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Strength Effect of Different U-Shaped HDR Thicknesses in Hook-End Precast Beam-Column Joint: A Nonlinear FE Analysis

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Abstract. A precast reinforced concrete frame constructed with new hook-end joint at both beam-column connections was numerical modelled and analysed using Finite Element Method, for its overall strength attainment under the action of horizontal cyclic loading. Five different thicknesses of U-shaped HDR, ranging from 15 to 35 mm thick in 5-mm intervals, were assigned in the numerical model as the vibrational absorber component in between the hook-end beam-column joints. The numerical force-displacement curves showed that precast frame with various thicknesses of U-shaped HDR had similar shape of hysteresis loops among each other. However, the precast frame with 25 mm thick of U-shaped HDR at its hook-end beam-column joint demonstrated the capacity to fulfil the highest force and displacement demands when compared with other thicknesses of HDR.

1 Introduction

High damping rubber (HDR) has been commonly being used as one of the damper materials at the foundation or connection of building structures [1-3] in seismic area and bearing of bridge girders. It is because HDR, as one of the viscoelastic material offers the advantage of reducing vibrations over a broad range of frequencies compared with tuned mass damper [4]. Furthermore, the use of viscoelastic materials is a cheap method to increase the damping of a structure if incorporated during construction [5]. However, the cyclic performance of a structure equipped with rubber damper may be affected by its thickness, other than the structural configuration and material properties of HDR. It is because sufficient thickness of rubber provides adequate deformation space and stiffness between the connected members [6]. Therefore, it can prevent serious local damage of concrete at the interspace between the connecting members.

Lu *et al*. [6] utilized 50 mm thick of rubber blocks to prevent local failure of concrete at the interspace between the precast prestressed column and base. Xing *et al*. [7] conducted

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dynamic stability study on various rubber damper thicknesses with shape factors ranging from 3.75 to 7.5, and found that instability in individual rubber bearings does not necessarily lead to global system instability. However, Banisheikholeslami *et al.* [3] found no sensible change in behavior of the steel beam-column connection equipped with different rubber damper thickness. It is because the opposing effects from the reduction of shear strain in thicker rubber layer and the increment of dissipated energy due to larger volume of thicker rubber, neutralize each other. Therefore, in this paper, the effect of HDR thickness in the newly developed hook-end joint is investigated in order to determine its optimum cyclic performance to a precast reinforced concrete frame structure.

2 Description of specimen

In this study, a precast reinforced concrete frame with dimensions of 2.3 m × 1.905 m was constructed with hook-end joint at both ends of precast beam and corbels. The hook-end configuration was intended to provide an interlocking mechanism between the precast beam and column components whilst maintaining the ease of installation, structural stability and integrity of the precast structure. The gap between the two hook-end components was filled with U-shaped HDR to provide some degree of translation and rotational restraints to the connected members under the action of cyclic loading. In addition, it reduces the potential points of impact and concrete crushing between the members.

Fig. 1 illustrates the reinforcement detail of the precast frame with hook-end beam-column joints. Both precast columns were in fixed connection at the bottom. A 500 kg of additional weight was loaded on top of the precast beam to simulate slab loading to the beam, as shown in Fig. 2. Displacement based cyclic loading was exerted at the mid span of the precast beam with its load profile illustrated in Fig. 3 according to ACI T1.1-01 [8].

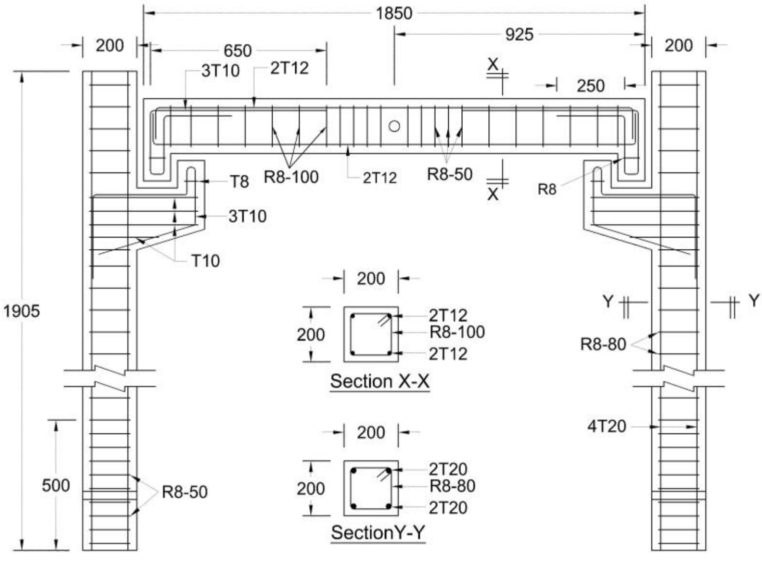

Fig. 1. Reinforcement detailing of precast frame with U-shaped HDR beam-column joint.

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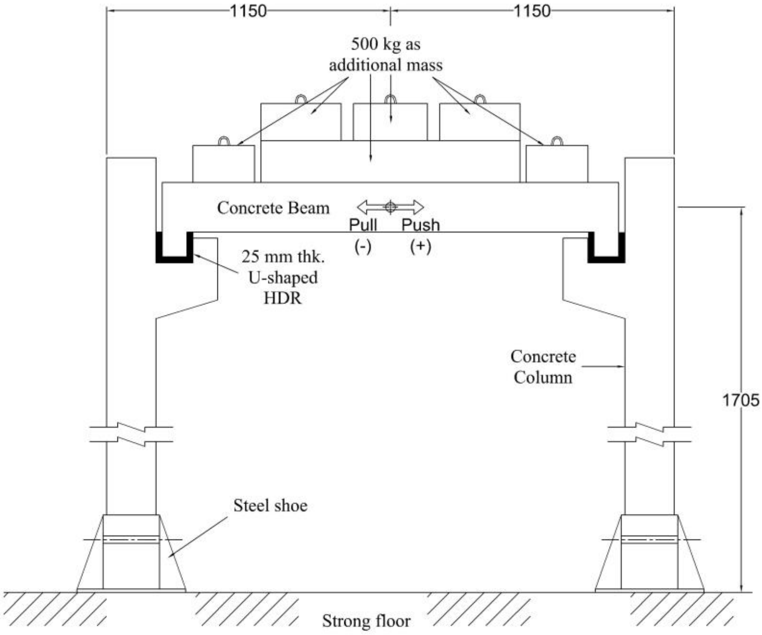


Fig. 2. Tests setup for precast frame with U-shaped HDR beam-column joint.

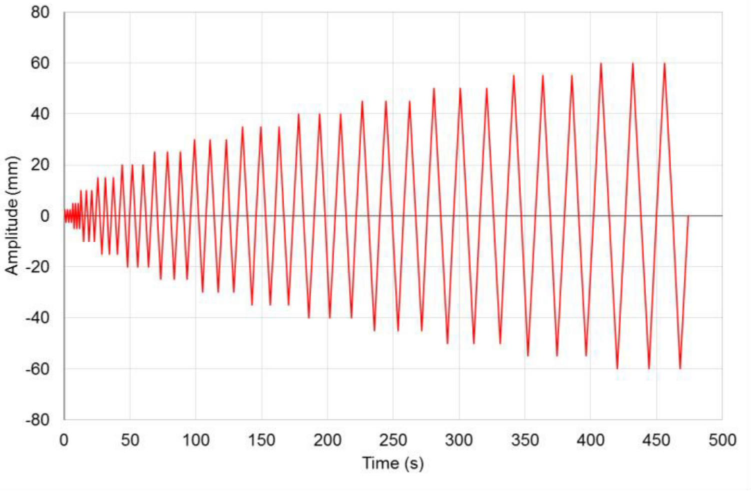


Fig. 3. Load profile of horizontal cyclic test [8]

3 Numerical modelling

A numerical model for precast frame with hook-end U-shaped HDR beam-columns joints, was developed using ABAQUS finite element analysis (FEA) software. Five different thicknesses of U-shaped HDR, ranging from 15 mm to 35 mm thick were involved in the numerical analysis. Table 1 lists the designated name of the numerical specimen.

Table 1. Numerical specimen name with its respective HDR thickness

Numerical specimen	NU-01	NU-02	NU-03	NU-04	NU-05
Thickness of U-shaped HDR (mm)	15	20	25	30	35

3.1 Material properties and types of element

The beam and column components were assigned with concrete C25/30 material using Concrete Damage Plasticity Model [9] to simulate its nonlinearity behaviour. The density, Young's modulus and Poisson ratio of the concrete were taken as 2500 kg/m^3, 26.4 GPa and 0.2, respectively. The compressive and tensile stress-strain relationships for concrete C25/30 were derived based on Hsu and Hsu model [10] and Wahalathantri *et al.* [11]. Classical Plastic Model was used to model the steel reinforcement. Table 2 summarises the properties of steel reinforcement used in the numerical modelling. The properties of HDR identified by Marshall [12] were adopted.

Both beam and columns were modelled in C3D8R elements (8-node linear bricks with reduced integration). The U-shaped HDR was modelled in C3D8RH elements (8-node linear bricks with reduced hybrid integration). The steel reinforcement was modelled by T3D2 elements (2-node linear 3D truss).

Table 2. Properties of steel reinforcement

Steel grade	**Density (kg/m^3)**	**Young modulus, E (kN/mm^2)**	**Poisson ratio, ν**	**Yield stress (N/mm^2)**	**Plastic strain**
High yield steel	7850	200,000	0.3	400 460	0 0.156
Mild steel				200 250	0 0.13

3.2 Interaction properties

Embedded element was selected to model the non-slip reinforcement condition at the interaction between the concrete and steel reinforcement. Meanwhile, the interaction between the U-shaped HDR and concrete surfaces was defined with a friction coefficient value of 0.59 in the tangential direction.

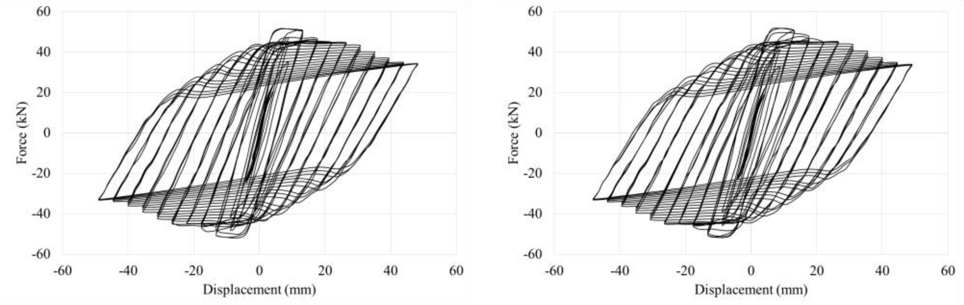
3.3 Finite element mesh sizes

All the components in the numerical model were meshed using the structured and free meshing technique. For beam and column components, mesh sizes of 50 mm × 50 mm × 50 mm were assigned in all regions, except at regions subjected to more tensile cracking and tremendous strain changes, where mesh sizes of 25 mm × 50 mm × 50 mm were assigned. Mesh sizes of 5 ~ 12 mm × 25 mm × 25 mm were used to assigned to represent the U-shaped HDR.

4 Numerical results

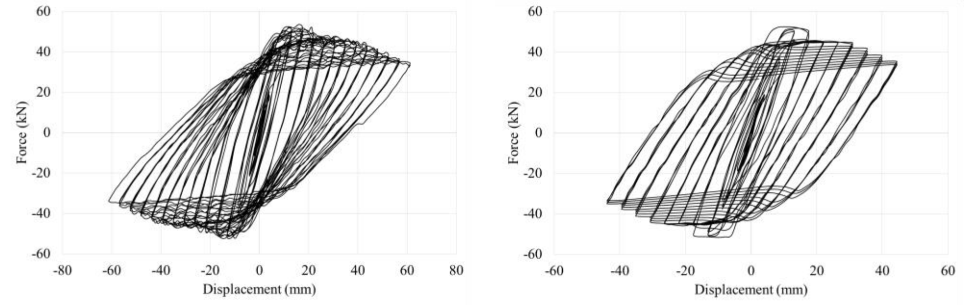
The strength effect of 15 mm, 20 mm, 25 mm, 30 mm and 35 mm thickness of U-shaped HDR to the hook-end precast frame under the horizontal cyclic loadings, were numerically analysed. The numerical analysis on the horizontal cyclic load test stopped when more than 20% of strength degradation was observed [13] or due to convergence problem aroused.

The force-displacement loops of each numerical specimen are presented in Fig. 4. It can be seen that the shape of the hysteresis loops are similar among each numerical specimen although different U-shaped HDR thicknesses were assigned in the analysis. Fig. 5 plots the force-displacement envelope for the numerical specimens and Table 3 tabulates their corresponding maximum force and displacement at the maximum force. It can be seen that minor differences were found between their force-displacement performance. However, the 25 mm thick U-shaped HDR provides the highest maximum force when compared with specimens of other thicknesses.



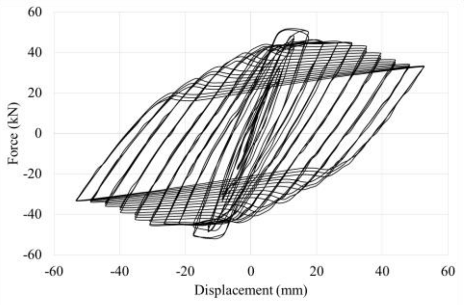
(a) NU-01

(b) NU-02



(c) NU-03

(d) NU-04



(e) NU-04

Fig. 4. Force-displacement diagram for numerical specimens with different thickness of U-shaped HDR

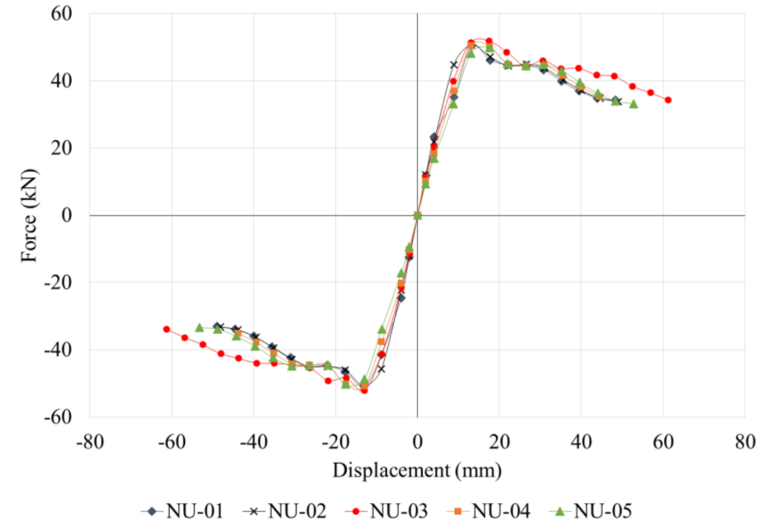


Fig. 5. Force-displacement envelope for numerical specimens with different thickness of U-shaped HDR

Table 3 also lists the normalized maximum force for each U-shaped HDR, F_{max} with respect to the corresponding maximum force for 25 mm U-shaped HDR thick, $F_{max,u}$. It can be seen that 25 mm thick of U-shaped HDR pad exhibits a 3% to 5% higher maximum strength than specimens of other HDR thickness. The phenomenon of thicker U-shaped HDR rubber in the hook-end beam-column joint has decreasing strength is similar to the parametric study by Kremmyda *et al*. [14]. However, the numerical results do not tally with Kremmyda *et al*. [14] when thinner U-shaped HDR pads were used. This is probably due to the hook-end connection not utilizing any dowel bar at the precast beam-column joint to achieve the shear strength. Whereas, the strength of the precast reinforced concrete frame studied in this research is depending on the hook-end connection system, which utilized U-shaped HDR as the vibration absorber component.

Table 3. The maximum force and maximum displacement of numerical specimens with different U-shaped HDR thicknesses.

Numerical specimen	**Maximum force, F_{max} (kN)**		**Displacement at F_{max}, Δ_{max} (mm)**		**Normalized maximum force, $F_{max}/F_{max,u}$**	
	Push	**Pull**	**Push**	**Pull**	**Push**	**Pull**
NU-01	50.51	-50.78	13.13	-13.13	0.962	0.975
NU-02	50.71	-50.69	13.11	-13.12	0.966	0.973
NU-03	52.50	-52.09	14.75	-13.00	1.000	1.000
NU-04	50.59	-50.75	13.06	-13.05	0.964	0.974
NU-05	49.90	-50.27	17.56	-17.56	0.950	0.965

5 Conclusion

The strength effect of five different thicknesses of U-shaped HDR, ranging from 15 mm to 35 mm with 5 mm of interval thickness, for precast hook-end beam-column joint were analysed numerically and evaluated. The specimens yielded approximately similar force-displacement hysteresis curves among each other. Under the application of horizontal cyclic loading, the 25 mm thick U-shaped HDR specimen yields approximately 3% ~ 5% and 20% ~ 25% higher strength than the precast frame that adopted the other U-shaped HDR thickness.

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