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To Evaluate Seismic Performance of Special Moment Resisting Frames by Retrofitting beam Column joints using Haunch An Experimental and Numerical approach

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Abstract: *This retrofitting method comprises of installing haunches at the beam column joints of a reinforced concrete frame, in order to modify structure's response to seismic hazards. The experimental program consists of two small scale models of one third of the actual structure sizes. The specimens were brought under construction at the civil engineering department, UET Peshawar. Test frame comprised of a regular reinforced concrete frame and a frame with haunch at various connections which were installed for the purpose of providing ample amount of joint rigidity to the structure. Using a natural accelerogram compatible to the design spectrum dynamic test were carried out with increasing levels of shaking. Dynamic characteristics were calculated for each phase of free vibration before and after every intensity check. Haunch sizes were computed on trial and error basis considering 60 percent of the excitation provided by the shake table. Displacement transducers and accelerometers were attached to the models for recording the structural response in terms of displacement and acceleration time histories. After the analysis the data was processed further to compute certain parameters including inter storey shears and base shear. Also the drift profile and the lateral deflected shape of the structure were obtained giving insight of the structure's behavior. Capacity curve was plotted co-relating the base shear with the lateral displacement. The research showed experimentally and numerically that the proposed retrofitting technique worked well in reducing the joint damageability of the RC frame structures enhancing the seismic capacity. The technique ensures safety for the occupant's lives during any devastating disaster promising less loss of economy and human lives in future.*

Keywords: *Seismic Performance; Joint Damage; Retrofitting; Haunch; shake table test*

"I. INTRODUCTION"

In 2005, on October 08 an earthquake of magnitude, $M_w = 7.6$ hit northern region of Pakistan and Kashmir. About 70,000 people lost their lives, thousands were injured and millions went homeless (Javed et al. 2016).Similar deadly and devastating failures had been observed also in other parts of the world as well.

Figure 1: Damaged beam column joints

While designing reinforced concrete frame structures it must be ensured to avoid global failure/brittle failure mechanisms incorporating ductile behavior in members. Member proportions should be made such that the reinforcement in the structure should reach its yielding point before concrete reaches its maximum limiting strain (i.e. core crushing). Thus avoiding shear failure of beams and columns.

Beam column joint is the most critical part of the structure. Its behavior during earthquake excitation has a crucial impact on the overall global response of the structure. To ensure sufficient deformability and strength with in the joints, various codes recommend incorporation of transverse reinforcement to enhance performance. Formation of plastic hinge in column members needs to be avoided to prevent sudden collapse of RC frame keeping capacity design recommendation in mind.

Figure 2: 1999 Chi-Chi Earthquake (Taiwan) *Figure 3: Wenchuan earthquake 2008 Insufficient confinement in the joint*

"II. EXPERIMENTAL PROGRAM"

"A. Idealization of Model"

For shake table testing 1:3 reduced scale model were used with simple model idealization .The beams, columns and slabs were scaled down and diameters of the bars were also reduced by one third of actual size as per similitude. A mix proportion of 1:1.80:1.60 (cement: sand: aggregate) with w/c 0.48 had been used to achieve 3000 psi (21 MPA). Base pad with depth 16" and length 8' was constructed. Width of the base pad was 20". Column steel was hooked properly at the base pads in order to avoid pulling out of steel during the test is being carried out. For a rigid fixation of the base pad to the shake table holes of diameter 3/8" are provided in both directions.

"B. Details of Experimental work"

In the present study, a one third reduced scale model with soil type B (Sb) on the basis of BCP 2007 and NEHRP was used. The RC model consists of one bay in Y direction and two bays in X direction. Frame was two storied. The seismic zone was 4 which mean 0.4g as per the code requirements. The size of the shake table used was 1.5m x 1.5m with a load carrying capacity of 8 ton. Due to limitation of the shake table size the middle frame will be extracted for analysis.

Table 1: Scale Factor Used

Physical Quantities	Relationships	Scale Factor
Length (l)	$Sl = Lp/Lm$	3
Stress, Strength (f)	$Sf = fp/fm$	1
Strain	$S\mathcal{E} = \mathcal{E}p/\mathcal{E}m$	1
Specific Mass	$S\rho = \rho p/\mathcal{E}m$	1
Displacement (d)	$Sd = dp/dm = S1$	3
Force (F)	$SF = Fp/Fm = S_1{}^2Sf$	9
Time (t)	$St = tp/tm = S_1\sqrt{(\frac{SeSp}{Sf})}$	3
Frequency (f)	$S\Omega = \Omega p/\Omega m = 1/St$	0.33
Velocity (v)	$Sv = vp/vm = \sqrt{(\frac{SeSp}{Sf})}$	1
Acceleration (a)	$Sa = ap/am = Sf/SSp$	0.33

"C. Pretest Analysis"

In this section preliminary calculations were made for designing the haunch. Dimension/ size of haunch was determined by trial calculations. The design was finalized by modelling RC haunches in Seismostruct. Design considerations are already mentioned in the table given below.

Table 2: Material properties

Material Properties		
Material	**Properties**	**Consider Value**
Concrete	Concrete Compressive Strength, fc'	2000 psi (14 MPa)
	Concrete Modulus Of Elasticity, Ec	3122018 psi
	Weight Per Unit volume	150 pcf
Steel	Steel Type	Grade 60,ASTM A615
	Reinforcement Yield Strength fy	60,000 psi (414 MPa)
	Steel Modulus Of Elasticity, Est	29000,000 psi
Site	Zone	4
	Soil Type	Sb

In order to achieve firm connection between the model and shake table, threaded rods were used for fixity. The section detailing is also given in figure 4.

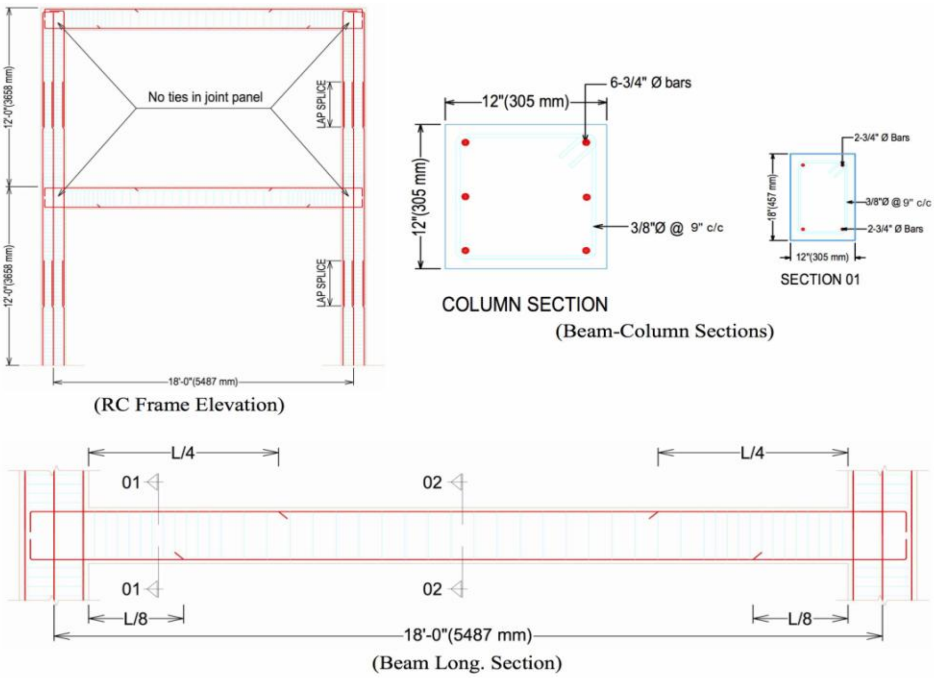


Figure 4: Section properties of beam and column

“D. Model Construction”

Concrete was prepared with the ratios of 1:3.5:2.87 with water to cement ratio of 0.8 according to the American concrete institute (ACI). In order to achieve strength of 2000 psi (14 MPa) the maximum aggregate size used was 3/8 inch down. A foundation pad with was 8 ft. long was used as a firm foundation for the super structure. Having a depth of 16 inch and width of 20 inch. This depth avoided the pulling out of column off the base pad during dynamic testing. Reinforcements were cut for making stirrups and longitudinal reinforcement. Column and beam longitudinal reinforcements were then caged in stirrups with 1” spacing. Form works of steel were set up and concreting was done. While the concreting of each storey, 3 specimens of concrete cylinders for every storey were casted and set aside for curing purpose. After gaining early strength the cylinders were tested one by one on the Universal testing machine for average compressive strength. The haunch bars were introduced in slab and column so that there should be proper fixity of haunch and the structure. Then the concrete was poured in the haunches. For making rigidity in connections to ensure rigidity of the holes epoxy was used for the haunches. Once the model construction ,28 days curing and white washing was completed, it was shifted to Earthquake Engineering Lab with the help of 20 Tons overhead crane.

“E. Allocation of Haunch”

After carrying out the design in seismostruct the haunches were installed at the locations shown in the plane frame. Details can be seen in the image below.

Figure 5: Location of Haunches

"F. Instrumentation of Model"

1. The model was fixed on the shake table by means of an overhead crane. Since some portion of it was projecting outward, a steel stool was used which acted as a roller support to the projected portion.
2. For the measurement of input time histories, five accelerometers were used. Capacities of the accelerometers and the displacement transducers were ±10g and ±12g respectively.
3. Two displacement transducers and accelerograms at each storey and one at the foundation were attached to the model for recording the response. Images below clearly show the locations of Accelerometers and displacement transducers.

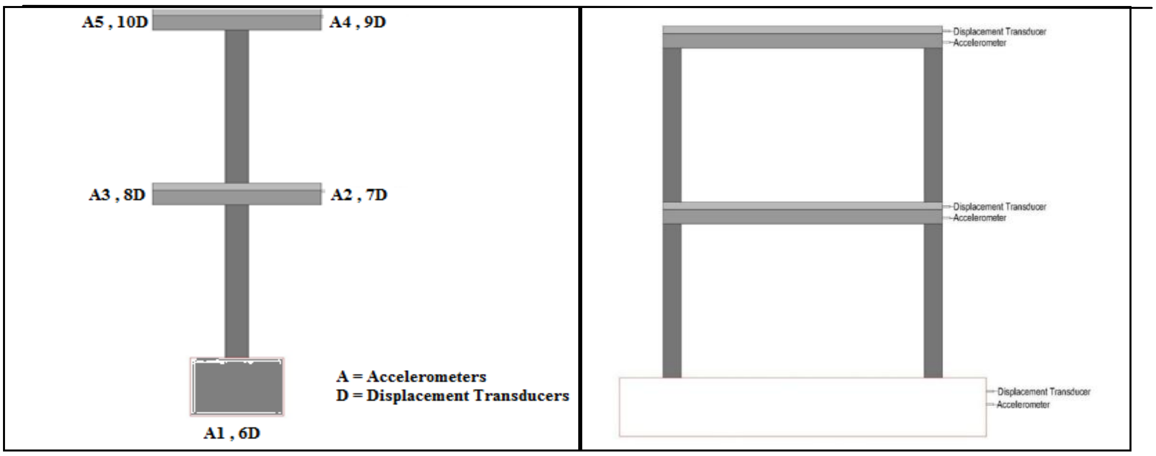


Figure 6: Location of Accelerometers and displacement transducers

"G. Input Excitation and Loading Criteria"

1. PEER NGA was the base of extracting data (natural acceleration time histories) for the Northridge 1994 time history. The accelerogram is shown in figure 7.
2. A software called seism-match was used to make the data compatible to building code of Pakistan 2007
3. Shaking intensities with doubling the percentage of increase at each stage were used as inputs for applying artificial earthquakes the oder was 5%,10%,20%,30%, 40%, 50%,60% till the structure collapsed.

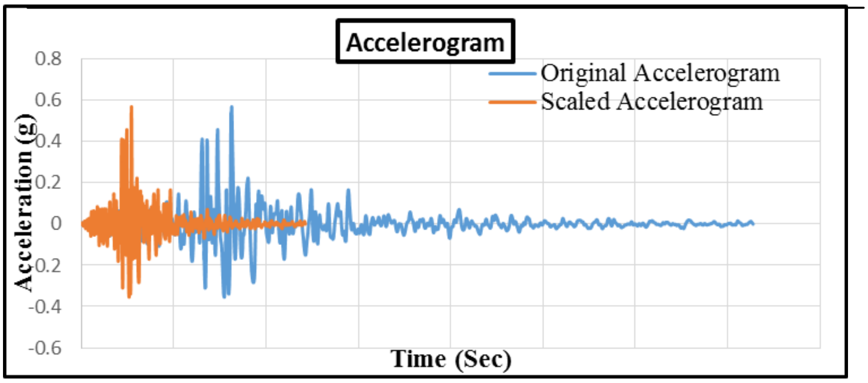


Figure 7: Accelerogram of Northridge 1994

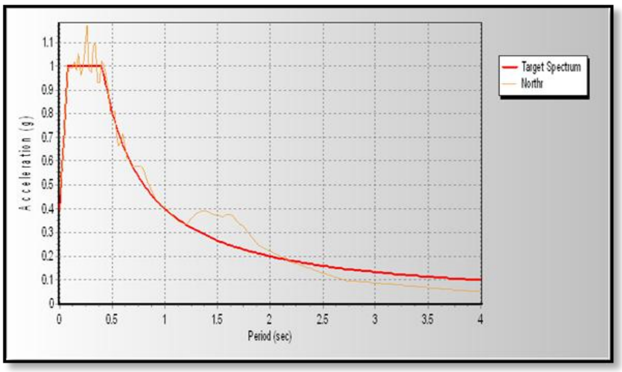


Figure 8: Accelerogram matched with Northridge 1994

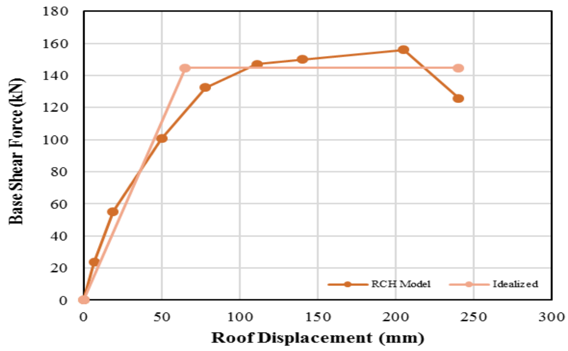


Figure 9: Experimental Capacity Curve

Figure 9 shows the response correlating base shear and the roof displacement. The curves show the idealized and actual structural response after the structure has undergone artificial seismic excitation. Table 6 comprises of seismic parameters of the as built and retrofitted model. It clearly depicts that inelastic seismic performance of the structure has shown considerable amount of increase in the R factor i.e. the response modification factor.

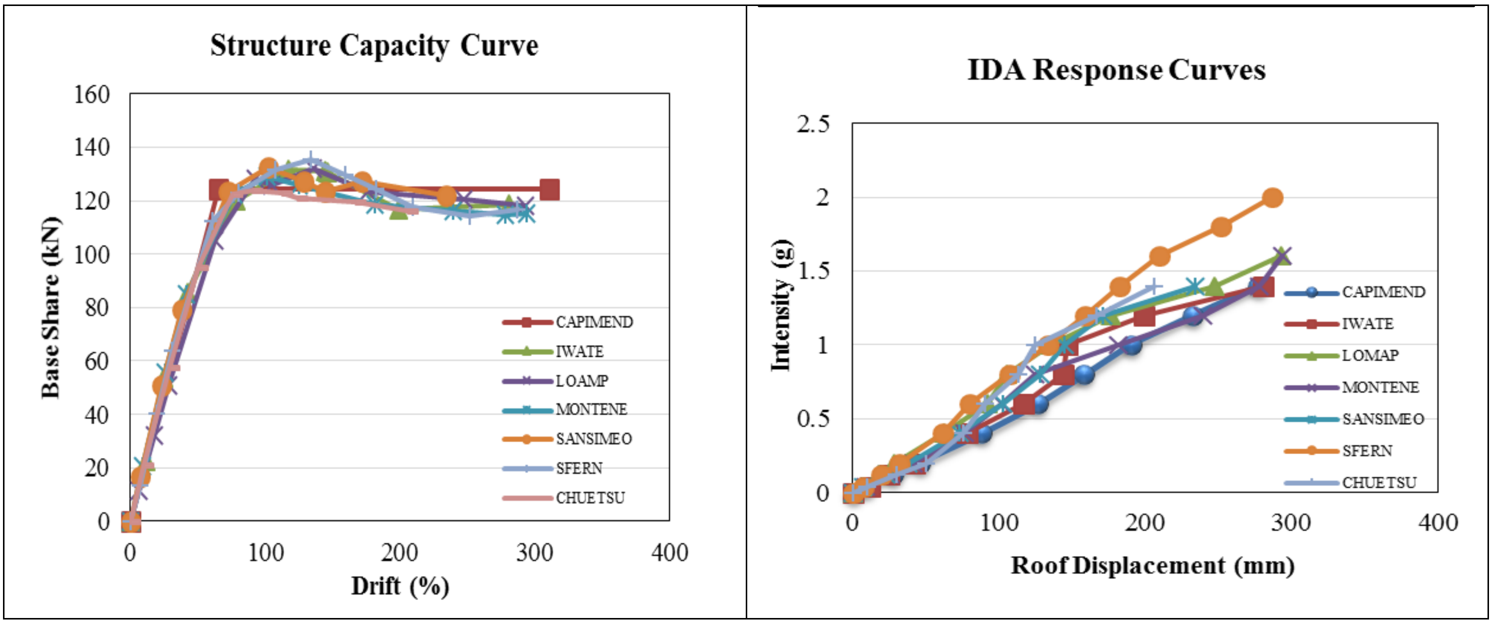
Table 6: Seismic parameters of as built and retrofitted model

As Built Model		Retrofitted Model	
Yield Stiffness (N/mm)	835.30	Yield Stiffness(N/mm)	2227.688
Ductility	1.354	Ductility	2.8137
Rμ	1.354	Rμ	2.8137
Rs	2.1461	Rs	2.7556098
VD (KN)	52.54	VD (KN)	52.544
R factor	**2.907**	**R factor**	**7.753**
W prototype	28	W prototype	28
Ty (sec)	1.1503	Ty (sec)	0.7044

"H. Results from Numerical Simulation"

The plots show the incremental dynamic analysis. This analysis was performed on the model that was retrofitted using haunch for increasing efficiency of the structure against lateral deformation.

Figure 10: Capacity and IDA curves



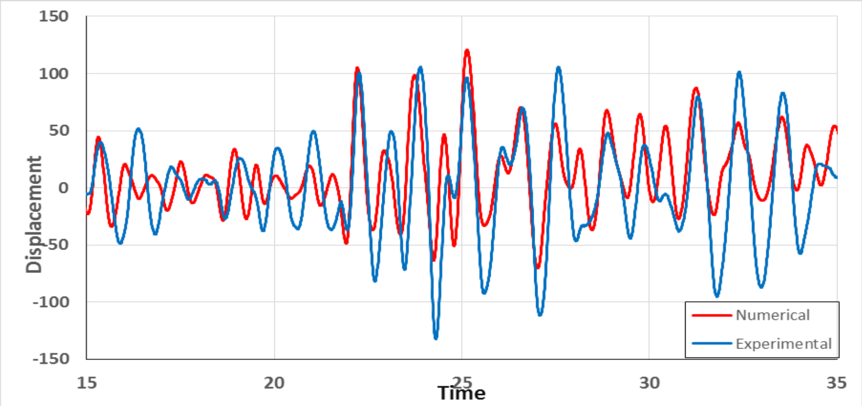


Figure 11: Result showing numerical and experimental values of displacements

"III. CONCLUSION"

After the experimentation and making various observations it was concluded that haunch were effective in resisting lateral loads upto greater extent. The structure was considered much safer in the earthquake. The safety percentage was predicted upto 80 %.

Upto 60 % no spalling and core crushing was observed. As required the stiffness and strength of the structure was increased. There was a considerable reduction in strains at the beam column connections. The joint panel zones were made much safer due to the haunches. The value of response modification factor was increased upto 7.5

"A. Recommendations for Future Work"

Haunches can be further examined for their performance when tested under Quasi static loading. Using variable dimensions of haunch parametric studies can be made. Seismic performance can be evaluated by varying the location of the haunch while changing the loading criteria.

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