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Cyclic Behavior of Concrete Columns With Steel Jacketing in Plastic Areas by Finite Element Method

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ABSTRACT : *Columns are important structural elements whose failure will have a direct impact on other structural components. Reinforced concrete columns need to be made with adequate ductility, to prevent sudden collapse due to cyclic loading. Cyclic load is a regular repetitive loading on a part that causes fatigue. Increasing the capacity of reinforced concrete columns in receiving static axial loads and cyclic lateral loads can be done by means of restraints in plastic areas that have the potential to become places of structural failure. A total of 4 models of reinforced concrete columns were made with a size of 250 mm × 250 mm × 850 mm. The compressive strength of the concrete used is fc' = 45.40 MPa. Reinforcement of concrete columns with longitudinal reinforcement 6 16 mm and stirrup reinforcement 8 - 100 mm. The yield stress of the longitudinal reinforcement is fy = 498.03 MPa and the yield stress of the stirrup reinforcement is fy = 428.62 MPa. Each model of concrete column is made without reinforcement, with steel jacketing reinforcement of 150 mm, 250 mm and 450 mm. Each model is given the symbol MKB 1, MKB 2, MKB 3 and MKB 4. The loading is carried out with a combination of cyclic lateral load of 20 kN and static axial load of 573 kN. The position of the cyclic lateral loading is 750 mm from the bottom of the column and the static axial loading is above the column surface. The test is carried out with displacement control loading. The resulting hysteretic curve and backbone curve show an increase in the cyclic capacity of reinforced concrete columns with steel jacketing reinforcement compared to concrete columns without steel jacketing reinforcement. Based on the hysteretic shear stiffness curve, MKB 1 = 10,583 kN/mm, MKB 2 = 17,412 kN/mm, MKB 3 = 19,606 kN/mm and MKB 4 = 25, 026 kN/mm. Based on the backbone curve, the cyclic capacity increase of MKB 1, MKB 2, MKB 3, and MKB 4 was 15.075%, 24.949% and 95.112%, respectively, compared to concrete columns without steel jacketing.*

KEYWORDS: *Column, Steel Jacketing, Plastic Area, Hysteretic curve, Backbone curve.*

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I. INTRODUCTION

Damage to the reinforced concrete frame structure due to earthquakes is generally the result of column failure. Most of these truss structures were built before the application of modern seismic design codes and seismic loads were not taken into account or were not adequately considered. As a result, the shear resistance capacity of the column is usually insufficient. The occurrence of shear failure or flexural shear failure in the column structure is most likely due to insufficient shear strength, causing serious damage to the structure or even collapse. Therefore, earthquake-prone concrete column reinforcement is needed (Deng and Zhang, 2017).

A cyclic load is a repetitive loading, such as regular repetitive stress on a part, that sometimes causes fatigue fractures. Restraint in the plastic hinge area of the column by closing the spacing of the stirrups will affect the increase in the lateral load capacity acting on the column, with the increase in the lateral load acting on the column, the column strength will also increase. The spacing of the stirrups that are closer together with the axial compression load does not exceed 0.2 fc'Ag, there will be an increase in ductility and the ability of the column to absorb energy is also large without much loss of strength and stiffness (Karimah and Wahyudi, 2010). The damage caused by the earthquake and the application of reinforcement to the column can be seen in Fig. 1.

Column reinforcement using steel jacketing method can be an alternative to increase column strength. Column reinforcement with this method will increase the shear strength and compressive strength as a result of the confinement of the steel material. The steel jacketing method is carried out by adding a steel plate to the concrete construction coating, this addition is useful for increasing the shear capacity so that it can anticipate collapse due to cyclic loads. By increasing the shear capacity of the column, it will increase the ability of the structure to deform.

Fig.1. Earthquake damage and application of reinforcement to columns

Analysis with the finite element method (FEM) can be an attractive alternative as a substitute and validator for experimental testing. Therefore, the author analyzes the cyclic behavior of concrete columns with steel jacketing in the plastic area using the finite element method.

II. RESEARCH METHODS

1. **Modeling**

This research will focus on defining the behavior of concrete columns due to cyclic loading using the finite element method. The result is a modeling of the cyclic behavior of a concrete column with steel jacketing in the plastic region using the finite element method. Research with this modeling uses the help of abaqus software whose results will be compared with experimental results. For this reason, material data from experiments that are included in the program are used. The modeling of the program will be adjusted to the conditions at the time of the experiment. The results of the experimental research used as a reference are those that have been carried out by Deng and Zhang in 2017.

In this model, the same dimensions as the experiment will be used, namely, the test object is in the form of a concrete column with dimensions of 250 mm x 250 mm x 850 mm. The placement that will be used is in the form of clamps at the bottom of the column foundation with dimensions of 400 mm x 400 mm x 1,200 mm. Loading is done by using cyclic loading at the top end of the concrete column.

4 models will be made. Each consists of 1 model of the same concrete column as the C1 specimen in the Deng and Zhang experiment, 2017. 3 concrete column models, each of which is reinforced with steel jacketing with a length of 150 mm from the bottom of the column, 250 mm from the bottom. column and 450 mm from the bottom of the column. The number and shape of the concrete column model to be analyzed can be seen in Table 1 and Table 2.

Table 1. Modeling of concrete columns

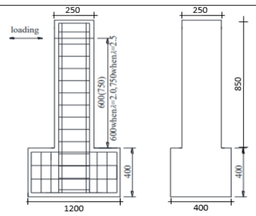
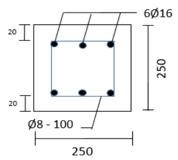
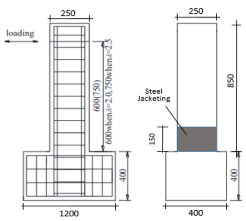
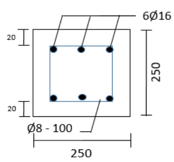
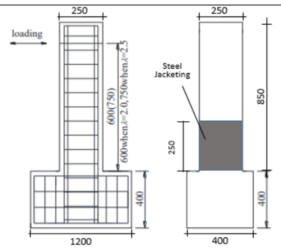
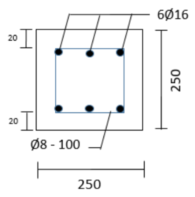
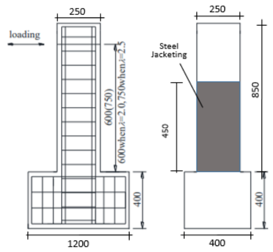
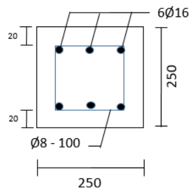
No	Model Image	Section	Description
1			**Code Model MKB 1** 1 Validation model, the dimensions are the same as the C1 specimen in the Deng M. and Zhang Y. experiment in 2017. Concrete Column Dimension 250mm x 250mm x 850mm Without reinforced steel jacketing.
2			**Code Model MKB 2** 1 Piece model Concrete Column Dimension 250mm x 250mm x 850mm Reinforced steel jacketing along 150 mm from the bottom of the column

Table 2. Modeling of concrete columns

No	Model Image	Section	Description
3			**Code Model MKB 3** 1 Model Concrete Column Dimension 250mm x 250mm x 850mm Reinforced steel jacketing 250 mm long from the column
4			**Code Model MKB 4** 1 Model Concrete Column Dimension 250mm x 250mm x 850mm Reinforced steel jacketing along 450 mm from the bottom of the column

2. Model loading

Model testing is done by placing the test object and loading as in the experiment. Loading procedure with displacement-controlled stages. The yield point is defined as the lateral displacement corresponding to the first yield of the longitudinal steel bar during the test. The displacement increment is 4 mm, n is the number of steps of the displacement load. Each load displacement step is repeated three times until the specimen fails or the lateral load of the specimen drops below 85% of the peak value.

The loading position on the model and the loading curve with displacement-controlled stages can be seen in Fig. 2 and Fig. 3.

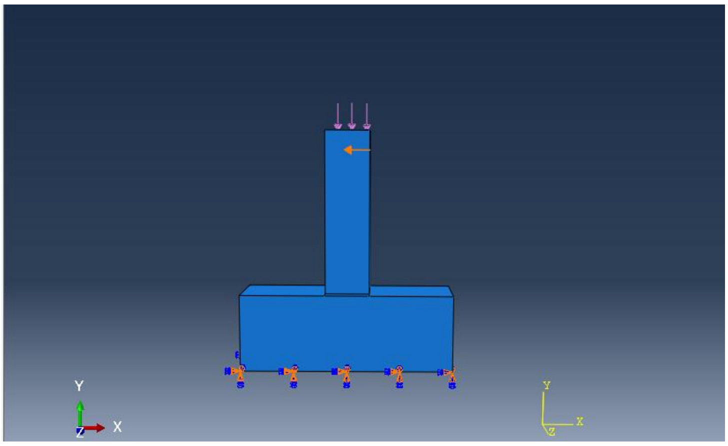


Fig.2. Loading position on the model

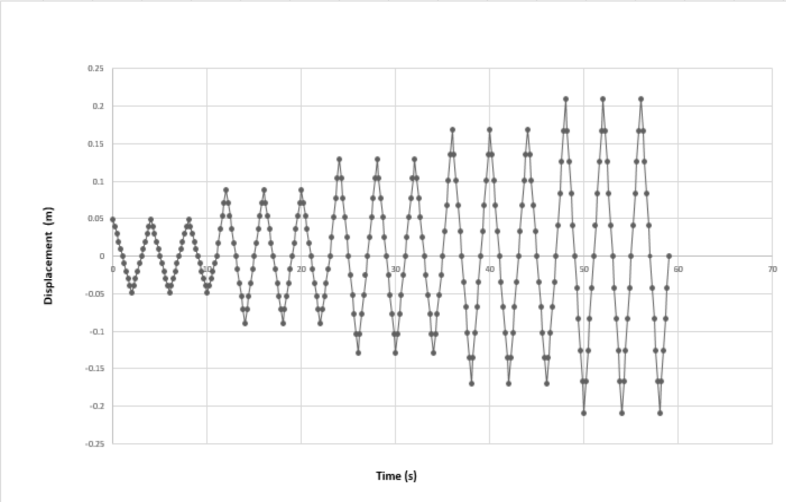


Fig. 3. Loading curve with displacement-controlled stages

3. Model validation

Validating the model is the process of testing the data from the modeling of the cyclic behavior of the concrete column with experimental data. The model validation in this study uses data from the results of the analysis of the concrete column model 1 (MKB 1) with data from the experimental results of the C-1 specimen from the research of Deng and Zhang (2017). Validation is done by comparing the data of the hysteretic curve and the backbone curve. The following is the validation process according to the specified parameters.

Hysteretic Curve

The hysteretic curve is the reaction force and displacement relationship curve that occurs in a structure that is subjected to cyclic loading. In a column, a hysteretic curve is created by measuring the reaction force that occurs in the column and the displacement at the end of the column, which is an important description of the behavior of the column due to cyclic loading.

In the experiments of Deng and Zhang (2017), hysteretic curves have been obtained for all test specimens. The hysteretic curve of experimental results for specimen C-1 can be seen in Fig. 4.

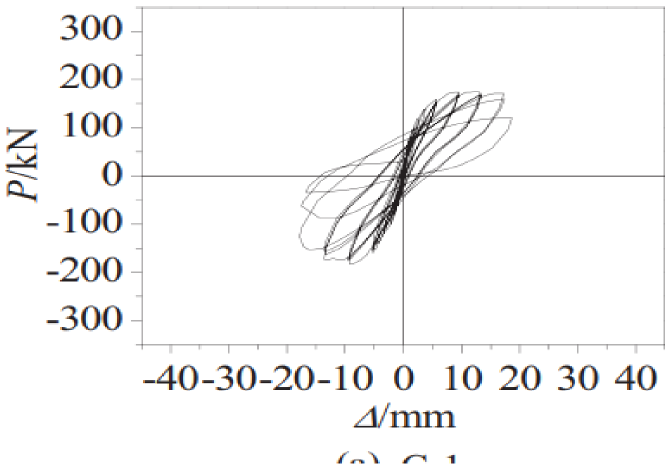


Fig.4. Hysteretic curve of experimental results for specimen C-1

The hysteretic curve of the concrete column model 1 (MKB 1) was obtained from plotting the data from the running results carried out during modeling with the abaqus software. The reaction of loading in the direction of the x-axis and displacement in the direction of the x-axis in the model is described in one plane of the x and y axes with positive and negative values. The hysteretic curve of the concrete column model 1 (MKB 1) can be seen in Fig. 5.

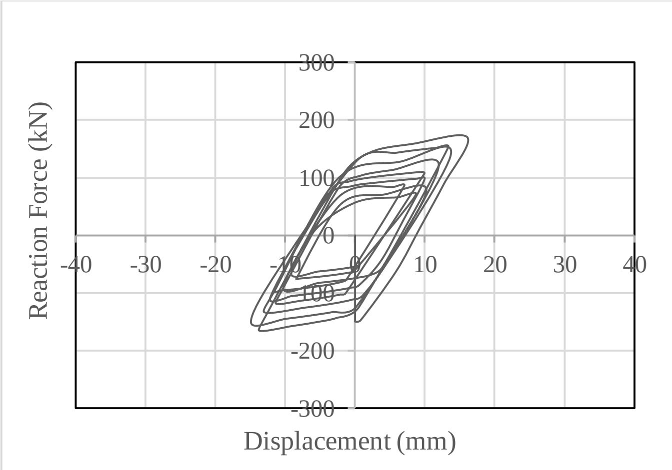


Fig. 5. Hysteretic curve of concrete column model 1 (MKB 1).

Reaction force data in the x-axis direction and displacement in the x-axis direction for concrete column model 1 (MKB 1) were obtained using the ODB history output menu then select RF 1 for reaction force in the x-axis direction and select U1 for displacement in the x-axis direction. Combine the reaction force data in the x-axis direction and displacement data in the x-axis direction in the x,y-coordinate axis and then plotted. Data can be copied to excel and presented in tabular form.

There are 5 data of reaction force and displacement of concrete column model 1 (MKB 1) which is used as a comparison with the experiment. The data is taken from the hiteretic curve of the experimental results and the model. The comparison of reaction force and experimental displacement with the concrete column model 1 (MKB 1) can be seen in Table 3.

Backbone Curve

Backbone curve is a curve that shows the relationship between the force and the deformation of the structural components or the whole structure that is used to determine the response characteristics of the nonlinear analysis model. The backbone curve in the cyclic test is derived from the hysteretic curve by depicting a line between the peak loads of each primary cycle. In the experiment of Deng and Zhang in 2017 a backbone curve was obtained for all specimens of the test object. The backbone curve of the experimental results can be seen in Fig. 6.

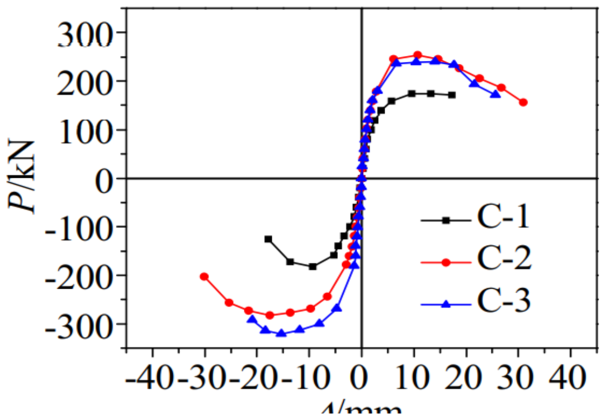


Fig.6. Backbone curve of experimental results for specimen C-1

The backbone curve of the concrete column 1 (MKB 1) model is obtained from the hysteretic curve of the modeling results. The comparison data of the experimental and model backbone curves can be seen in Table 4 and the experimental and model backbone curves can be seen in Fig. 7.

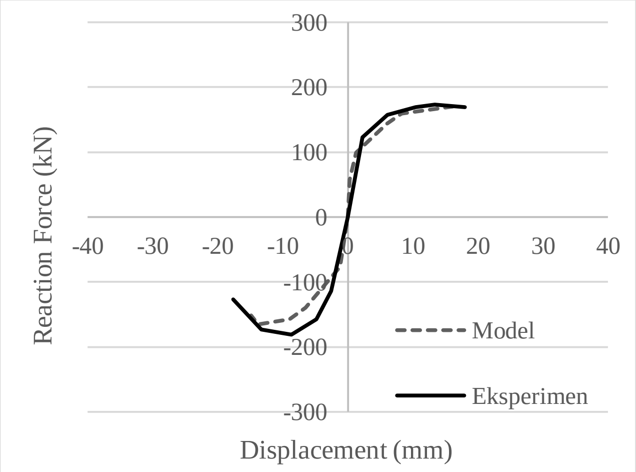


Fig.7. Backbone curve of experimental results and models

Table 3. Comparison of reaction force and experimental displacement with concrete column model 1 (MKB 1).

No	Displacement (mm)		Comparison	Reaction force (kN)		Comparison
	Experiment	Model		Experiment	Model	
1	17.059	16.080	0.943	178.571	170.185	0.953
2	16.765	13.622	0.813	160.714	136.290	0.848
3	13.235	13.313	1.006	185.714	152.399	0.821
4	-16.765	-14.889	0.888	-146.429	-151.779	1.037
5	-13.235	-13.750	1.039	-175.000	-165.197	0.944
Rata-rata			0.938	Rata-rata		0.920

Table 4. Comparison of experimental and model backbone curve data

No	Experiment		Model	
	Displacement (mm)	Reaction Force (k.N)	Displacement (mm)	Reaction Force (k.N)
1	17.963	169.231	16.080	170.185
2	13.333	173.077	8.293	159.052
3	10.370	169.231	5.976	143.589
4	6.111	157.692	1.240	98.869
5	2.222	123.077	0.261	58.140
6	0	0	0	0
7	-2.593	-113.846	-1.222	-76.6735
8	-4.815	-157.692	-6.503	-139.438
9	-8.704	-180.769	-8.974	-157.462
10	-13.333	-173.077	-13.750	-165.179
11	-17.593	-126.923	-14.889	-151.779

From the comparison of the displacement values and the loading reaction between the experiment and the concrete column model 1 (MKB 1) which is shown by the hysteretic curve and the backbone curve, it is known that the model can be considered validated.

III. RESULTS AND DISCUSSION

1. Hysteretic Curve

Hysteretic curve is a curve that describes the relationship between reaction force and displacement. The relationship between load and displacement shows the capacity and behavior of the structure in receiving and holding loads in each cycle. The flatter the hysteretic curve that occurs in each cycle, the lower the shear stiffness caused by external loads. The hysteretic curve of the concrete column model can be seen in Fig. 8.

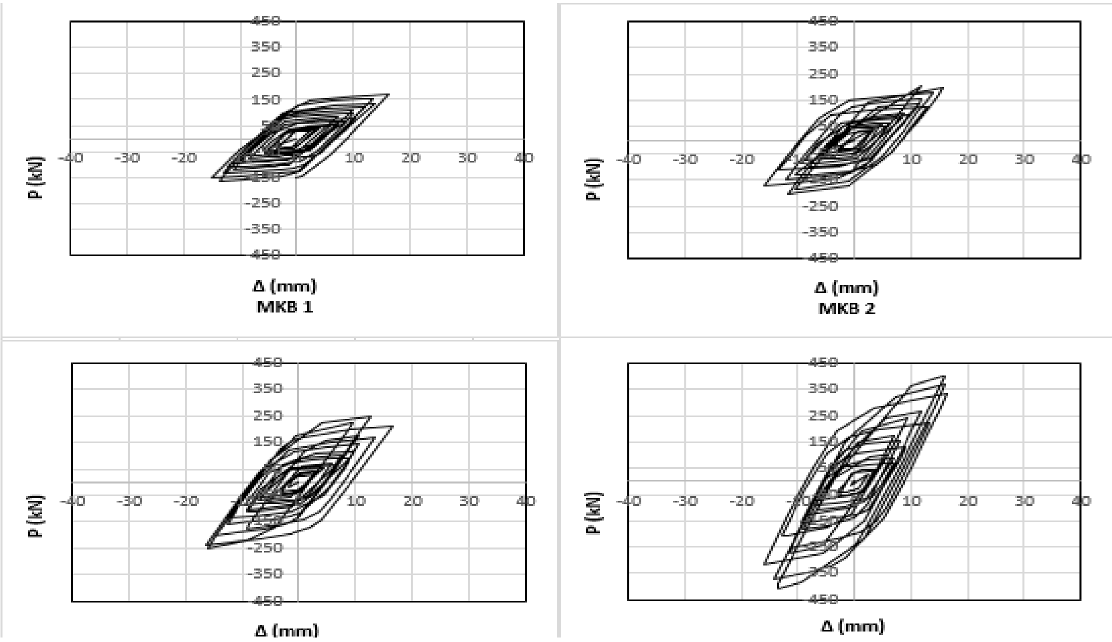


Fig.8. Hysteretic curve of concrete column model.

By analyzing the hysteretic curve of the column model, it is known that the shear stiffness of MKB 1 = 10.583 kN/mm, MKB 2 = 17.412 kN/mm, MKB 3 = 19.606 kN/mm and MKB 4 = 25.026 kN/mm. So, the shear stiffness in the model with steel jacketing reinforcement (MKB 2, MKB 3 and MKB 4) is greater than the model without steel jacketing (MKB 1).

2. Hysteretic Energy and Potential Energy

The calculation of hysteretic energy and potential energy is done by calculating the area of the triangle formed between the hysteretic curve and the x-axis. In this calculation, 3 cycles are taken for each model. The results of the calculation of hysteretic energy and potential energy for MKB 1, MKB 2, MKB 3 and MKB 4 can be seen in Table 5, Table 6, Table 7 and Table 8.

Table 5. Data from the calculation of hysteretic energy and potential energy of MKB 1.

Cycle	PE	HE	PE	HE	EVDR	Kc (Cyclic Stiffnes)		
	(N.mm)	(N.mm)	(kN.mm)	(kN.mm)	(%)	(N.mm)	(kN.mm)	(%)
3	1368313	1634050	1368	1634	19	10583	11	108
2	914290	914290	914	914	16	10158	10	103
1	755129	961677	755	962	20	9823	10	100
0	0	0	0	0	0	0	0	0
1	671915	2503428	672	2503	59	10444	10	100
2	1153883	3533970	1154	3534	49	9982	10	96
3	1183424	2824836	1183	2825	38	11530	12	110

Table 6. Data from the calculation of hysteretic energy and potential energy of MKB 2

Cycle	PE (N.mm)	HE (N.mm)	PE (kN.mm)	HE (kN.mm)	EVDR (%)	Kc (Cyclic Stiffnes) (N.mm)	(kN.mm)	(%)
3	1640055	4056584	1640	4057	39	11693	12	90
2	1372431	2554729	1372	2555	30	12235	12	94
1	932846	2728094	933	2728	47	13026	13	100
0	0	0	0	0	0	0	0	0
1	888686	1693120	889	1693	30	12610	13	100
2	1647252	2128354	1647	2128	21	9070	9	72
3	1240666	2663026	1241	2663	34	17221	17	137

Table 7. Data from the calculation of hysteretic energy and potential energy of MKB 3

Cycle	PE (N.mm)	HE (N.mm)	PE (kN.mm)	HE (kN.mm)	EVDR (%)	Kc (Cyclic Stiffnes) (N.mm)	(kN.mm)	(%)
3	1610303	2306938	1610	2307	23	19606	20	117
2	1916241	3150598	1916	3151	26	11798	12	70
1	916708	1674308	917	1674	29	16811	17	100
0	0	0	0	0	0	0	0	0
1	1574092	3993162	1574	3993	40	12642	13	100
2	1879429	3952501	1879	3953	33	15146	15	120
3	2091332	1791494	2091	1791	14	14779	15	117

Table 8. Data from the calculation of hysteretic energy and potential energy of MKB 4

Cycle	PE (N.mm)	HE (N.mm)	PE (kN.mm)	HE (kN.mm)	EVDR (%)	Kc (Cyclic Stiffnes) (N.mm)	(kN.mm)	(%)
3	1573701	7023870	1574	7024	71	25026	25	109
2	3234034	4819112	3234	4819	24	17046	17	74
1	3195093	4338022	3195	4338	22	23016	23	100
0	0	0	0	0	0	0	0	0
1	3145087	2914603	3145	2915	15	18021	18	100
2	2354091	6621852	2354	6622	45	29852	30	166
3	2836142	2037628	2836	2038	11	26615	27	148

From the calculation data, it can be seen that the maximum hysteretic energy of MKB 4 is 7,024 kN.mm, the maximum potential energy is 3,234 kN.mm. So, the effect of steel jacketing reinforcement is that the hysteretic energy and the potential energy of the concrete column 4 (MKB 4) increase compared to the concrete column model 1 (MKB 1). It can be seen that the hysteretic energy and maximum potential energy of MKB 2, MKB 3 and MKB 4 with steel jacketing have an increase compared to MKB 1 without steel jacketing. Provision of reinforcement with steel jacketing on the column is proven to improve the cyclic behavior of the concrete column.

3. Backbone Curve

Backbone curve is a curve that shows the relationship between forces and deformations (stress and strain) on structural components or the whole structure which is used to determine the response characteristics in nonlinear analysis models. The backbone curve in the cyclic test is derived from the hysteretic curve by depicting a line between the peak loads of each primary cycle. The backbone curve of each concrete column model in this study can be seen in Fig. 9.

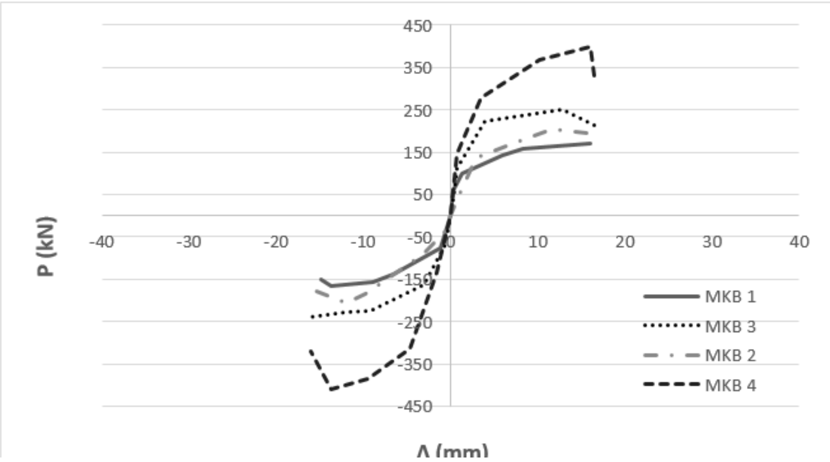


Fig.9. Backbone curve of each concrete column model

Table 9. Comparison data of backbone curve model

No	MKB 1		MKB 2		MKB 3		MKB 4	
	Δ (mm)	P (k.N)	Δ (mm)	P (k.N)	Δ (mm)	P (k.N)	Δ (mm)	P (k.N)
1	16.0803	170.185	15.621	195.841	16.391	212.644	16.451	332.051
2	8.2931	159.052	11.654	202.919	12.817	251.282	15.979	399.904
3	5.9763	143.589	7.1905	171.156	3.9726	222.447	10.164	366.569
4	1.24023	98.8691	2.865	137.151	0.786	111.867	3.50798	280
5	0.2608	58.1401	0.830	44.219	0.389	59.418	0.694	146.880
6	0	0	0.000	0.000	0.000	0.000	0.000	0.000
7	-1.22187	-76.6735	-0.798	-38.659	-0.608	-65.653	-1.546	-133.825
8	-6.50314	-139.438	-3.154	-92.678	-3.127	-162.440	-4.669	-315.062
9	-8.974	-157.462	-9.843	-185.243	-9.133	-223.235	-9.538	-386.036
10	-13.7498	-165.179	-12.004	-206.714	-11.973	-228.688	-13.731	-409.158
11	-14.8887	-151.779	-16.147	-172.858	-16.297	-238.603	-16.101	-319.718

From the data obtained on the hysteretic curve and backbone curve, it is known that MKB 2 has a maximum reaction force capacity of 15.075% stronger than MKB 1. MKB 3 has a maximum reaction force capacity of 24,949% stronger than MKB 1. MKB 4 has a maximum reaction force capacity of 95,112 % stronger than MKB 1. So, it can be seen that the reaction force capacity of the model with steel jacketing is greater than the model without steel jacketing. This proves that reinforcement with steel jacketing contributes to increasing the capacity of the concrete column.

4. Stress Contour and Crack Pattern

Stress contours and crack patterns occur in concrete elements and in reinforcing steel elements. The stress contours and crack patterns that occur in the concrete column models MKB 1, MKB 2, MKB 3 and MKB 4 can be seen in Fig. 10., Fig. 11., Fig. 12. and Fig. 13.

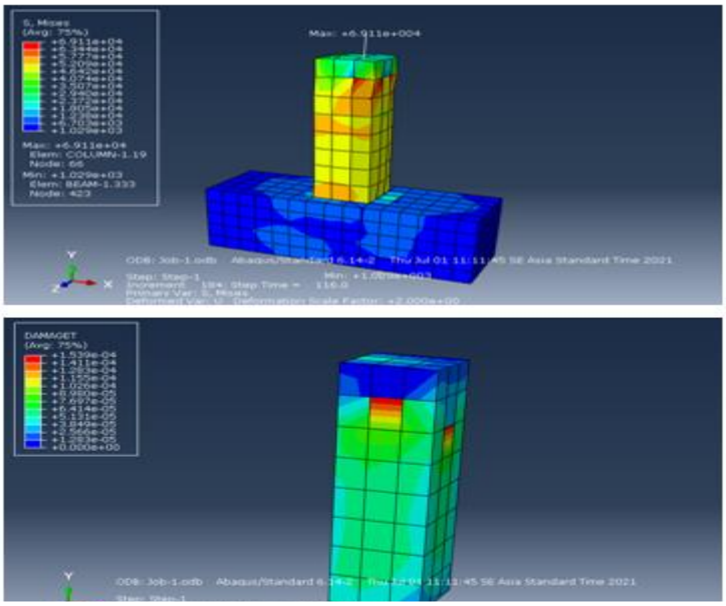


Fig.10. Stress contour and crack pattern for concrete column model 1 (MKB 1)

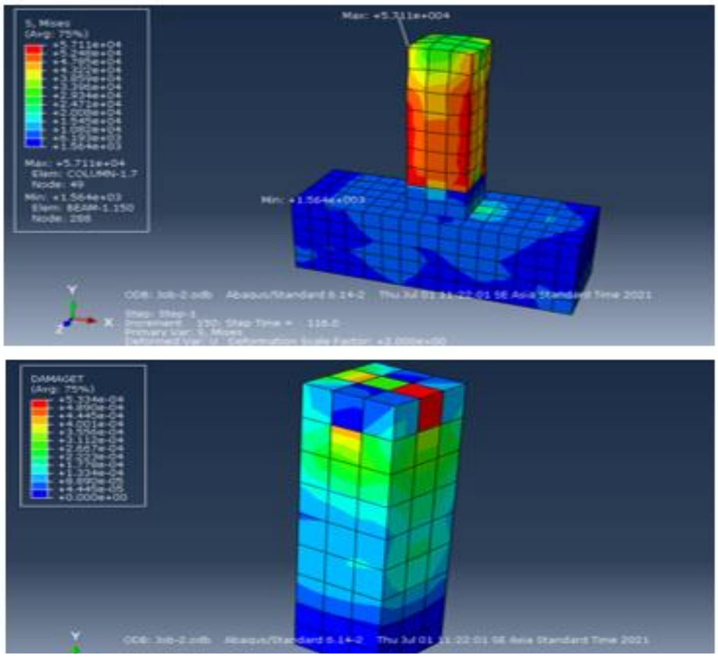


Fig.11. Stress contour and crack pattern for concrete column model 2 (MKB 2)

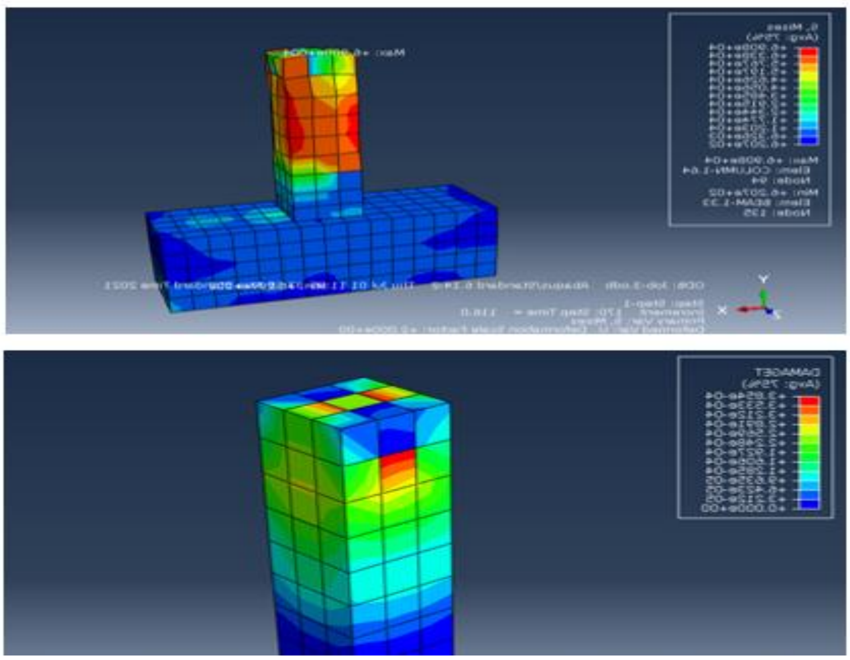


Fig.12. Stress contour and crack pattern for concrete column model 3 (MKB 3)

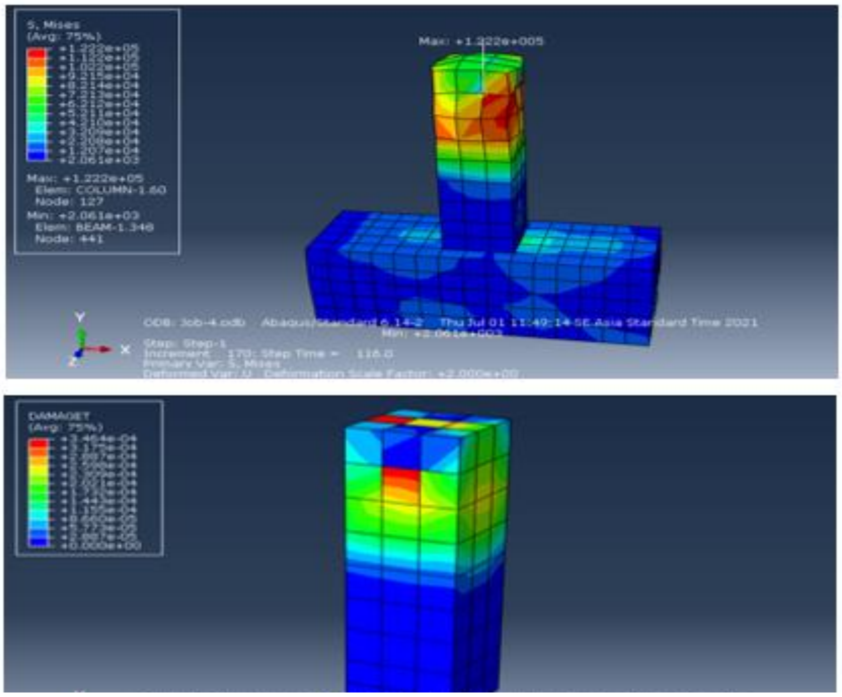


Fig.13. Stress contour and crack pattern for concrete column model 4 (MKB 4)

IV. CONCLUSION

From the results of modeling and analysis, the following conclusions can be drawn :

1. Comparison of modeling results with the finite element method and experimental results of specimens C-1 Deng and Zhang in 2017 for the cyclic behavior of concrete columns with steel jacketing in the plastic area shows a good value, with an average ratio of 0.929 on the hysteretic curve.
2. The hysteretic curve of reinforced concrete column with steel jacketing in the plastic area looks steeper, this indicates that the shear stiffness is higher than that of the unreinforced column. The shear stiffness of MKB 1 = 10.583 kN/mm, MKB 2 = 17.412 kN/mm, MKB 3 = 19.606 kN/mm and MKB 4 = 25, 026 kN/mm.
3. Backbone curve of concrete column with steel jakcketing reinforcement in plastic area is better. The increase in the capacity of the concrete columns of MKB 2, MKB 3 and MKB 4 to withstand cyclic loads

based on the peak of the backbone curve increased by 15.075%, 24.949% and 95.112% compared to MKB 1.

4. Hysteretic energy and potential energy increased in MKB 2, MKB 3 and MKB 4 with steel jacketing compared to MKB 1 without steel jacketing. The hysteretic energies of MKB 1, MKB 2, MKB 3 and MKB 4 are 3,534 kN.mm, 4,057 kN.mm, 3,993 kN.mm and 7,024 kN.mm, respectively. The potential energy of MKB 1, MKB 2, MKB 3 and MKB 4 are 1,367 kN.mm, 1,647 kN.mm, 2,091 kN.mm and 3,234 kN.mm, respectively. This shows that the energy dissipation ability of the model with steel jacketing reinforcement is higher than the model without reinforcement.
5. The use of steel jacketing in the plastic area can increase the column capacity under cyclic loading.

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