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Connections Behaviour in Precast Concrete Structures Due to Seismic Loading

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ABSTRACT

This paper presents a finite element analysis on 4 types of precast connections which are pinned, rigid, semi rigid and a new proposed connection. The stiffness of the new connection is obtained from the slope of the total load versus deflection graph in the elastic range. Then the seismic loading from El Centro earthquake modified with 0.15g and 0.5g were applied to the whole structure. From the analysis results, new connection has sufficient stiffness, strength and also higher ductility. Meanwhile, the whole structure analysis results showed that the new connection behaves as semi rigid connection. LUSAS and SAP2000 have been used for analysis.

Keywords: *Finite Element Analysis, Precast, Seismic Loading, Connection*

1. INTRODUCTION

This is an investigation of the seismic response on the precast structures due to the beam to column connection behaviour. Earthquake could damage the whole structure if it is not properly designed, especially in high seismic regions. Connection is one of the crucial elements to limit building damage. A lot of researches have been done on monolithic reinforced concrete buildings but none of them gives information on the behaviour of precast connection under seismic effect for the whole structure [1]. Although several moment resistant connections are designed through researches to sustain high intensity seismic, the connection fabrication is complex which will slow down the construction period. Besides, the actual behaviour of these connections is still vague. The understanding of the actual connection behaviour is very important, especially designed and constructed for high seismic region [2-5].

Precast technology offers benefits such as reduce construction period, better quality control, cleaner and safer construction sites and others. Precast concrete means concrete which has been prepared for casting and the concrete either is statically reinforced or prestressed [6-7-8]. Meanwhile a precast concrete element is of a finite size and must therefore connect with other elements to form a complete structure. When two elements are connected, problems such as shrinkage, thermal or load will induced strains and cause volumetric changes [9]. The volumetric changes cause movement between the two elements and internal friction between the two elements surface is provided by using various methods such as inserting dowel between beam to column connection. Apart from that, local crushing at the top of column occurs due to the flexural rotation of the beam. Therefore, a bearing pad is provided to overcome this problem. Another factor need to be considered is the narrow bearing of the suspended element on the vertical element. Consideration for the overall stability of the structure is important too. Precast concrete structure refers to the combination of precast concrete elements and the structure is able to sustain vertical and horizontal loads or even dynamic loads. So the design and construction of the joints and connections is important to ensure the stability and robustness of the overall structure [10-14].

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The design of connection should be able to sustain various kinds of loads (static and dynamic) in terms of strength and ductility [15]. Besides, the connection should be simple for construction. Constructability of connection is important to reduce fabrication period [16]. As lack of knowledge and information on the connection behaviour in seismic load, this research is to understand the behaviour of several selected precast connections [17].

2. PRECAST CONCRETE SYSTEM

There are three types of precast building systems. The most common is the skeletal structure. The skeletal structure is the combination of beams and columns which are able and strong enough to resist vertical and horizontal loads. Sometimes, this system needs vertical wall (shear wall) to sustain horizontal loads. The second type is precast wall system or known as panel system. This system is normally built on ground and depends on load bearing wall to resist vertical and horizontal loads. The last system is portal frame. This type of system normally used in industrial building and warehouse.

To sustain lateral load, the stability of the systems is important. In precast structures, especially skeletal system, there are two important stabilizing systems. These are horizontal system and vertical system. The horizontal system is a floor diaphragm and the vertical system is the bracing system [18].

2.1. Frame Subjected To Cyclic Seismic Loading

The current philosophy for earthquake design is to prevent total collapse due to severe earthquake but minor damage is allowed for moderate earthquake [19-20]. However, this would lead to non-structural damage such as architectural, mechanical and electrical elements. To limit damage, there are three methods as below [21]:

i. Eliminate coupled force in non supporting members to reduce deformation
ii. Reduce support member deflection to limit architectural damage
iii. Provide ductile connection to sustain large deformation and rotation.

2.2. Basic Mechanism Of Joints And Connections

The term of mechanism refers to the action of forces between structural elements. There are two kind of precast elements, namely isolated and non-isolated elements. Isolated element means connected elements sustained first means of load transfer such as beam to column connection while the non-isolated element is a joint between two elements which transfer secondary load such as hollow slab units [22].
There are three most widely used connection analysis method. These are strut to tie (Beam on Corbel to transfer bearing forces), coupled joint (column splice to transfer bearing forces, bending and/ or torsional moment), and finally shear friction (shear key to transfer shear with or without compression) [16].

3. FINITE ELEMENT ANALYSIS

3.1. Nonlinear Concrete Material Modeling

One of the methods to model nonlinear concrete material modeling is multi-cracking concrete with crushing model. This model stimulates the nonlinear behaviour of concrete in both compression and tension at the same time. Therefore, the yield function consists of the two main parameters which are the tension softening of concrete and compression crushing. As a result, this model is suitable for cracking and crushing failure at the same time [23]. The typical behaviour of the tension stiffening effect and concrete crushing is shown as below:

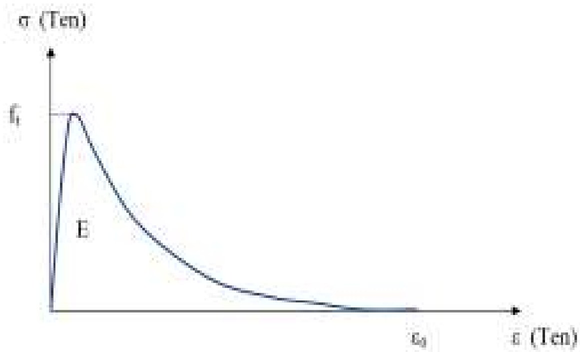

Figure 1: Tension Softening Behaviour of Concrete

Figure 1 shows that the tension behaviour of the concrete. The peak stress of the graph is the tensile strength, f_t and the slope is the elastic modulus value, E. The peak stress is end up at the end of tension stiffening value, ε_o. This behaviour is important when model the concrete crack. The concrete crack happens to be loss its strength gradually once the concrete tensile strength reaches the peak. Therefore, the problem arises when the crack is modeled as discrete crack because it would increase the ductility of the concrete which may not be true.

Table 1: Material Properties for Concrete Components

Elastic	
Young Modulus	$42000\ N/mm^2$
Poisson Ratio	0.3
Plastic (Cracking & Crushing Model)	
Tensile Strength	$4\ N/mm^2$
Compressive Strength	$40\ N/mm^2$
Strain at Peak Compressive Stress	0.0030
Strain at End of Compressive Softening Curve	0.0035
Strain at End of Tensile Softening Curve	0.13-0.8

3.2. Nonlinear Steel Material Modeling

To choose a suitable model, we have to know the behaviour of the steel. The model must able to stimulate the behaviour of the steel. Here we choose stress potential method. The stress potential method able to simulate the yield behaviour in all direction of stress space required under multiaxial stress. Besides that, it could also show the hardening properties of steel in terms of hardening gradient and effective plastic strain [23]. The graph is shown in Figure 2.

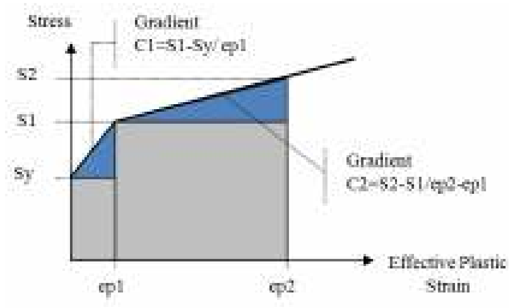

Figure 2: Hardening Properties of Steel

Table 2: Material Properties for Reinforcement and Steel Plate Components

Elastic	
Young Modulus	$210000\ N/mm^2$
Poisson Ratio	0.2
Plastic (Stress Potential Model)	
Initial Uniaxial Yield Stress	$560\ N/mm^2$
Hardening Gradient	2121
Plastic Strain	5

3.3. Elements Type

In this study we use plane stress theory in FE analysis for simplification of the modeling. Although, it is probable that plane-stress formulation can not reflect the exact behavior, but can give results with a good accuracy. A plane stress is subjected with stress at two directions and it is suitable to thin element such as beam and column body. This means that there is no zero stress at z direction. The stress, σ and strain, ε tensors are as below [24]:

$$\sigma_{ij} = \begin{bmatrix} \sigma_{11} & \sigma_{12} & 0 \\ \sigma_{21} & \sigma_{22} & 0 \\ 0 & 0 & 0 \end{bmatrix} \quad (1)$$

$$\varepsilon_{ij} = \begin{bmatrix} \varepsilon_{11} & \varepsilon_{12} & 0 \\ \varepsilon_{21} & \varepsilon_{22} & 0 \\ 0 & 0 & \varepsilon_{33} \end{bmatrix} \quad (2)$$

Bar element is subjected to one direction stress which is axial force. Therefore, bar element is modeled as reinforcement bar which embedded in concrete.

4. PROPOSED CONNECTION

The stiffness for the new connection is obtained from the slope of the Total Forces versus Deflection graph in elastic zone for finite element analysis. The geometry and dimension of typical connection from experiment and proposed new connection are shown in Figures 3 and 4 respectively [25].

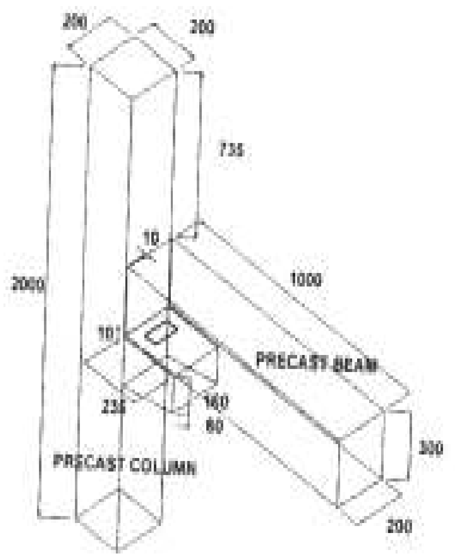

Figure 3. Experimental Connection

5. STRUCTURAL MODELING (SAP2000)

The 3 dimensional frame consists of 2 x 3 bays is loaded with dead load 4kN/m^2 and live load 2.5kN/m^2. The length and width of the frame are 6m and 3m respectively. Besides, the column height is 3m. The frame is analyzed without any bracing. This frame is then compared with pin jointed frames and fixed frames.

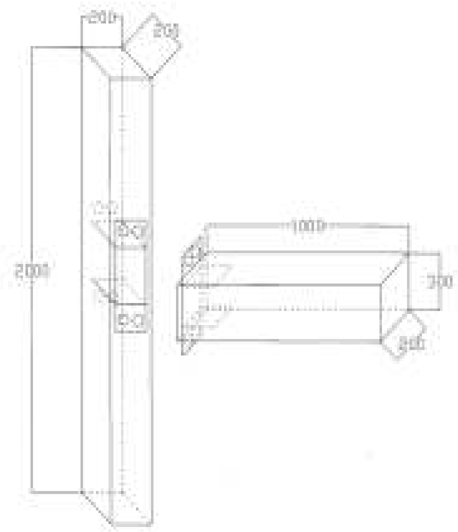

Figure 4. Proposed New Connection

Figure 5 is a three storey frame. The dead load and live load are distributed along the 6m length main span as the slab spans in one direction. The end column is fully fixed. Besides that, seismic load for linear time history analysis is introduced on the frames. The time history loading is El Centro and amplifies with 0.15g and 0.50g. The seismic graph is shown in Figure 6.

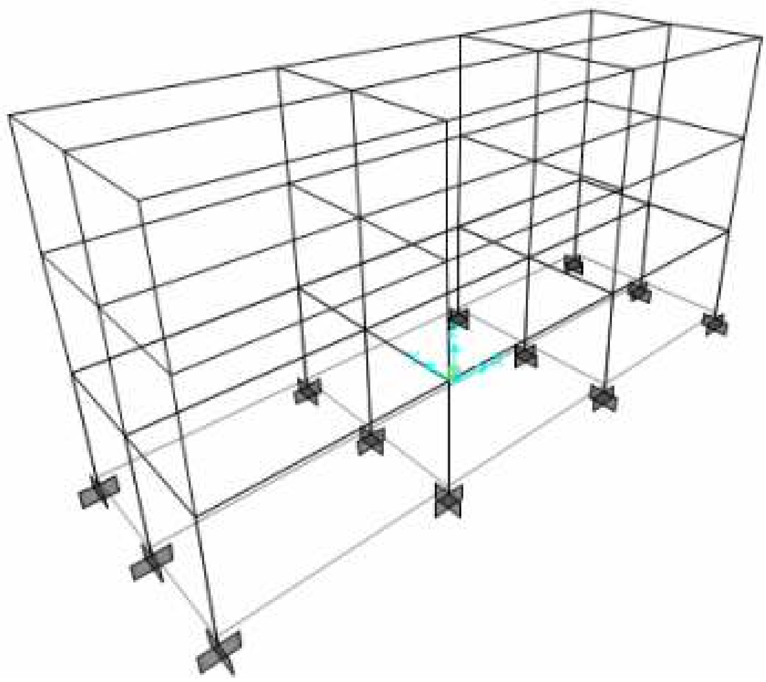

Figure 5: 3 Storey 3 Dimensional Frame (SAP2000)

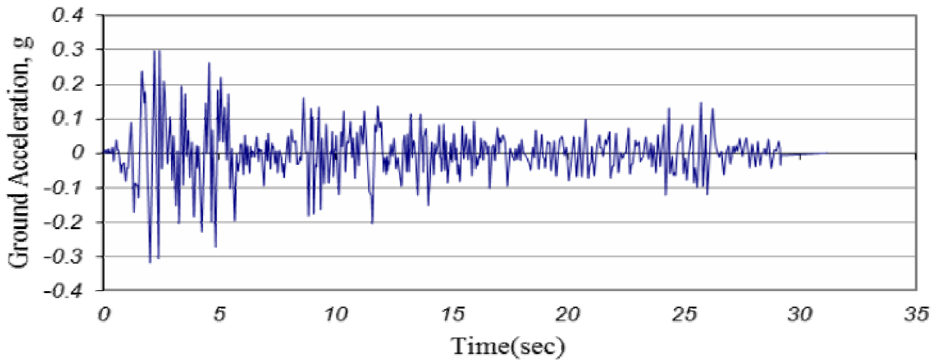

Figure 6: El Centro Time History at Surface (North-South Component)

6. FINITE ELEMENT MODELING (LUSAS)

Finite element models are shown in Figures 7 to 10. The geometry for column, beam and corbel is the same for all the models either it is new or it is old. In this paper, column, beam, dowel, plate, stiffener and bolt are assigned with plane stress because they are subjected by two forces in two directions which are x-direction and y-direction. Since the reinforcement bar is subjected by x-direction only, the reinforcement is modeled as bar element.

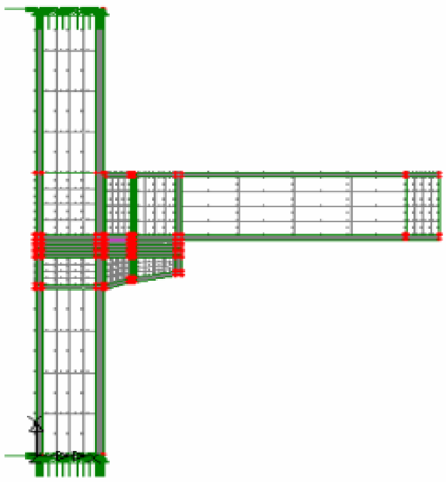

Figure 7: Corbel Only Model

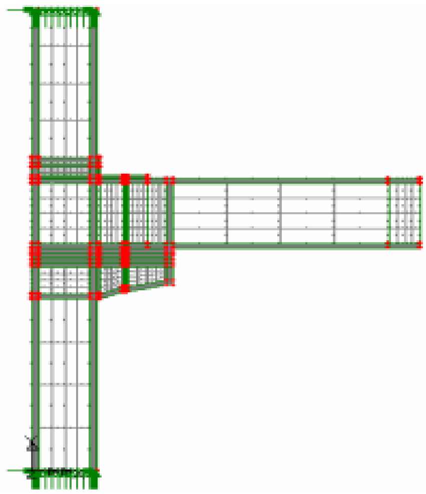

Figure 8: Corbel + Plate and Bolt on beam Top Model

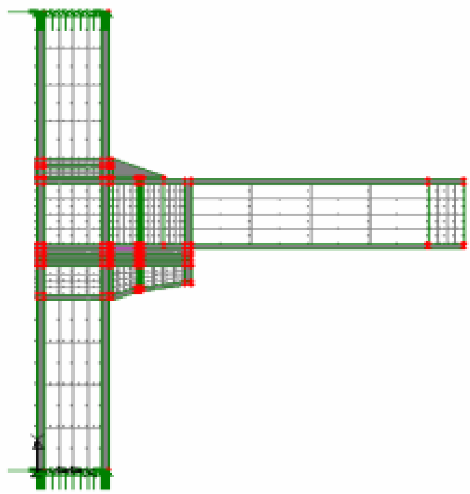

Figure 9: Corbel+ Plate and Bolt on Beam Top + Stiffener

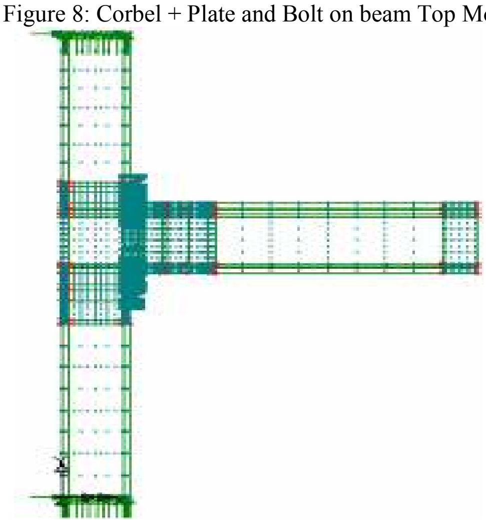

Figure 10: New Connection Plate 10mm and Bolt 22mm

Figures 7 to 9 are corbel connections. The corbel acts as a support for the beam and the whole connection strength depends on the corbel. This can be proven when shear cracks occur at the corbel. The experimental connection strength depends mainly on the interaction of the plate and bolt [25]. The main reason is shear cracks happen at the plate and bolt area on top of the beam. Therefore, the new connection is modeled to fully utilize the bolt and concrete interaction. When the bolt is embedded in the concrete, it is pulled out by the beam which is loaded by a point load until yields.

7. ANALYSIS AND RESULTS

In the finite element analysis, material properties also play an important role in the modeling. The material properties are obtained initially according to the value recommended by the LUSAS Manual but these values were reviewed a few times to obtained a better result when verified with the experimental result. Since the cracks are model discretely (without predefined the crack opening), we cannot predict accurately when the model is actually fail. Therefore, we try to optimize the strain at the end of tensile softening curve value in the model by maximize the concrete compressive strength. Thus, the total load stops when the normal compressive stress reaches maximum.

Table 3 shows the FE analysis results for peak stress of the concrete for different models. The highest Von Mises stress is 46.37 N/mm^2 and the lowest value is 39.70 N/mm^2. These values belong to new connection model and corbel only model. These stress values are suitable for steel material elements and they are listed for reference only. Von Mises contours are shown in Figures 11 to 14. The normal stresses are also shown in Table 3 because these values are used for compressive strength comparison purpose. Theoretically, these values should equal to 40 N/mm^2. The highest value for normal stress is 45.72 N/mm^2 in the new connection modeling. Therefore, it is obvious that there is a large discrepancy between the compressive strength and normal stress. To overcome this problem, try to decrease the iteration total load factor for a more accurate value. Apart from that, the highest value for shear stress is 20.73 N/mm^2. This stress happens in Corbel + Plate and Bolt on Beam Top Model. Meanwhile, there is an interesting value that should be highlighted. This value is 10.14 N/mm^2 which happen in the new connection. This means that shear stress does not govern the new connection failure.

Table 3: Peak Stress of the Concrete for Different Models

Model	Von Mises Stress, σ_{von} (N/mm^2)	Normal Stress, σ_y (N/mm^2)	Shear Stress, γ (N/mm^2)
Corbel Only	*39.70*	*41.78*	*8.62*
Corbel + Plate	*42.25*	*41.35*	*20.73*
Corbel + Plate + Stiffener	*42.81*	*41.14*	*19.20*
New Connection	*46.37*	*45.72*	*10.14*

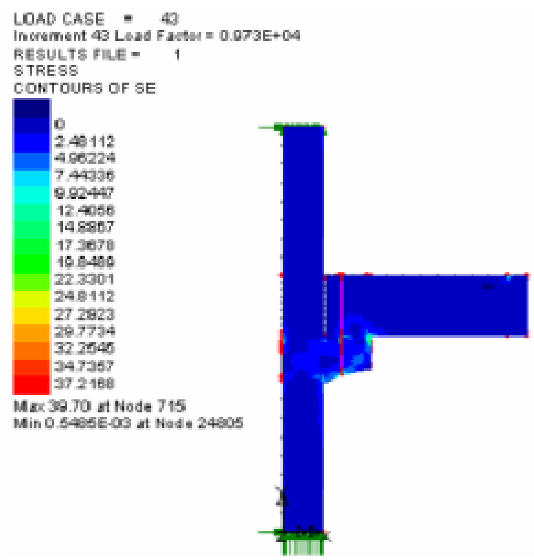

Figure 11: Von Mises Stress for Corbel Only Model

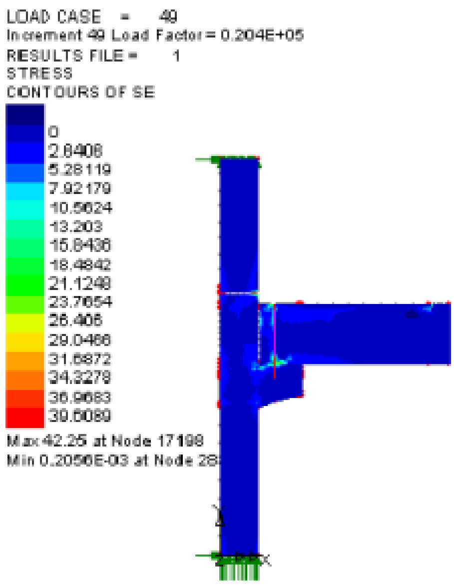

Figure 12: Von Mises Stress for Corbel +Plate Model

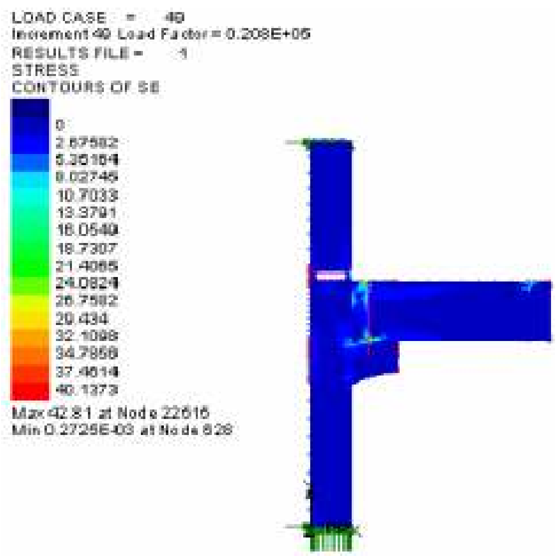

Figure 13: Von Mises Stress for Corbel +Plate + Stiffener Model

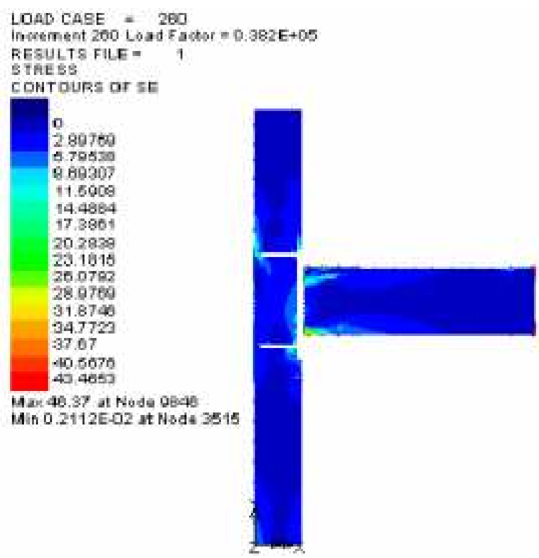

Figure 14: Von Mises Stress for New Connection Model

The finite element models starts to crack when the tensile strength of the concrete is exceeded. In Figures 15 to 18 the cracks pattern are shown according to FE analysis, the red lines represent tensile cracks while the blue lines mean the compressive cracks.

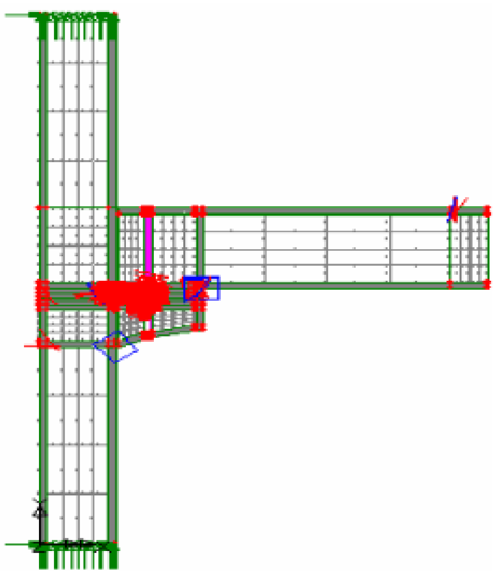

Figure 15: Crack Location for Corbel Only

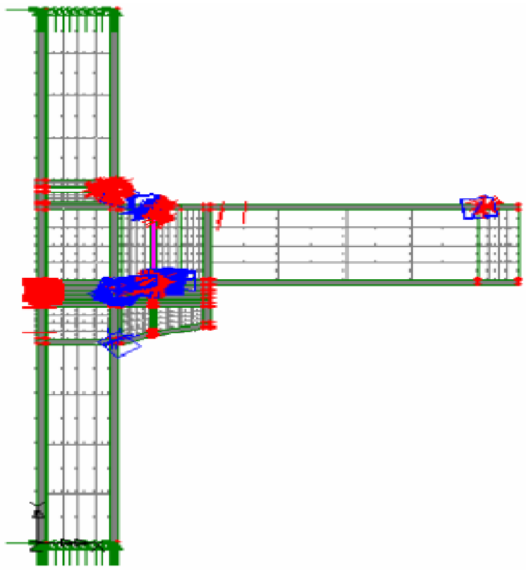

Figure 16: Crack Location for Corbel +Plate

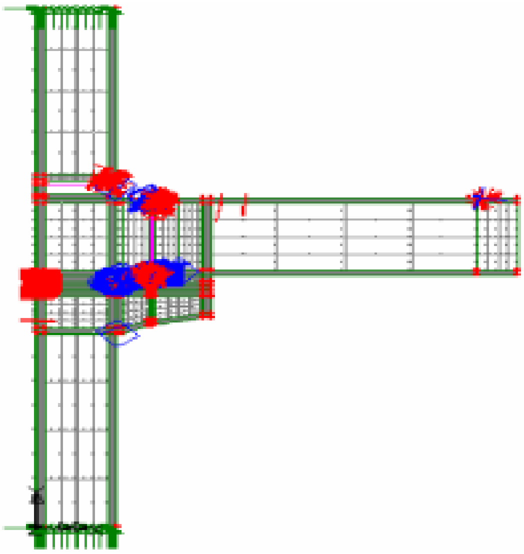

Figure 17: Crack Location for Corbel + Plate + Stiffener

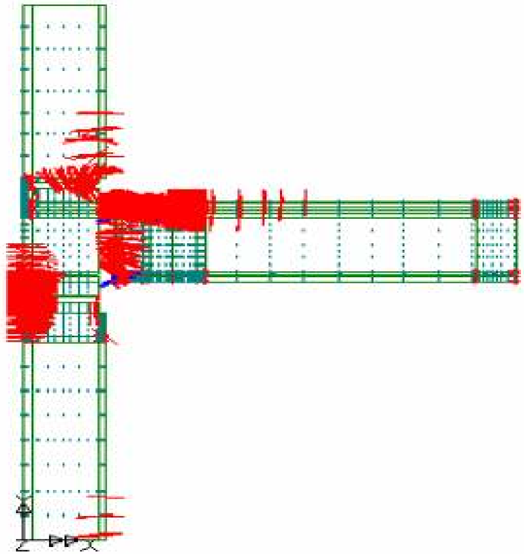

Figure 18: Crack Location for New Connection

Modal analysis results for seismic intensity loads 0.15g and 0.50g are shown in Table 4. The frequency for each model is almost the same with different load intensities and this is true. There are some discrepancies for the frequency because of the modeling error such as member size. Pinned connection frame has the lowest frequency and the value for 0.15g is 0.11 Hz. The highest frequency is for the fixed connection which is 0.40 Hz for 0.15g. In 0.50g, the lowest and highest frequency also happens in pinned and fixed connections respectively [26].

Table 4: Modal Analysis Results for Seismic Intensity Load 0.15g and 0.5g

0.15g			.5g		
Connection	Period (s)	Frequency(Hz)	Connection	Period (s)	Frequency(Hz)
Pinned	*10.52*	*0.11*	Pinned	*12.90*	*0.09*
Semi-Rigid	*4.23*	*0.24*	Semi-Rigid	*4.37*	*0.23*
Rigid	*2.57*	*0.40*	Rigid	*2.25*	*0.39*
New Connection	*3.81*	*0.26*	New Connection	*3.92*	*0.22*

According to SAP2000 outputs the 0.50g seismic load intensity causes the highest moment in beam to column connections. The comparison between different types of connection in terms of maximum moment and shear is shown in Table 5.

Table 5: Maximum Moment and Shear according to Static and Seismic loading

Moment (kN.m)			Shear (kN)		
Connection	Static	Seismic	Connection	Static	Seismic
Pinned	*95.6*	*0*	Pinned	*63*	*0*
Semi-Rigid	*86.3*	*12.7*	Semi-Rigid	*63*	*5.2*
Rigid	*73.1*	*22.3*	Rigid	*63*	*9.3*
New Connection	*69.4*	*11.5*	New Connection	*63*	*4.4*

The frame analysis results show that the beam capacity is sufficient to sustain both shear and moment force for all types of connection stiffness. However, the column for fixed and pinned connections fails for both moment and shear forces. Also from the analysis results, the connection stiffness does have an effect on the moment and shear capacities of members. When the connection stiffness increases, the members such as columns and beams sustain heavier load that may lead to failure in the end. However, this conclusion is not totally true in precast structural design. For pinned connection frames, the seismic forces are very low and do not tends to fail the structure. In reality, this type of connection may fail due to instability. Unfortunately, the SAP2000 software uses the stiffness method for linear time history analysis and unable to detect the stability failure of the connection.

According to modal analysis, 3 storey frame does not show any sign of drifting. The frame sways frequently in the direction of a longer length dimension as we applied the lateral loading in the longer dimension. The sway modes which can be detected are Mode 2, Mode 3, Mode 4, Mode 6, Mode 7 and Mode 8. (See Figure 19)

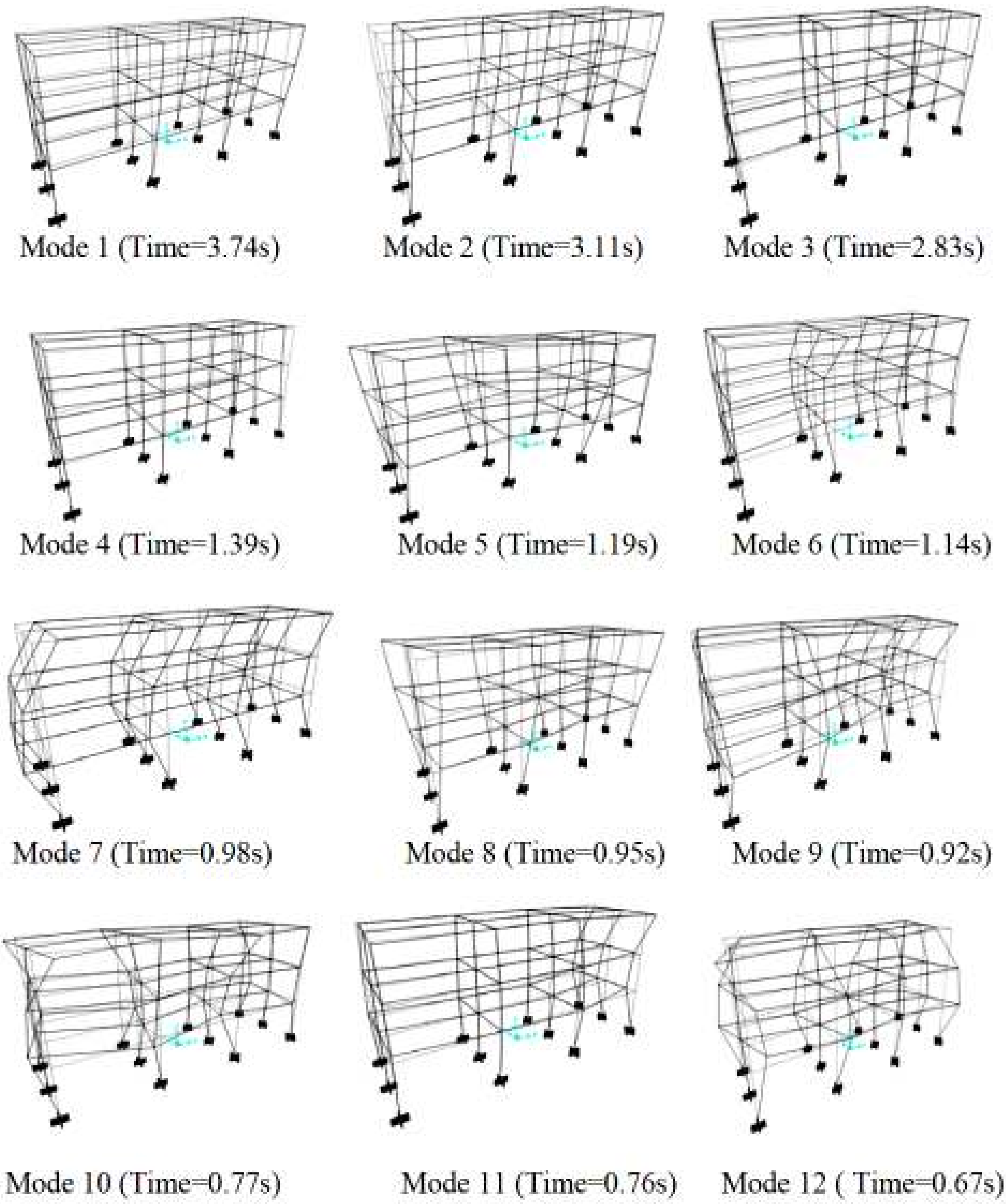

Figure 19: Deformed Mode for Modal Analysis (Proposed Connection)

8. CONCLUSIONS

1) The new connection shows better stiffness, strength and ductility when using 10mm plate thickness and 22mm diameter bolt size. However, this new connection should be verified against laboratory test.
2) From the frame analysis above, the connection stiffness does have a significant effect to the frame member for moment and shear forces under linear time history loading.
3) The new connection has a value of 2253 kN/m stiffness which demonstrates the behaviour of semi-rigid if compare with pined

and fixed connections under 0.15g and 0.50g seismic intensity in linear time history analysis.

REFERENCES

[1] Kai, L.M., "*The Behaviuor of Pinned Beam to Column Connection in Precast Concrete*", MSc. Thesis, University of Technology Malaysia, 2004.

[2] HUI, L.M., "*Seismic Effect on Precast Concrete Structures*", MSc. Thesis, University of Technology Malaysia, 2008.

[3] Hart, G.C., Fai, K.K. and Wong, "*Structural Dynamic for Structural Engineers*", John Wiley and Sons, New York, 2000.

[4] Han, Q., "*Behaviour of Precast Reinforced Concrete Beam-Column Connections under Static and Repeated Loading*", ME Thesis, University of Wollongong, Australia, 170 pp, 1994.

[5] J.F. Stanton, S. Nakaki, "*Design Guidelines for Precast Concrete Seismic Structural Systems*", PRESSS Report No. 01/03-09, Seattle, WA, 2002.

[6] "*PCI Design Handbook Precast and Prestressed Concrete*", PCI Prestressed Concrete Institute, 1985.

[7] Potter, R. J., "*Developments in Precast Concrete*", Proceedings, Second Australian National Structural Engineering Conference, Adelaide, Institution of Engineers Australia, North Sydney, pp. 136-140, October 1990.

[8] "*Guidelines for the Use of Structural Precast Concrete in Buildings",* Report of a Study Group of the New Zealand Concrete Society and the New Zealand National Society for Earthquake Engineering, Centre for Advanced Engineering, University of Canterbury, Christchurch, New Zealand, 1991.

[9] "*Precast concrete structural elements*", Advanced Concrete Technology Set, Pages 3-46 John Richardson, 2003.

[10] Clough, D. P., "*Design of Connections for Precast Prestressed Concrete Buildings for the Effects of Earthquake*" Technical Report No. 5, Pre-cast/Prestressed Concrete Institute, Chicago, IL, March 1985.

[11] Pillai, S. U., and Kirk, D. W., "*Ductile Beam-Column Connection in Precast Concrete*", ACI Journal, Vol. 78, No. 6, pp. 480-487, November-December 1981.

[12] Stanton, J. F., Anderson, R. G., Dolan, C. W., and McCleary, D. E, "*Moment Resistant Connections and Simple Connections*", Research Project No. 1/4, Precast/Prestressed Concrete Institute, Chicago, IL, 1986.

[13] Clarke, J. L., "*The Behavior of a Precast Beam-Column Joint*", Precast Concrete, United Kingdom, pp. 503-504, October 1978.

[14] Martin, L. D., and Korkosz, W. J., "*Connections for Precast Prestressed Concrete Buildings, Including Earthquake Resistance*", PCI Technical Report No. 2, Precast/Prestressed Concrete Institute, Chicago, IL, pp. 4.25-4.50, 1982.

[15] Elliot, K.S., "*Precast Concrete Structures*", Great Britain, Antony Rowe Ltd, 2002.

[16] Seckin, M., Fu, H.C., "*Beam-Column Connections in Precast Reinforced Concrete Construction*", ACI Structural Journal, Vol 87, No.3, pp 252-261, 1990.

[17] Bhatt, P., and Kirk, D. W., "*Tests on an Improved Beam Column Connection for Precast Concrete*", ACI Journal, Vol. 82, No. 6, pp. 834-843, November-December 1985.

[18] Elliot, K.S., Workshop on Design & Construction of Precast Concrete Framed Structures, 7-8 April 2005.

[19] Applied Technology Council, "*Design of Prefabricated Concrete Buildings for Earthquake Loads*", Berkeley, CA, 1981.

[20] Alcocer, S.M., Carranza, R., Perez-Navarrete, D., Martinez, R., " *Seismic tests of beam-to-column connections in a precast concrete frame Seismic tests of beam-to-column connections in a precast concrete frame* ", PCI Journal 47 (3), pp. 70-89, 2002.

[21] Geraldine, S., Cheok, and H.S.Lew, "*Performance of Precast Concrete Beam-to-Column Connections Subject to Cyclic Loading*", PCI Journal, Vol. 36, No.3, pp 56-67, May-June 1991.

[22] Restrepo, J.I. and Park, R., "*Design of Connections of Earthquake Resisting Precast Reinforced Concrete Perimeter Frames*", PCI Journal, Vol.40 No.1-3, pp 44-61, July-August 1995.

[23] LUSAS Software Manual, 2004.

[24] Zienkiewicz, O.C., Taylor, R.L., "*The Finite Element Method for Solid and Structural Mechanics*", Sixth ed., Elsevier, 2005.

[25] Leong, D.C.P, "*Behaviour of Pinned Beam to Column Connections for Precast Concrete Frames*", Msc.Thesis, University Teknologi Malaysia, 2006.

[26] Sucuoglu, H., "*Effect of Connection Rigidity on Seismic Response of Precast Concrete Frames*", PCI Journal, Vol.40 No.1-3, pp 94-103, January-February 1995.