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Parametrical Study in Non-Linear Numerical Analysis of a Coupling Beam with Steel Truss Configuration in Shear Wall System

Nursiah Chairunnisa[1], Iman Satyarno[2], Muslikh[2], Akhmad Aminullah[2]

Abstract – *The coupling beam with steel truss configuration is a viable alternative for steel coupling beam structure. The system uses a steel truss, which is easier to be constructed than the typically reinforced concrete coupling beam. In this paper, a simple type of coupling beam with steel truss configuration created by angle profiles has been modelled in numerical simulation for replacing typical reinforcement of coupling beams. The experimental study has shown that steel truss-coupling beam using the steel angle profiles can show fairly well behaviour under lateral load. In this study, the non-linear finite element using non-linear time history analysis in SAP2000 has been applied to simulate the overall behaviour of previously tested of steel truss coupling beam. The strength of the material, the geometrical and the loading history are adopted from experimental testing. Several parameters in quasi-static loading analysis need to be determined such as the non-linear material of plastic hinge, the time step, and the damping. The numerical results will be compared to the experimental result in order to validate the outcomes. From the numerical analysis, it can be appointed that the ultimate strength capacity adequately shows behaviours between the actual tests. Finally, the model that considers the appropriate non-linear material of plastic hinge due to buckling, the time step with slow hydraulic jack movement, and damping ratio as main parameters can predict quite well the test results in term of hysteretic shape. According to the numerical simulation, the degree of rigidity also plays an important role and should be considered in the design phase in order to investigate the end connections of truss element in the steel truss coupling beam in the shear wall system.* ***Copyright © 2019 Praise Worthy Prize S.r.l. - All rights reserved.***

Keywords*: Coupling Beam, Steel Truss Configuration, Non-Linear Material, Numerical Analysis*

Nomenclature

f_{ys}	Yield stress
ε_{ys}	Yield strain
f_{su}	Ultimate stress
ε_{su}	Ultimate strain
K	Stiffness matrix
u	Displacement
C	Damping matrix
$\dot{u}$	Velocity
M	Diagonal mass matrix
$\ddot{u}$	Acceleration of structure
r	Applied load
P_n	The capacity of members (kN)
F_{cr}	The critical stress (MPa)
f_y	Yield stress of steel (MPa)
A_g	Gross area of member (mm^2)
F_e	Elastic buckling stress (MPa)
E	Modulus of elasticity (MPa)
K	Effective length factor
L	Length of member (mm)
r	Radius of gyration (mm)
r_x	Radius of gyration-x direction
Q	Net reduction factor
Q_s	Net reduction factor for slender unstiffened element
Q_a	Reduction factor for slender stiffened element

I. Introduction

The coupling beam is an essential component in the coupled shear wall system, which is expected to form a plastic hinge mechanism before the shear walls yield.

The performance of the coupled shear wall system is mainly affected by the failure mechanism of the link beam between both shear walls called the coupling beam.

Therefore, it is essential for the proper design of the coupling beam to predict the overall behaviours of the coupled shear wall system under the lateral load.

According to [1] the coupling beam with the ratio of span to the depth lower than two should be reinforced by diagonal bars for resisting the lateral load. Previous studies have concluded that the steel truss-coupling beam could be used as an alternative method for the coupling beam in order to resist to the lateral load [2]-[3].

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Nowadays, numerical seismic analysis of structures using linear and nonlinear method progress rapidly as the improvement of computer technologies. Non-linear analysis can calculate the response of the structure due to any type of dynamic loading such as seismic ground motion, blast, waves, wind, etc. Moreover, this analysis can be used to predict the nonlinear behaviours of the structure such as the force-displacement relationship for a structure element.

The research of coupling beam using ABAQUS Software has been done by [4], [5]. Gwon et al. [6] have investigated modelling RC coupling beam in term of the nonlinear parameter based on ASCE 41-13 and have summarized that the modelling parameters from ASCE 41-13 tend to underestimate of yield rotation.

Moreover, Bengar and Aski [7] have evaluated the influence of steel and concrete coupling beam under seismic loading using nonlinear analysis of PERFORM 3D. From this research, it can be concluded that steel and concrete coupling beams have showed similar behaviours in term of drift in each level of the building. Laila et al. [8] have studied the performance of a concrete gravity DAM using nonlinear seismic response obtained by pushover analysis and have compared it to the nonlinear time history analysis.

Furthermore, Turker et al. [9] have investigated about the effect of rigidity element connection on the performance of steel frame structures and have concluded that the welded connection on the steel structures can be classified as a semi rigid connection for obtaining accurate results.

In addition, Yapici et al. [10] have investigated the effect of non-linear material of steel elements under different loading protocols for experimental and numerical test. The result has showed that the change in displacement step size for the cyclic loading test has a minor effect on the test results.

In summary, this research presents a comprehensive numerical investigation of coupling beam with steel truss configuration in shear wall for obtaining the adequately numerical model of coupling beam under quasi-static loading protocols in terms of the behaviour of structure such as strength capacity, displacement-load relationship, and hysteretic loop. For this purpose, the displacement control parameter and the non-linear material of steel truss are statistically analyzed. This study quantifies the time step response due to the hydraulic jack movement based on quasi-static loading test with fast, moderate and slow movement.

The response of parameters such as rigid body, stiff variety and flexible structural elements with the rate of rigidity 0%, 30%, 50% and 100% are subjected to create appropriate end connection modelling of elements. The results from the proposed model are in accordance with the quasi static loading protocol suggested by ACI T-11-01 that used in experimental test, and indicate that the rate of rigidity plays important factor to simulate the end connection of steel truss configuration of coupling beam in shear wall.

II. Modelling Method

II.1. Overview of Experimental Data

In order to validate the proposed numerical model used in this research, the previous experimental study of steel truss coupling beam in coupled shear wall system is used [2]. A simple type of steel truss coupling beams that created by the horizontal member using double steel angle profiles and diagonal members using steel angle profile. The tested shear wall is 730 mm wide, 1430 mm high and 180 mm thick. Moreover, the dimension of the coupling beam is 60 mm×225 mm. The length of the coupling beam is 400 mm.

The detail and the material properties of the specimen are given in Tables I and II, and Figs. 1 to 3. From the material testing, it is found that the yield stress (f_{ys}) and yield strain (ε_{ys}) of steel angle profile are 356.2 MPa and 0.002 respectively.

The steel reaches an ultimate stress (f_{su}) at 502 MPa with an ultimate strain (ε_{su}) of 0.13. Thereafter, the post-yield region remains flat until the onset of strain hardening at ε_{sh}=0.02. Table II describes the steel angle profile properties. Fig. 4 depicts the stress-strain relationship of materials steel angle profile.

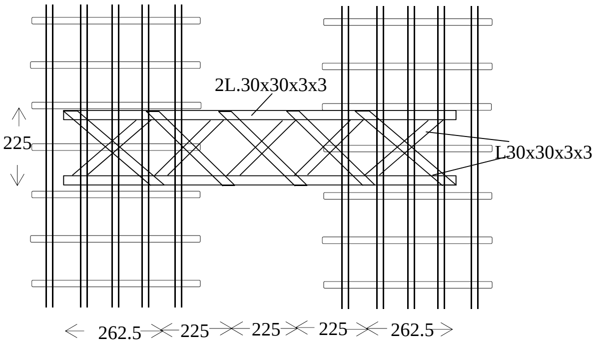


Fig. 1. The configuration of steel truss coupling beam with shear wall (The dimensions are expressed in mm)

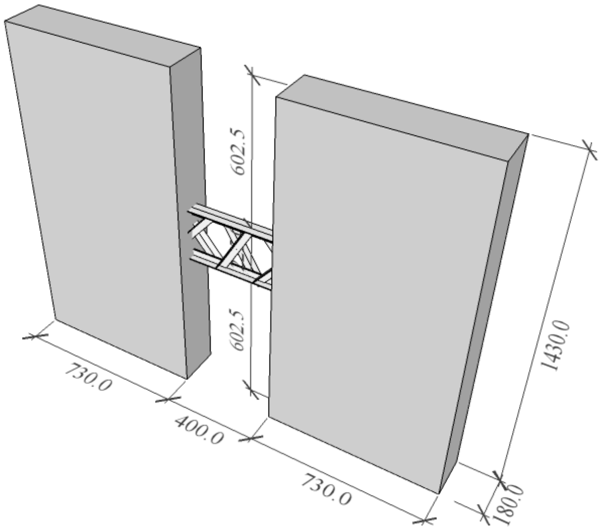


Fig. 2. The model of coupling beam

Table III summarizes the unconfined concrete properties of shear wall according to material testing.

The unconfined concrete strength (f'_{co}) and unconfined concrete strain (ε_{co}) are 40 MPa and 0.0022 respectively.

Moreover, the unconfined concrete reach the spalling strain (ε_{sp}) at 0.005. Considering the above properties for concrete in SAP 2000, Fig. 5 depicts the stress-strain relationship of concrete materials.

Fig. 3. The coupling beam with shear wall (laboratory specimen)

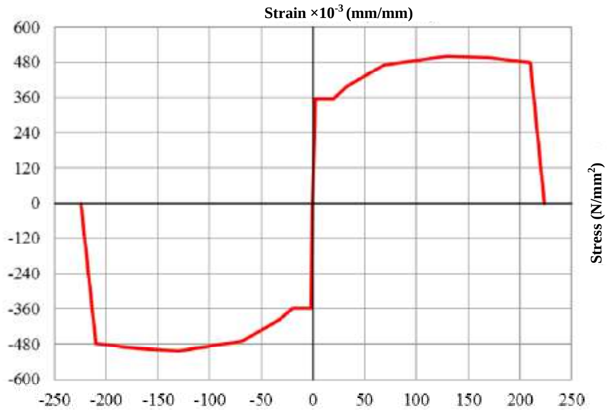


Fig. 4. Steel angle profile stress strain relation ship

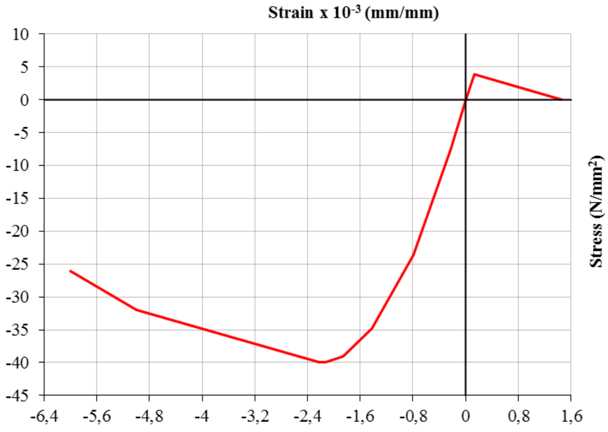


Fig. 5. Unconfined concrete stress strain relation ship

TABLE I
THE DETAIL OF SPECIMEN

Type	Span to depth ratio	Horizontal element	Diagonal Element
Steel Truss CB	1.78	2L.30.30.3.3	L.30.30.3.3

TABLE II
MATERIAL PROPERTIES OF STEEL ANGLE PROFILE

Type	f_{ys} (MPa)	ε_{ys} (m/m)	f_{su} (MPa)	ε_{su} (m/m)	ε_{sh} (m/m)
Angle Profile	356.2	0.002	502	0.13	0.02

TABLE III
MATERIAL PROPERTIES FOR UNCONFINED CONCRETE

Type	f'_{co} (MPa)	ε_{co} (m/m)	ε_{sp} (m/m)
Grade 40	40	0.0022	0.005

II.2. Numerical Model

In this research, a model for predicting the displacement-load relationship under quasi-static loading is proposed for steel truss coupling beam based on numerical analysis using SAP 2000 software. According to Chairunnisa et al. [11], the coupling beam can be modelled by frame element in order to predict internal forces. In this case, the steel truss coupling beams are modelled as frame element for both coupled shear wall and coupling beam element by considering rigid body at the interface between truss element and shear wall (Fig. 6). Moreover, there are some idealization in numerical simulation in order to represent the joints or supports condition. There are three types of connection in the truss system such as pinned, semi-rigid and rigid [12]-[13].

The variety of connections in frames have studied intensively by many researchers [14]-[16]. In SAP 2000, the connection types can be assigned using the release/partial fixity menu. The release/partial fixity in SAP 2000 can be used to determine the appropriate end connection of element and to obtain the realistic and reliable result.

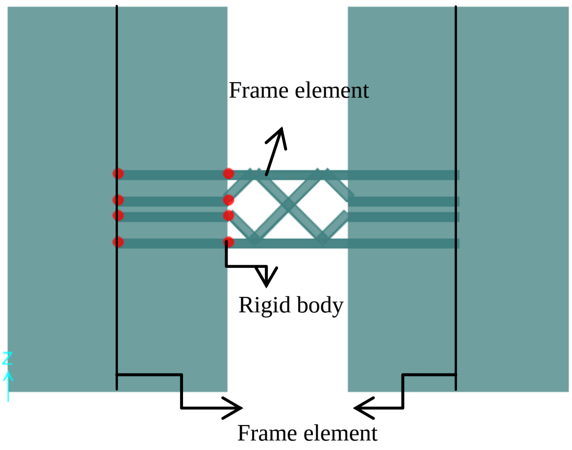


Fig. 6. The model of coupling beam in SAP 2000 software

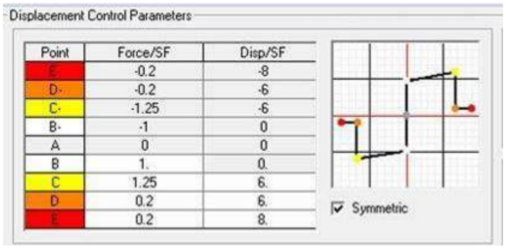
In SAP 2000 [17] time history with direct integration analysis which has simulated the quasi-static loading is applied to specify the behaviours of the structure. The equilibrium equations can be calculated by:

$$Ku(t)+C\dot{u}(t)+M\ddot{u}(t)=r(t) \tag{1}$$

where K=stiffness matrix, u=displacement, C=damping matrix, $\dot{u}$=velocity, M=diagonal mass matrix, $\ddot{u}$=acceleration of structure, r=applied load.

Hinge properties can be used to predict nonlinear displacement-load or moment-rotation behaviours of the element that can be assigned along the length of the element. Nonlinear hinge property can be simulated for static nonlinear analysis and nonlinear direct integration time history. There are three kinds of hinge properties in SAP 2000 such as auto hinge properties, user-defined hinge properties and program generated hinge properties. In this case, user-defined hinge properties are used to represent the actual condition of the experimental study.

According to FEMA-356 [18] and SAP 2000 [17], general displacement-load relationship for plastic hinge can be described in Fig. 7. There are five points that define the force-displacement behaviours of a plastic hinge. Point A and B can be defined as original point and yield point respectively. Point C is the ultimate point where point D and E are residual strength and total failure respectively. Moreover, in seismic analysis hysteretic curves are defined as hysteretic models that depend on material properties and can provide the displacement-load behaviours of structure members. SAP 2000 analysis has three hysteresis models namely Kinematic Hysteresis, Takeda Hysteresis and Pivot Hysteresis. From the previous study [19], Takeda Hysteresis type can be selected as an appropriate model for describing the strength degradation of the structure under cyclic loading. Takeda Hysteresis also offers advantages in term of less computational requirements if compared to the other hysteresis models.



Displacement Control Parameters

Point	Force/SF	Disp/SF
E	-0.2	-8
D-	-0.2	-6
C-	-1.25	-6
B-	-1	0
A	0	0
B	1.	0.
C	1.25	6.
D	0.2	6.
E	0.2	8.

☑ Symmetric

Fig. 7. Feature frame hinge properties in SAP 2000 [17]

II.3. Research Method

According to Equation (1), some parameters need to be determined for numerical modelling such as:

1. The non-linear material modelling of plastic hinge [K];
2. The time step due to fast or slow movement $[\ddot{u}]$;
3. The damping ratio [C].

The first variable is the nonlinear material model of coupling beam, which is generally based on plastic hinge model at the diagonal elements of the steel truss coupling beam due to buckling mechanism. According to the previous study [2], the critical strength capacity of the diagonal element (Pcr) of the diagonal element that uses steel angle profile L.30.30.3 can be predicted in Table IV. In this case, Takeda Hysteresis has been adopted as a hysteresis type for simulating the load-displacement performance.

TABLE IV
CRITICAL COMPRESSIVE CAPACITY OF STEEL ANGLE PROFILE

Type	Theory (N)		Experimental (N)	
	V_{cr}	P_{cr}	V_{cr}	P_{cr}
L.30.30.3	37,320	26,660	37,230	26,320

Table IV summarizes the comparison calculation of critical shear force of coupling beam (V_{cr}) and critical strength capacity of diagonal element (P_{cr}) of steel truss coupling beam based on Indonesian Steel Code SNI 1729:2015 [20] which refers to AISC 2010 [12] and the previous experimental result. In the proposed model of SAP 2000, acceptance criteria for nonlinear analysis and modelling parameters of structures as structural steel components have been adopted according to FEMA 356 [18] and adjusted according to material testing in Laboratory. According to SNI 1729:2015 [20], the critical stress of the slender element of the model can be estimated by Eqs. (2) to (4):

$$P_n = F_{cr} A_g \tag{2}$$

If:

$$\frac{Kl}{r} \le 4.71\sqrt{\frac{E}{Qf_y}}\left(\text{or } \frac{Qf_y}{F_e} \le 2.25\right)$$

then:

$$F_{cr} = Q\left[0.658^{\frac{Qf_y}{F_e}}\right] \tag{3}$$

$$F_e = \frac{\pi^2 E}{\left(\frac{KL}{r}\right)^2} \tag{4}$$

where P_n=the nominal compressive strength/the capacity of members (kN), F_{cr}=the critical stress (MPa), f_y=yield stress of steel (MPa), A_g=gross area of member (mm^2), F_e=elastic buckling stress (MPa), E=modulus of elasticity (MPa). The effective slender ratio KL/r for steel angle profile can be calculated based on section E-5 [20] and by Eq. (5). When $\frac{L}{r_x} \le 80$:

$$\frac{L}{r_x} \le 80 \Rightarrow \frac{Kl}{r} = 72 + 0.75\frac{L}{r_x} \tag{5}$$

where K=effective length factor, L=length of member (mm) and r=radius of gyration (mm), r_x=radius of gyration-x direction. Q is net reduction factor, which can be determined according to Eq. (6):

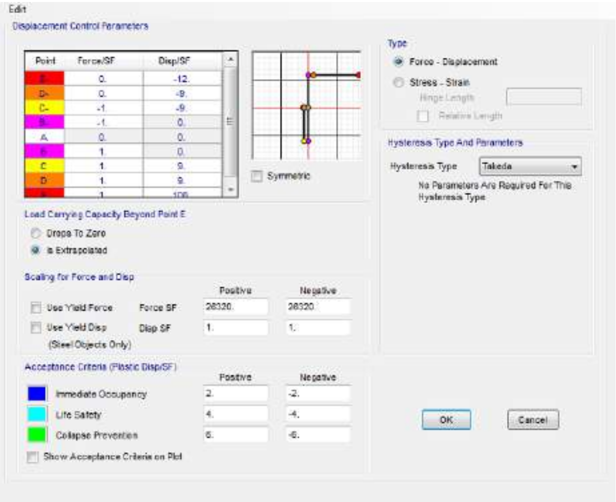
$$Q = Q_s Q_a \tag{6}$$

where Q_s is net reduction factor for slender unstiffened element and Q_a is reduction factor for slender stiffened element. The angle steel profile of model can be determined as unstiffened slender element with Q_a=1 and Q=Q_s is formulated by Eqs. (7) and (8).

If $0.45\sqrt{\dfrac{E}{f_y}} < \dfrac{b}{t} < 0.91\sqrt{\dfrac{E}{f_y}}$, then:

$$Q_s = 1.34 - 0.76\left(\frac{b}{t}\right)\sqrt{\frac{f_y}{E}} \tag{7}$$

The characteristics of the displacement parameter of the diagonal element and the horizontal element in the steel truss coupling beam are modelled according to Figures 8 and 9.



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Displacement Control Parameters

Point	Force/SF	Disp/SF
E-	0.	-12.
D-	0.	-9.
C-	-1	-9.
B-	-1.	0.
A	0.	0.
B	1.	0.
C	1.	9.
D	1.	9.
E	1	106

☐ Symmetric

Load Carrying Capacity Beyond Point E

○ Drops To Zero

● Is Extrapolated

Scaling for Force and Disp

		Positive	Negative
☐ Use Yield Force	Force SF	26320.	26320.
☐ Use Yield Disp (Steel Objects Only)	Disp SF	1.	1.

Acceptance Criteria (Plastic Disp/SF)

	Positive	Negative
🟦 Immediate Occupancy	2.	-2.
🟦 Life Safety	4.	-4.
🟩 Collapse Prevention	6.	-6.

☐ Show Acceptance Criteria on Plot

Type

● Force - Displacement

○ Stress - Strain

Hinge Length

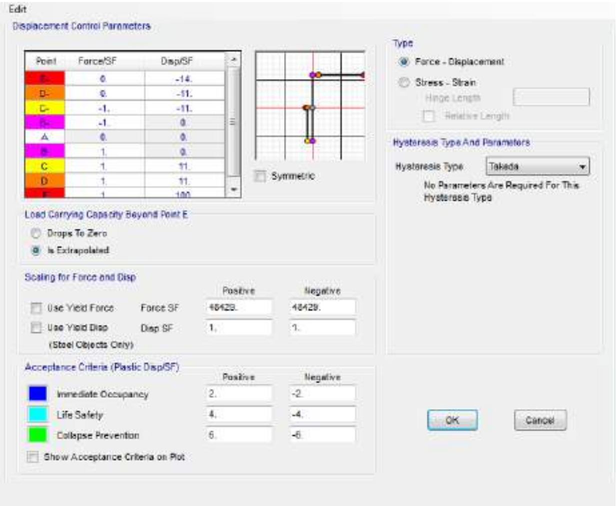
☐ Relative Length

Hysteresis Type And Parameters

Hysteresis Type: Takeda

No Parameters Are Required For This Hysteresis Type

Fig. 8. Displacement control parameters model of diagonal element



Edit

Displacement Control Parameters

Point	Force/SF	Disp/SF
E-	0.	-14.
D-	0.	-11.
C-	-1.	-11.
B-	-1.	0.
A	0.	0.
B	1.	0.
C	1.	11.
D	1.	11.
E	1	100

☐ Symmetric

Load Carrying Capacity Beyond Point E

○ Drops To Zero

● Is Extrapolated

Scaling for Force and Disp

		Positive	Negative
☐ Use Yield Force	Force SF	48429.	48429.
☐ Use Yield Disp (Steel Objects Only)	Disp SF	1.	1.

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	Positive	Negative
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🟦 Life Safety	4.	-4.
🟩 Collapse Prevention	6.	-6.

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Type

● Force - Displacement

○ Stress - Strain

Hinge Length

☐ Relative Length

Hysteresis Type And Parameters

Hysteresis Type: Takeda

No Parameters Are Required For This Hysteresis Type

Fig. 9. Displacement control parameters model of horizontal element

The load and the displacement values in the displacement control parameter for both positive and negative modes are calculated according to the cross-section of the diagonal element and the critical compressive stress (F_{cr}) of elements, which can be determined by Eq. (3). In this case, the cross section of angle steel profile L.30.30.3 is 154.71 mm^2, and the critical compressive stress of diagonal element is 170.64 MPa.

The value of scaling for force and displacement is 26,320 N. Similarly, the hinge property data for the horizontal element has been assumed to reach the critical stress at 156.50 MPa, and the cross section of the horizontal element is 309.42 mm^2. Finally, the value of scaling for displacement double angle 2L.30.30.3 of the horizontal element is 48,429 N. The second variable considered in this study is the time step. The application of the lateral quasi-static load during SAP 2000 analysis is assumed as displacement load that considered the time history displacements as spatial load vector. The analysis is undertaken at several time steps appointed by a number output time steps and time step size. The total length of the analysis is calculated by the multiplication of the number of output time steps with time steps size. In this model, the nonlinear displacement time history according to ACI-T11-01 [21] has been applied at the experimental testing which can be shown in Fig. 10 has been adopted and modified to the numerical simulation.

There are three variation function values with the same displacement target in SAP 2000 which are studied in this research for investigating the effect of time step in the time history function which can be described in Figs. 11 to 13.

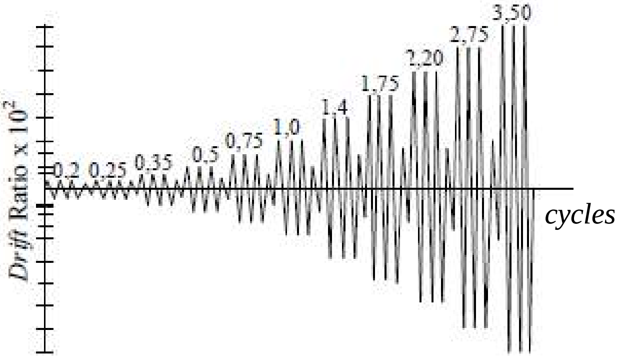

Fig. 10. Detail of loading history function according to ACI-T11-01 [21]

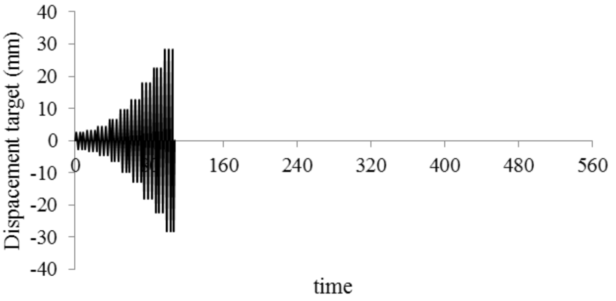

Fig. 11. Fast hydraulic jack movement of time history function (108 s)

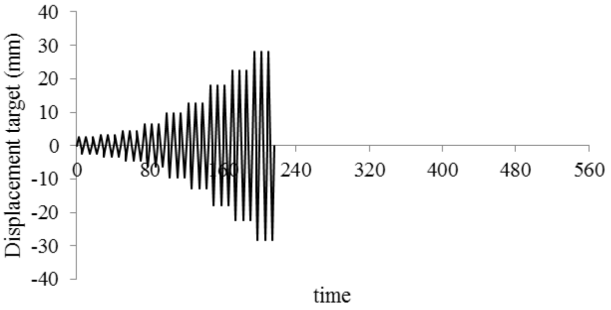

Fig. 12. Moderate hydraulic jack movement of time history function (216 s)

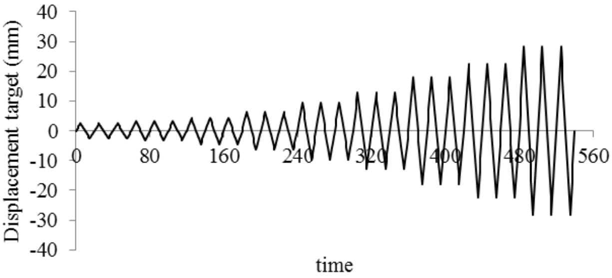

Fig. 13. Slow hydraulic jack movement of time history function (540 s)

The third important parameter for modelling the non-linear time history analysis is the damping parameter.

The proportional damping is one of the primary keys for determining the structure response. In the present work, the mass and the stiffness damping equivalent to 5%, 25% and 50% of critical damping are used during the nonlinear analysis. Furthermore, Table V shows overall the type of parameter models that are investigated in this research. As described previously, the release/partial fixity also plays an important role in order to create appropriate end connection modelling of elements. Four varieties of degree of rigidity are chosen in order to investigate the actual end connection of steel truss coupling beams such as 0%, 30%, 50% and 100%.

The degree of rigidity 30% means that the end connection in each element close to being pinned connection or semi-rigid connection and 100% can be classified as fixed or rigid connection. Last, the degree of rigidity of 0% can be categorized as the pinned connection.

The initial models are prepared to calculate the values of rotation of each element that create steel truss configuration for coupling beam. In this study, frame with fixed-free ends are assumed to predict of rotation using SAP 2000 software.

TABLE V
THE MODELS OF NUMERICAL SIMULATION

Models	Movement	Damping Ratio
Model-1	108 s	0.05
Model-2	216s	0.05
Model-3	540s	0.05
Model-4	108s	0.25
Model-5	108s	0.50
Model-6	540s	0.25
Model-7	540s	0.50

According to the initial results, the varying degree of rigidity, which represents release partial/fixity in SAP 2000, can be arranged in Table VI. The loading method of the experimental test is shown in Fig. 14, which is based on the previous test [22].

Loading on the coupling beam that simulated quasi-static loading is applied through the stiff steel profile, which is installed on the top of the specimen. In order to consider the constraint condition in the actual test, the numerical model is restrained for analysis at the joint at the top of the shear wall in x-direction thereby creating a pinned condition.

The test set up of the model in SAP 2000 can be seen in Fig. 15.

TABLE VI
THE VARIETY OF RIGIDITY (STIFFNESS OF ELEMENTS)

Length span of steel truss (mm)	Rotation (rad)	Degree of rigidity (Nmm/rad)		
		100%	50%	30%
87.5	1.50	66666667	33333333	20000000
123	4.22	23696682	11848341	7109005
225	3.85	25974026	12987013	7792208
318	10.91	9167583	4583792	2750275

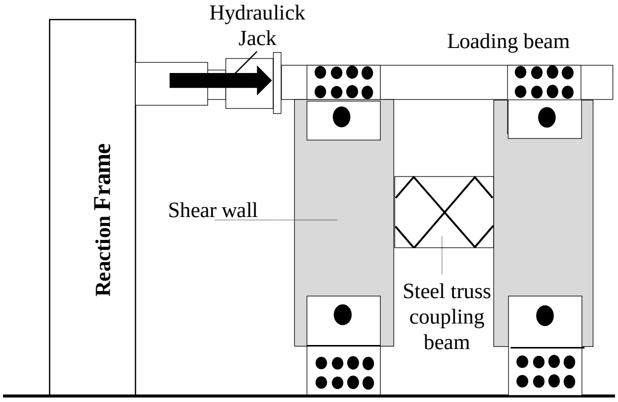

Fig. 14. The specimen loading method at actual test

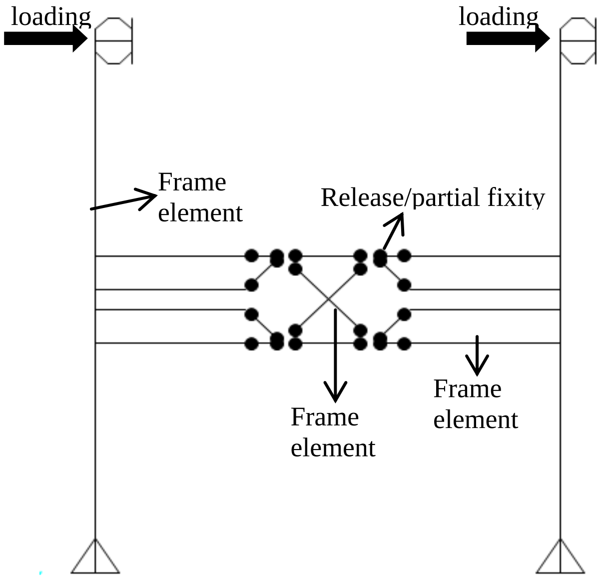

Fig. 15. The specimen loading method at numerical analysis

III. Result and Discussion

At the end of simulation analysis with using SAP 2000 modelling, the behaviours of the structure including the strength capacity, displacement-load relationship and failure mechanism of steel truss coupling beam are observed. Fig. 16 shows the force-displacement relationship for model-1, model-2 and model-3. Fig. 16 shows that the effect of time step due to hydraulic jack movement regarding displacement- lateral load curves.

After attaining the ultimate capacity, the curves decline slightly. From Fig. 16, it also can be seen that the change of time step due to hydraulic jack movement functions can reduce overshoot of displacement-lateral load curve in the strength degradation model. The black circle graph shows the overshoot shape. The model-3 with slow hydraulic jack movement at 540s creates smoother curve if compared to the model-1 with fast hydraulic jack movement at 108 s. Model-1, model-4, and model-5 have simulated the variety of damping ratio with fast hydraulic jack movement at 108s. Fig. 17 depicts the hysteresis curve of those models. Fig. 17 presents the effect of damping ratio in term of the hysteretic curve.

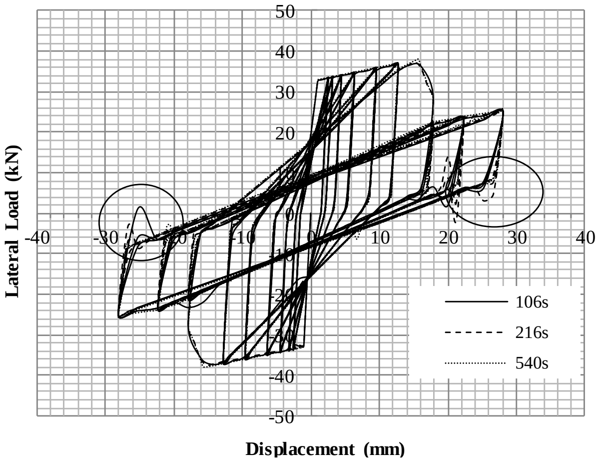

Fig. 16. The hysteresis curve for model-1, model-2 and model-3

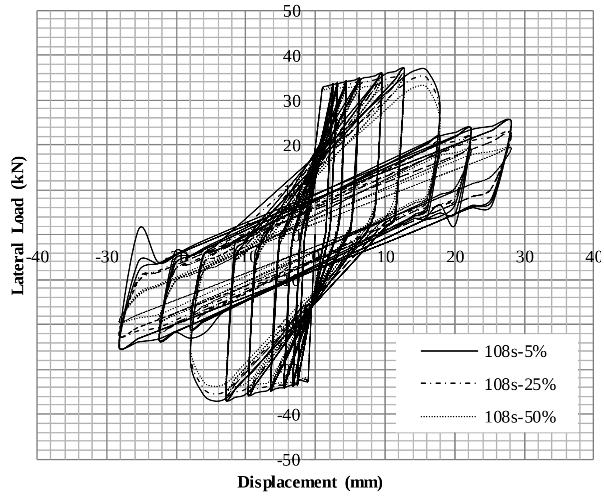

Fig. 17. The hysteresis curve for model-1, model-4 and model-5

It can be seen that the increasing of damping ratio will be able to change the displacement-load curve. The overshoot effect can be diminished for the model with higher damping ratio, but at the same time it also reduces the area of the loop of displacement-load if compared to the smaller damping ratio with the fast hydraulic jack movement of the time history. As mentioned above model-3, model-6, and model-7 are developed in order to investigate the effect of a slow hydraulic jack movement at 540s with various damping ratios such as 5%, 25%, and 50%. The numerical analysis shows that the enhancement of damping ratio until 50% at 540s does not show discrepancy in term of loop area of the displacement-load curve and the overshoot effect. For investigating the effect of time step due to the hydraulic jack movement function, Fig. 18 shows the extreme comparison of the hysteretic curve at 108 s and 540 s with damping ratio of 5%. From Fig.18, it can be concluded that the increasing time step of time history function in term of the slow movement with lower damping parameter can indicate the excellent performance in term of strength capacity if compared to the increase of damping parameter in the direct integration analysis. Moreover, the enhancement of movement of time history function from fast to slow motion can be taken as a solution in order to minimize the overshoot effect in the hysteretic curve. However, it will need more time to execute. Fig. 19 indicates that the value degree of rigidity element can significantly influence the ultimate capacity of the structure or the shear capacity of the steel truss coupling beam. The degree of rigidity 100% which is applied in the numerical modelling can be classified as a fixed connection leads to the higher ultimate capacity if compared to the degree of rigidity 50% and 30%. On the other hand, if pinned connection or the degree of rigidity 0% is applied, the ultimate capacity cannot be achieved. It is found out that, the degree of rigidity 30% gives a better prediction if it has to be matched with the experimental test result. From the analysis, it can be concluded that the end connection of each element in steel truss configuration can be classified as the semi-rigid connection.

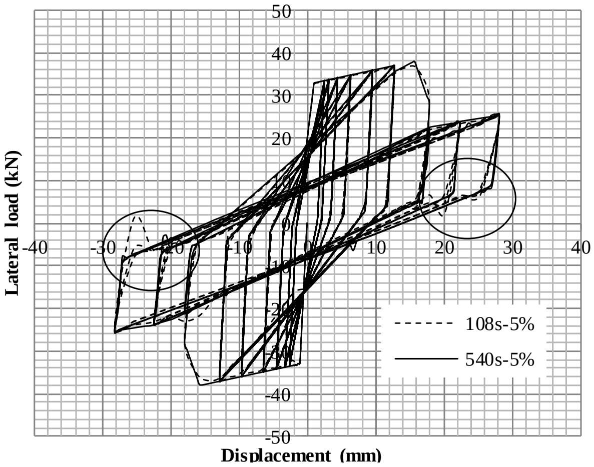

Fig. 18. The comparison hysteresis curve for model-1and model-3 [23]

Finally, the hysteretic curve obtained from the actual test and the numerical simulation is shown in Figures 20 and 21. Figure 21 shows the model of numeric that considering the above parameters such as the degree of rigidity, the non-linear material modelling of plastic hinge due to buckling mechanism, time step and damping ratio. From both of the curve, it can be appointed that the ultimate strength capacity of numerical simulation shows behaviours adequately between the experiment result.

The hysteretic shape of the actual test can be adequately modelled by considering, appropriate model of non-linear material modelling of plastic hinge, slow movement of hydraulic jack and damping ratio.

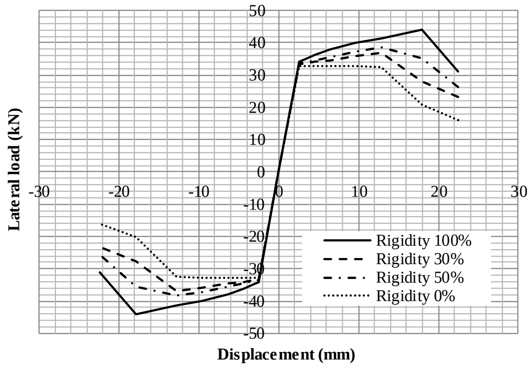

Fig. 19.1 The effect of rigidity on the hysteretic curve [23]

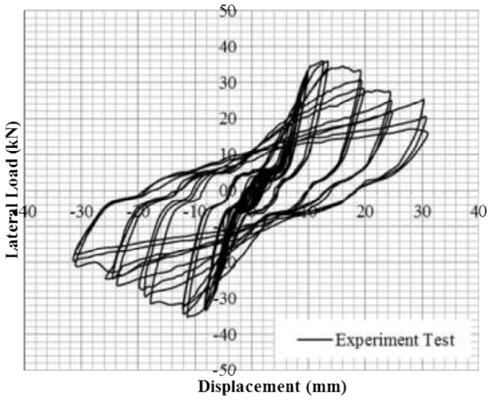

Fig. 20. The hysteretic curve of steel truss coupling beam (actual test)

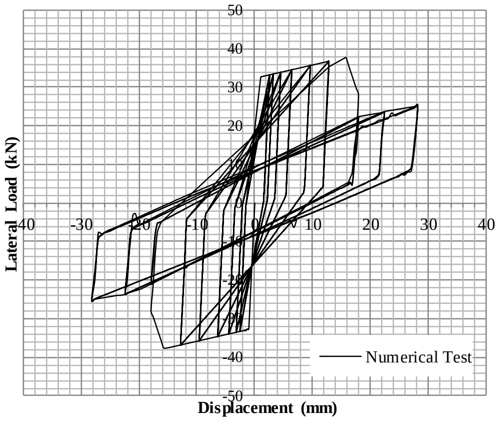

Fig. 21. The hysteretic curve of steel truss coupling beam (numerical test)

Lastly, the degree of rigidity of element joint cannot be ignored in the design phase of the steel truss-coupling beam in shear wall system using SAP 2000. Tables VII and VIII depict the values of displacement and lateral load in each step of loading at the first cycle of loading step based on the actual experiment and the numerical simulation with SAP 2000 software. Base shear and displacement curve can be defined as the capacity curve, which represents the global behaviour of the shear wall with steel truss coupling beam. The comparison of capacity curves of the specimen under lateral load pattern based on the experimental test and numerical analysis is depicted in Fig. 22. It indicates that the graph of the actual test slightly different with the numerical analysis at the initial loading because of the imperfection of supports at the laboratory test which cannot be simulated and detected in numerical analysis.

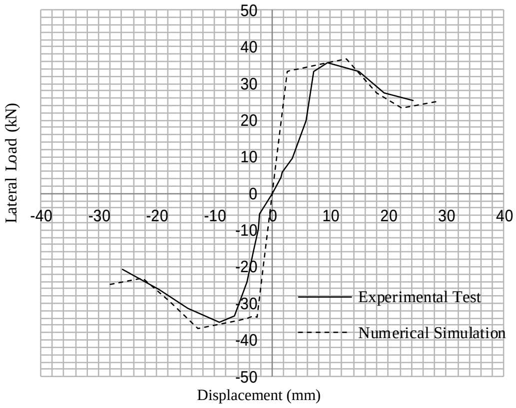

Fig. 22. The displacement and lateral load back bond curve of steel truss coupling beam in shear wall system

TABLE VII
BACKBONE CURVE OF STEEL TRUSS COUPLING BEAM (EXPERIMENT TEST)

No.	Tension Loading Displ (mm)	 Load (N)	Compression Loading Disp (mm)	 Load (N)
1	0	0	0	0
2	1.51	4500	-2.15	-5500
3	1.77	5700	-2.35	-9700
4	3.52	9700	-3.31	-15900
5	5.74	19800	-4.29	-24000
6	7.19	33100	-6.48	-33400
7	9.44	35800	-9.22	-35100
8	14.9	33300	-14.60	-31300
9	19.26	27400	-19.58	-26100
10	24.19	25200	-25.81	-20700

TABLE VIII
BACKBONE CURVE OF STEEL TRUSS COUPLING BEAM(NUMERICAL TEST)

No.	Tension Loading Displ (mm)	 Load (N)	Compression Loading Disp (mm)	 Load (N)
1	0	0	0	0
2	2.56	33360	-2.56	-33.45
3	3.20	33620	-3.52	-33.58
4	4.48	33950	-4.48	-33.82
5	6.40	34620	-6.40	-34.64
6	9.60	35680	-9.60	-35.71
7	12.80	32750	-12.80	-36.73
8	17.92	28440	-17.92	-28.64
9	22.40	30160	-22.40	-30.13
10	28.16	31900	-28.16	-31.78

IV. Conclusion

In this research, a model steel truss coupling beam in SAP 2000 has been developed to represent the performance and behaviour under lateral load. Several conclusions can be made.

1. From the numerical analysis, it can be concluded that a model of steel truss coupling beam could be adequately modelled and predicted by frame element of SAP 2000 with non-linear analysis.
2. The ultimate strength capacity of numerical simulation shows behaviours adequately between the experiment result
3. The value of rigidity of elements should be considered in term of appropriate end connections of steel truss coupling beam. In this case, the end connection of the steel truss can be categorized as the semi-rigid connection.
4. The model which consider slow hydraulic jack movement and lower damping ratio show the fairly well behaviour for describing the hysteretic curve of coupling beam with steel truss configuration in the shear wall.

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Authors' information

[1]Program Study of Civil Engineering, Faculty of Engineering, University of Lambung Mangkurat, Indonesia.

[2]Department of Civil and Environmental Engineering, Faculty of Engineering, Universitas Gadjah Mada, Indonesia.

Nursiah Chairunnisa was born in 1979. she obtained her M.Eng degree and Doctoral degree in Department of Civil and Environmental Engineering, Faculty of Engineering at the Universitas Gadjah Mada, Indonesia. She is lecturer in Study Program of Civil Engineering, Engineering Faculty, Universitas Lambung Mangkurat, Indonesia. Her research of interest related with structures such as strengthenning of reinforced concrete beam and coupling beam in coupled shearwall. Ms. Chairunnisa is member of Indonesian Society of Civil and Structural Engineers (HAKI).

Iman Satyarno was born in 1963. He obtained his M.E degree and Ph.D degree in Civil Engineering at Department of Civil Engineering, University of Canterbury, New Zealand. He is a Professor and lecturer in Department of Civil and Environmental Engineering, Faculty of Engineering at Universitas Gadjah Mada, Indonesia. His area of interest is related with building material technology and the earthquake Engineering. Prof. Satyarno is member of Indonesian Society of Civil and Structural Engineers (HAKI), Indonesian Engineer Association (PII) and Indonesia Professional Engineering.

Muslikh was born in 1957. He obtained his M.Sc degree in Structural Engineering at Strachyde de University , United Kingdom. He also received M.Phil degree in Structural Engineering at Strachyde de University, United Kingdom. He did his Doctoral degree in Civil Engineering at Department of Civil Engineering, Institut Teknologi Bandung (ITB), Indonesia. He is lecturer in Department of Civil and Environmental Engineering, Faculty of Engineering at Universitas Gadjah Mada, Indonesia. His reseach of interest related with structure. Dr. Muslikh is member of Indonesian Society of Civil and Structural Engineers (HAKI).

Akhmad Aminullah was born in 1979. He obtained M.T degree in Departement of Civil and Environmental Engineering, Engineering Faculty at Universitas Gadjah Mada, Indonesia. He did his Ph.D degree in Civil Engineering at Inha University, Korea. He is lecturer in Department of Civil and Environmental Engineering, Faculty of Engineering at Universitas Gadjah Mada, Indonesia. His reseach of interest related with Bridge, Steel Structure, Programming in Civil Engineering. Dr. Aminullah is member of Indonesian Society of Civil and Structural Engineers (HAKI).