PAPER • OPEN ACCESS

Hysteresis loops validation using hysteres program for corner beam-column joints under lateral cyclic loading

Hysteresis loops validation using hysteres program for corner beam-column joints under lateral cyclic loading

A H Nor Hayati[1], A H Nurfarhana Diyana[2], A Hayati[3]

[1]Institute for Infrastructure Engineering and Sustainable Management (IIESM), Shah Alam, Malaysia
[2]Faculty of Civil Engineering, Universiti Teknologi MARA, Shah Alam, Malaysia
[3]Faculty of Civil Engineering and Earth Resources, Universiti Malaysia Pahang, Malaysa

Email: norha454@salam.uitm.edu.my

Abstract. This paper presents the comparison of experimental and modelling of hysteresis loops for a corner beam-column joint under lateral cyclic loading. The beam-column joint is a sub-assemblage of a two-story precast school building. The modelled hysteresis loops were carried out using HYSTERES Program using IHYST 44 rule which is under the Ruamoko 2D folder. Modelling of hysteresis loop is one of the important processes in determining the right hysteresis model to be used in predicting the performance of the whole RC building under different level of earthquake excitations. The validation was made by determining the parameters required based on experimental loops and comparing the hysteresis loops and it response in terms of ductility, stiffness and equivalent viscous damping which obtained from both experimental and modelled hysteresis loops. It was found that the program was able to give a good agreement between them with percentage different between 2.68% and 28.49%.

Keyword: Hysteresis loops validation, lateral cyclic loading, earthquake

1. Introduction

The occurrence of real earthquake cannot be known but it can be predicted within specific durations only. However, the research and advanced technology can be used to predict the occurrences with some major loss and damage caused by earthquakes based on the previous earthquakes data. Few research had been conducted done in Malaysia regarding about the seismic performance of reinforced concrete buildings under low to high earthquake excitations which designed using non seismic code of practice such as BS8110 [1,2]. It was found that the non-seismic design of local buildings did not perform very well under moderate earthquakes. Therefore, it is important to provide sufficient information about detailing and design of structural component to improve the seismic performance of local buildings. It includes discovering the seismic response of frames and members through experimental works and modelling it under level of different earthquake records. The Ruaumoko 2D program was designed to carry out non-linear behaviour analysis of structures, such as buildings and bridges under different earthquake excitations using time history analysis [3]. There are at least 11 modelling options available in the Ruaumoko 2D program. Previous studies had used HYSTERES Program to model the hysteresis loops for the tested structure and compared them between analytical results to experimental results for validation purposes before using it in modelling of the real buildings [4-6]. It has been proven that with accurate input of parameters using the experimental hysteresis loops will give a good modelling result. In this study, HYSTERES Program was used to determine the inelastic behaviour of the sub-assemblage by modelling corner beam-column joint using the most

suitable hysteresis loop in Ruaumoko 2D analysis. It takes a displacement history and computes the associated hysteresis loop for a specified stiffness, yield strength and post-yield behaviour. The sub-assemblage of corner beam-column joint (C1) includes a column with one in-plane beam and one out-of-plane beam. It was designed using Eurocode 8 and equipped with unbonded fuse bars and tested under lateral cyclic loading. Fuse bar is a type of Passive Energy Dissipator which helps to absorb the seismic energy applied and reduce the energy dissipation on primary structural members [7]. Fuse bar is a high yield bar with a reduce cross section as shown in Figure 1. It was attached to the main reinforcement bars using couplers closed to the critical regions. The sub-assemblage C1 was tested for 13 sets of drifts (±0.01%, ±0.05%, ±0.1%, ±0.2%, ±0.5%, ±0.75%, ±1.0%, ±1.15%, ±1.25%, ±1.35%, ±1.5%, ±1.75% and ±2.0%). The specimen was tested until it reaches the maximum target drift. Nine LVDTs were used to measure the lateral displacement of the beams, column and foundation as shown in Figure 2. The result of experimental hysteresis loops was then compared to those which obtained from HYSTERES Program. The result from the modeling was then compared with the experimental results for validation purposes.
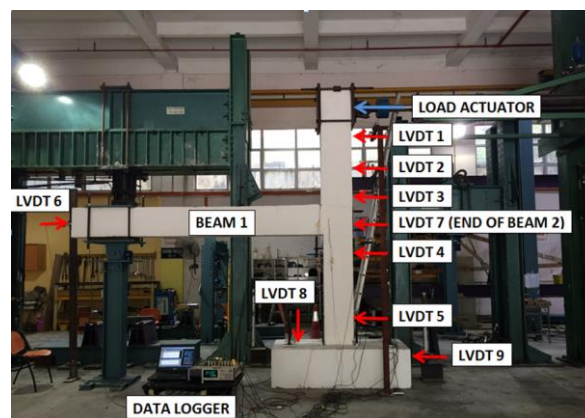

Figure 1. Fuse bar equipped with strain gauges

Figure 2. Position of LVDTs on corner beam-column joint

2. Research Methodology

The proposed method of modelling for non-linear behaviour of the corner beam-column joint was adopted as a preliminary analytical work. Pampanin Reinforced Concrete Beam-Column Hysteresis (IHYST=44) was assigned to the selected corner beam-column joint since the pattern and condition fits the most. Prior to this, the experimental hysteresis loops have been compared with Takeda with Slip (IHYST=25) and major differences has been seen as the rule over estimate the slip condition present in the hysteresis loops. The Pampanin RC beam-column hysteresis includes bilinear unloading and a slip on reloading. Therefore, make it suitable for defining the behaviour of reinforced concrete sections, as the characteristic pinching behaviour can be described. There are six main parameters which required to run this rule as shown in Figure 3. All parameters must be within the given ranges

and it can be calculated based on experimental hysteresis loops. The value of K_o as shown in Figure 4 is the initial stiffness and it can be calculated using Equation 1.

$$Ko = \frac{y_2 - y_1}{x_2 - x_1}$$

(1)

Where x_1 and y_1 are the forces and displacements from initial point of loading and x_2 and y_2 are forces and displacements at yield point. K_{a1}, K_{a2} and K_{s1} are slip stiffness, initial unloading stiffness and final unloading stiffness with au1, au2 and as1 being its respected factor. DeltaF (Df) and Beta were calculated from the positive and negative yield forces taken from the experimental hysteresis loops. These parameters were calculated and tabulated in Table 1.

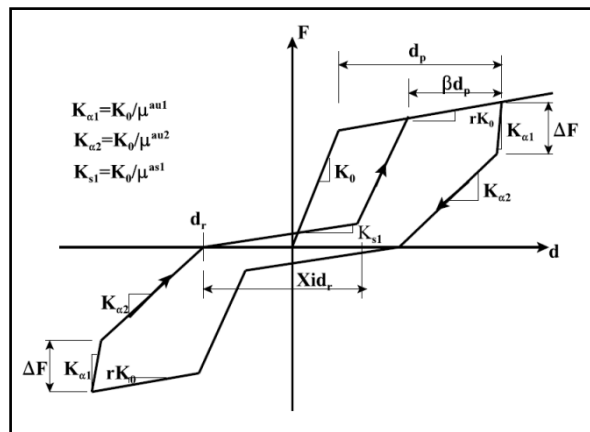**Figure 3.** Parameter for Pampanin Hysteresis [8]

Figure 4. Analytical hysteresis for IHYST 44 under IOP 2 [8].

Table 1. Parameters calculated based on experimental hysteresis loops

Parameters	
i. Reloading Factor Option, IOP	2
ii. Slip Stiffness Power Factor, As1	1.5
iii. Reloading Slip Factor, Xi	1.5
iv. Initial Unloading Power Factor, Au1	0
v. Final Unloading Power Factor, Au2	0.3
vi. Unloading Force Factor, DeltaF	20
vii. Reloading Factor, Beta	-0.3

3. Theoretical Background

There are three main parameters which are related to the performance of the structure that can be compared which are stiffness, ductility and equivalent viscous damping. Stiffness measures the rigidity of an object to resist deformation under an applied load. It measures the amount of load (F) required to displace a building by a certain amount of displacement (Δ) and can be expressed as F/Δ [9]. Under lateral load, the lateral stiffness of a building refers to the initial effective stiffness (Ke), and it reduces with increasing damage [10,11], which later became secant stiffness (Ksec). Ke and Ksec are expressed in Equation 2 and 3.

$$Ke = \frac{Yield\ Load, H_y}{Yield\ Displacement, \Delta_y} \tag{2}$$

$$Ksec = \frac{Ultimate\ Load - Yield\ Load,\ H_u - H_y}{Ultimate\ Displacement - Yield\ Displacement,\ \Delta_u - \Delta_y} \tag{3}$$

Energy dissipation and equivalent viscous damping are the two main factors that affect the seismic performance of a building [12]. Equivalent viscous damping is a way for measuring response of a system to harmonic force at exciting frequency. Higher value of equivalent viscous damping factor indicates that the seismic performance of the structure is good. The energy dissipated in a vibration cycle of the structure can be determined by calculating the equivalent viscous system. An equivalent viscous damping factor can be calculated by using Equation 4 [13].

$$\xi eq = \frac{1}{4\pi}\ x\ \frac{E_D}{Eso}\ x\ 100\% \tag{4}$$

Where E_D = energy dissipation represents the area under one hysteresis loop and E_{SO} = strain energy. Based on Figure 5, energy dissipation (E_{Diss}) is determined by the area of the hysteresis loops while the strain energy (E_{sto}) is taken as half of the peak displacement with its corresponding load.
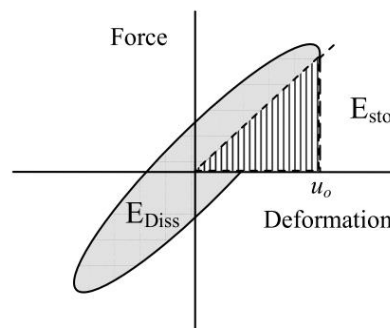

Figure 5. Dissipated and stored force for viscous damping of a hysteretic loop [14] .

4. Results and Discussions

The experimental results of load verus displacement was recorded through data logger during testing while the modelling result was obtained from WRI file generated from the Hysteres Program. To check the accuracy of the selection, the Pampanin hysteresis rule without strength degradation was selected and compared to the experimental response of C1 and is shown in Figure 6. The solid line represents the modelled hysteresis loops while the dotted line represents the experimental hysteresis loops. The rule incorporated a bilinear unloading and a slip on reloading which allowed pinching, and therefore a reasonable fit was achieved. Although similar behaviour was shown between all loops, there are still discrepancies between both of the results that resulted in value of the modelling results higher than the experimental results at some certain areas.
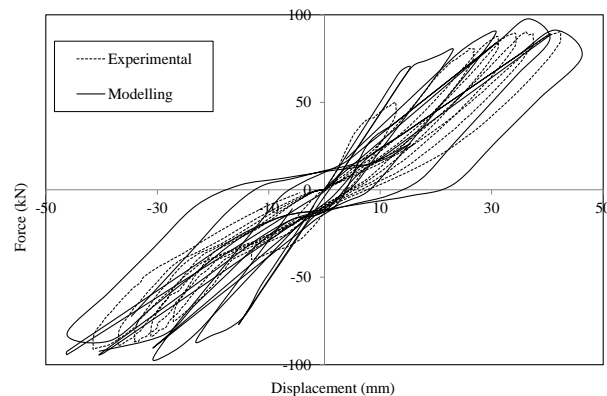
Figure 6. Experimental and modelling hysteresis loops comparison

The response for C1 was compared in terms of lateral strength, stiffness, ductility and equivalent viscous damping. The comparison was considered at 1.15%, 1.25%, 1.35% and 1.50% drifts at both pushing and pulling direction and tabulated in Table 2 for positive direction and Table 3 for negative direction. A decent representation of the experimental response was achieved and the differences between the experimental and modelled response occurred due to the over estimating unloading and reloading load and displacement, especially in later cycles. The lateral strength was taken as the force at the maximum displacement for every drifts. In positive direction, the experimental and modeled ultimate force were 90.29kN and 96.27kN and it was achieved at 1.35% and 1.5% drifts respectively. While for negative direction, the maximum force for experimental and modeled was achieved at 1.5% and 1.25% drifts respectively. This is evident on Figure 6 as the ultimate force for modeled loops achieved ultimate force earlier. The ductility is a result of maximum displacement to the yield displacement. For ductility, the overall results shows good agreement as the most of the ductility value for both modeled and experimental loops in positive and negative direction are within the same range which is 2 to 3 and resulted in low percentage difference. Same goes to stiffness as the percentage of differences are within an acceptable limit with the highest percentage being 18.89% in positive direction and 28.49% n negative direction.

Table 2. Comparison of lateral strength, ductility and stiffness for positive direction

Parameters	Target Drift (%)	Positive Direction		
		Model (kN)	Exp (kN)	Difference (%)
Lateral Strength	1.15	80.19	87.62	8.48
	1.25	90.20	89.54	0.74
	1.35	93.71	90.29	3.79
	1.50	96.27	89.75	7.26
Ductility	1.15	2.08	1.93	7.89
	1.25	2.42	2.29	5.51
	1.35	2.76	2.69	2.64
	1.50	3.23	3.11	3.86
Stiffness	1.15	3.47	2.82	18.89
	1.25	2.93	2.62	10.39
	1.35	2.56	2.50	2.48
	1.50	2.33	2.12	8.99

Table 3. Comparison of lateral strength, ductility and stiffness for negative direction

Parameters	Target Drift (%)	Negative Direction		
		Model (kN)	Exp (kN)	Difference (%)
Lateral Strength	1.15	-87.01	-83.88	3.73
	1.25	-97.02	-86.87	11.68
	1.35	-92.31	-89.00	3.72
	1.50	-86.33	-90.93	5.06
Ductility	1.15	1.79	2.00	10.71
	1.25	2.02	2.33	13.26
	1.35	2.54	2.65	4.15
	1.50	2.90	2.98	2.68
Stiffness	1.15	3.77	2.69	28.49
	1.25	3.15	2.55	19.08
	1.35	2.66	2.41	9.61
	1.50	2.24	2.19	2.38

The modeled damping percentage was shown higher than experimental damping percentage. The differences at 1.15%, 1.25%, 1.35% and 1.50% drifts went up to 51% as seen in Table 4. The damping percentage was calculated using Equation 4. The area of the elasto-plastic loops created by both experimental and modeled hysteresis loops represent the amount of energy dissipated. Since the modeled hysteresis loops are bigger than experimental hysteresis loops, the damping percentage of the modeled damping percentages are generally higher than experimental ones. The HYSTERES Program tends to overestimate the results, however, the results are still good to use in Ruaumoko 2D for dynamic analysis since the requirement is only from the overall shape and behavior of the hysteresis loops.

Table 4 Differences of equivalent viscous damping (ζeq) between modelling and experimental

Equivalent Viscous Damping			
Target Drift (%)	Model (%)	Exp (%)	Difference (%)
1.15	5.57	5.55	0.46
1.25	6.44	4.48	30.42
1.35	9.83	4.83	50.83
1.50	11.17	5.44	51.28

5. Conclusions

This paper presents the comparison of load versus displacement and its response between experimental results and modeling results using HYSTERES program for corner beam-column joint. Hysteresis loops of the sub-assemblage C1 was modeled and revealed good agreement corresponding to the hysteresis loops obtained from experimental results. The percentage difference of maximum strength, effective stiffness, displacement ductility and equivalent viscous damping between experimental and modeling were presented earlier as. However, different hysteresis rule gives different results and to get the most accurate fit, trying different sets of rule is needed. This to ensure

future works will not be affected by preliminary error. Further work can be done using RUAUMOKO2D and DYNAPLOT to give more detailed analysis on inelastic behaviour of the two story school building under different earthquake excitation.

References

[1]   Azuan, T. M., Kay Dora, A. G., & Nor Hayati, A. H. 2016. Modeling of two-storey precast building under past earthquake records using Dynaplot program. *AIP Conference Proceedings*, *1774*

[2]   Hamid, N. H., Mohamad, N. M., & Anuar, S. A. 2014. Modeling of Sinngle Bay Precast Residential House Using Ruauumoko 2D Program. *International Journal of Civil, Architectural, Structural and Construction Engineering*, *8***(12)** 1247–1251.

[3]   Carr, A. J. 2004 *The Maori God of Volcanoes and Earthquakes* **(3)**

[4]   Magenes, G., & Pampanin, S. 2004. Seismic response of gravity-load design frames with masonry infills. *13th World Conference on Earthquake Engineering*, 4004.

[5]   Abd Ghani, K. D., Abdul Hamid, N. H., & Jaafar, M. S. 2013. Load versus Displacement Validation between Ruaumoko Hysteresis Program and Experimental Work on CFRP Retrofitted Precast Beam-Column Exterior Joint. *Key Engineering Materials*

[6]   Ireland, M. 2007 *Development of a Selective Weakening Approach for the Seismic Retrofit of Reinforced Concrete Structural Walls* (Master thesis) Retrieved from https://ir.canterbury.ac.nz/handle/10092/1200

[7]   Shanmuga, P.D., Cinitha, A., Umesha P.K. and Nagesh, R. I. 2014 Enhancing the Seismic Response of Buildings with Energy Dissipation Methods – An Overview *Journal of Civil Engineering Research* **(4)** 17-22

[8]   Carr, A. J. 2007 *Ruaumoko Manual-Theory* **(1)** 3-4

[9]   Ghani, K. D. A. 2015 *Seismic Performance of Full-Scale Precast Non- Seismic Beam-Column Joints With Corbels Under in-Plane Lateral Cyclic Loading* (Phd thesis) Retrieved from http://ir.uitm.edu.my/16196/

[10]   Misir, I. S., & Kahraman, S. 2013 Strengthening of non-seismically detailed reinforced concrete beam-column joints using SIFCON blocks. *Sadhana - Academy Proceedings in Engineering Sciences*, *38***(1)**, 69–88.

[11]   Lehman, D., Stanton, J., Anderson, M., Alire, D., & Walker, S. 2004 Seismic performance of older beam-column joints. *Proc. 13th World Conf. Earthquake Engineering*, 1464

[12]   Yuping, S., & Dingwei, J. 2012. Analysis of seismic performance of steel moment connection with welded haunch and cover plate. *Research Journal of Applied Sciences, Engineering and Technology*, **4(14)**, 2199–2204

[13]   Chopra, A. K. 2013 *Dynamics of structures*. *Journal of Chemical Information and Modeling* **(4)**

[14]   Blandon, C. and Priestley, M. Equivalent Viscous Damping Equations for Direct Displacement Based Design *Journal of Earthquake Engineering* **(9)** 257-278

Acknowledgement