 specimens is greater than the energy dissipation value in KK specimens, while the energy dissipation value in KR02 looks higher than KR01 at drift ratio of 3.5 to 4.48% and decreases again at a drift ratio of 5.73%. While accumulatively KR02 specimens from Figure 10.b, are able to provide more energy than KK and KR01 specimens. When compared with the accumulative energy dissipation value in KK specimens at a drift ratio of 3.5%, there was an increase in energy dissipation by 23.32% in KR01 specimens and 26.30% in KR02 specimens. In all specimens the accumulative value of energy dissipation tends to increase towards increased drift levels, but the amount of energy dissipation tends to decrease for each repeat cycle at each drift level. This condition can be caused by the development of cracks at the same level of drift relatively constant, so that no new cracks are formed but only the addition of the width of the cracks at the same crack location.

To control the stability of the structure system at the maximum drift level due to the cyclic load working on the specimen, SNI 7834:2012 [11] requires that the relative energy dissipation ratio (β) should not be less than 0.125 calculated based on the third cycle at the end of loading. The results of analysis of relative energy dissipation ratio in specimens are presented in Figure 11.

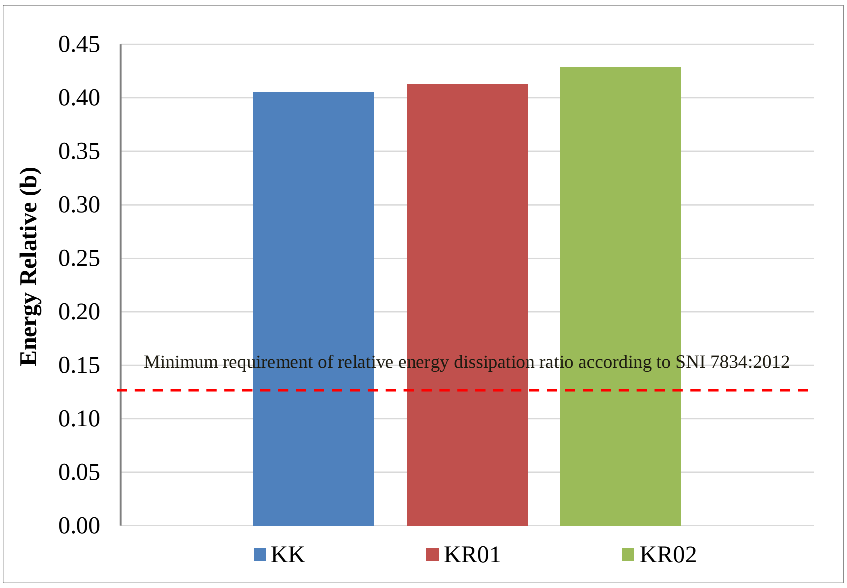

Figure 11. Minimum criteria relative energy dissipation ratio

The relative energy dissipation ratio value in Figure 11, calculated from the ratio of actual energy dissipation value to ideal energy dissipation value and based on the analysis results, it can be concluded that the ratio of relative energy dissipation (β) in the three specimens meets the minimum requirements in SNI 7834:2012 [11], so that the three test specimens still have the ability to maintain their stability before collapse.

4. Conclusion

From the test results can be concluded the capacity of the column in receiving cyclic loads that work on the model of the retrofited column is filled with wire mesh and SCC along the column body and on the model of the column that is retrofitted with wire mesh and SCC on the plastic hinge area, resulting in a force that is close to. Both models have a greater capacity in receiving cyclic load compared to column models that are not retrofitt with wire mesh and SCC. The ductilitys value in the retrofited column model filled with wire mesh and SCC along the column body increased by 52.6% on compressive loading and 51.4% on tensile loading. In the column model that was retrofit with wire mesh and SCC in the plastic hinge area, the ductility value increased by 57.9% on compressive loading and 57.7% on tensile loading, when compared to the ductility value in the column model that was not retrofited with wire mesh and SCC. As for the decrease in the value of stiffness occurs in specimens that are not retrofit with wire mesh and SCC. The capacity of energy dissipation and accumulative energy dissipation in the retrofitted column model is full of wire mesh and SCC along the column body and the column model is retrofitted with wire mesh and SCC on the plastic hinge area, almost the same and larger when compared to the column model that is not retrofitted with wire mesh and SCC.

From the results of this study can conclude that the use of 1 layer of wire mesh in this case woven iron with a diameter of 6 mm (M6) combined with quality SCC (f'_c) 25 MPa can increase the strength capacity of the column, increase the value of ductility and stiffness, and have the ability to dissipate energy better so that this combination of materials can be used as retrofit materials on reinforced concrete square columns burdened with cyclic loads. Considering this research is an early study, so it is expected that in the future there will be many further research. For future research opportunities, it is necessary to conduct research with the parameters of the use of geometry variations, column dimensions, longitudinal reinforcement diameter, transverse reinforcement diameter, wire mesh size, thick variation of retrofit layer, number of wire mesh layers, and addition of anchors mounted on plastic hinge area. In addition, it is necessary to conduct research with a combination of cyclic load and constant a axial load, considering that in practice in the field the column structure also carries an a axial load, as well as a combination of the use of wire mesh as a reinforcement in the replacement of confinement and the use of wire mesh as retrofit.

5. Declarations

5.1. Data Availability Statement

The data presented in this study are available in article.

5.2. Funding

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5.3. Conflicts of Interest

The authors declare no conflict of interest.

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