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Evaluation of Response Modification Factors for RCC Frame Structure

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Abstract — *This paper presents research carried out on beam column connections of Reinforced Concrete Structures to evaluate Response Modification Factors. R factors are important seismic design tools, which characterizes the level of inelasticity expected in structural framework thought an earthquake incident. R factor reflects the capacity of structure to dissipate energy through inelastic behavior. R factor is utilized to decrease the design forces in earthquake resistant design, accounts for energy dissipation capacity, damping and for over-strength of the structure. RCC beam column connections were subjected to quasi-static testing procedures and the data collected using data acquisition system was analyzed to compute structural parameters including R-factor. It has been concluded that Scatter value of R exists as compared to a single value of R= 8.5 being adopted in BCP SP-07.*

Keywords- *RC structure, R-factor, Quasi-static test, BCP SP-07.*

I. INTRODUCTION

Pakistan lies at the collision boundaries of Indian, Eurasian and Arabian tectonic plates [1]. This region is more vulnerable to earthquakes [2]. Quetta earthquake of 1935 having magnitude of 7.7 Mw was the first devastating earthquake in this region which had killed about 30,000 and 60,000 people [3]. In 2005 Kashmir earthquake of magnitude 7.6 Mw, due to damage of 450,000 buildings, more than 80,000 people were killed and about 2.8 million people became homeless [4]. Pakistan is a developing country and 6th most heavily populated country of the world [5]. For reinforced concrete members Ultimate strength design is based on inelastic performance of materials. Equivalent Lateral Load and Response Spectrum Analysis methods are actually based on elastic static analysis which is by far the most used methods for evaluating earthquake resistance and design of structures since they are. However, they do not reflect the complex building behavior subjected to earthquake ground motions. A new procedure called Performance Based design is now gaining the popularity, stepping more advanced of above-mentioned elastic procedures by performing the inelastic static analysis (pushover) fundamentally in design process. In order to achieve this particular goal, an experimental test (quasi static test) performed on RCC code compliant beam column connection. Consequent to this hysteresis loop and back bone curve established from which response modification factor evaluated in terms of over strength factor and ductility factor.

II. BASIC TESTING ON MATERIALS

A. COMPRESSIVE STRENTH OF CONCRETE

Total 06 number of concrete cylinders were casted in order to ensure the 28 days compressive strength according to ASTM-39 for the development of material model of the concrete. The batching proportion of 1: 1.99: 2.55 with the 0.45 cement ratio used to achieve the 4000-psi concrete strength. As per ASTM-39 concrete cylinders having a length of 12 in and dia of 6 inches were casted, cured and tested after 07 days and 28 days for compression in Universal Testing Machine (UTM) as shown in Figure 1 and 2. The results of the compressive strength test are shown in Table 1.

Table 1: Compressive strength values for concrete

S.No	Designation	After days	Load (ton)	Area (in^2)	Compressive Strength (fc') ksi	Average Compressive Strength (ksi)
1.	Sample 01	07	38	28.28	39.7	39.53
2.	Sample 02	07	42	28.28	38	
3.	Sample 03	07	41	28.28	40.9	
4.	Sample 01	28	42	28.28	46.2	48.00
5.	Sample 02	28	38	28.28	48.4	
6.	Sample 03	28	38	28.28	49.4	

Figure 1: Testing of Concrete Cylinders

B. YIELD STRENTH OF STEEL

The structural steel was purchased from Peshawar city with a mild-steel composition and yield strength of 40 ksi complying with ASTM-615. In RCC Beam column connection 6/8 in Dia bars were used as longitudinal bar and 3/8 in bar Dia were used as tie bars. The average yield strength of steel reinforcement samples is 55162 psi which is more than the minimum requirement of 40000 psi for 6/8 in Dia bar.The average yield strength of steel reinforcement samples was 50059 psi which was more than the minimum requirement of 40000 psi for 3/8 in Dia bar. The steel bars were tested in UTM as shown in Figure 2.

Figure 2: Testing of Steel Bars

III. MODEL DESCRIPTION

Two samples of beam column connection of same configuration and material properties as per code compliant model were tested in the loading frame of structural lab, Department of Civil Engineering, University of Engineering and Technology Peshawar. The model consists of 8 feet long beam and 9 feet long column having cross sectional Dimension of 12 in X 18 in beam and cross sectional Dimension of 12 in X 12 inch column where beam was connected to column at mid height. The beam is reinforced with 3, #6 bars at both top and bottom and shear reinforcement with 3/8 inch Dia is provided having center to center spacing of 3 inch near the beam column connection up to 3 feet from the face of the support. For rest of the beam length, the shear reinforcement 6 inch center to center spacing provided and all the stirrups are bent 135o as per SMRF detailing requirements. Similarly the column longitudinal reinforcement consists of 8, #6 bars equally distributed along the perimeter of the column and shear reinforcement of 3/8 inch Dia is provided as closed ties equally spaced throughout the length of the column at center to center spacing of 3 inch. In joint region ties of 3 inch spacing center to center are provided with 135^o bends as per SMRF requirements. Concrete used in both models had a compressive strength of 4000 psi and reinforcement conformed to ASTM-A615 had a yield strength of 40000psi. The scheme of construction of testing models is shown in Figure 3.

Figure 3: Model Construction

IV. TEST SETUP

The schematic representation of the code compliant model represents the beam column connection shown in figure 3.8 where beam has length of 8 feet length and column has a length of 9 ft. The beam has cross sectional area of 12(Width) X18 (Depth) and column has cross sectional area 12in X 12in. The beam is reinforced with 3, #6 bars in the bottom and 3, #6 bars in the top region while The column is reinforced with 8, #6 bars throughout the perimeter of the column.
Quasi static test was used to determine the cyclic behavior of the RCC beam column connection. It can be used by two methods, Displacement controlled method or force-controlled method. Displacement controlled method is commonly used to study the post peak behavior. The main purpose of quasi static test is to determine the force deformation curve, elastic stiffness, lateral strength and ductility ratio. Test setup is shown in Figure 4.

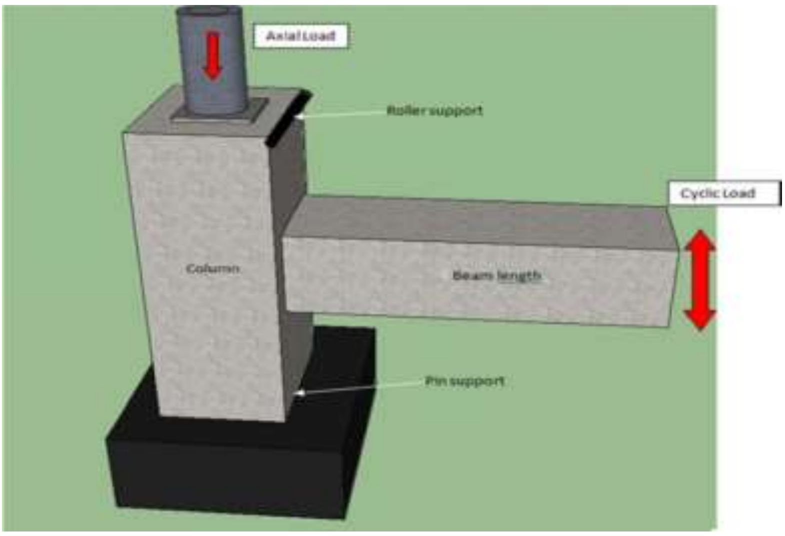

Figure 4: Testing Setup/ Procedure

V. MODEL TESTING

Prior to the application of the vertical and lateral loading on the RCC beam column connection, various loading stages in the form of Drift ratio (in percentage) were finalized as 0.25%, 0.5%, 1.0%, 1.5%, 2.0%, 2.5%, 3.0%, 3.5%, 4.0%, 4.5%, 5.0%, 5.5%, 6.0%. Reverse cyclic load was applied to the beam end of the beam column connection where positive loading indicates a push on the beam end downward direction and negative loading depicts the upward direction. The damage pattern of the tested models are shown in Figure 5.

Figure 5: Damage pattern of tested models

VI. RESULTS AND DISCUSSIONS

The force deformation hysteresis loops, force deformation envelop curve and bilinear idealized curves of tested code compliant models discussed below. Hysteresis loops were constructed from the Data analysis of experimental Program. An Excel sheet in Visual Basic Application (VBA) was used to filter the raw data, convert the data to plot the hysteresis loops of the specified gauges. Back bone curve was constructed from hysteresis loops for positive and negative cycles. It was developed by joining the points of maximum value of lateral loads of each hysteresis loop cycle. Average envelope curve was developed from positive and negative envelope curve.

The data obtained from the test was analysed and the load and displacement was plotted against each other for every cycle to obtain the hysteresis loop. From the hysteresis loop back bone curve was obtained which was then idealized bi-linearly, as shown in Figure 6 for specimen 1. From the idealized plot the structural parameters i.e. R-factor was obtained as shown in Table 2.

Table 2: Structural Parameters

Specimen ID	Effective Stiffness KN/MM	Displacement Ductility μ	R Factor=$(2\mu-1)^{1/2}$
Sample 01	*1.096*	*2.39*	*1.94*
Sample 02	*1.109*	*2.501*	*2.004*

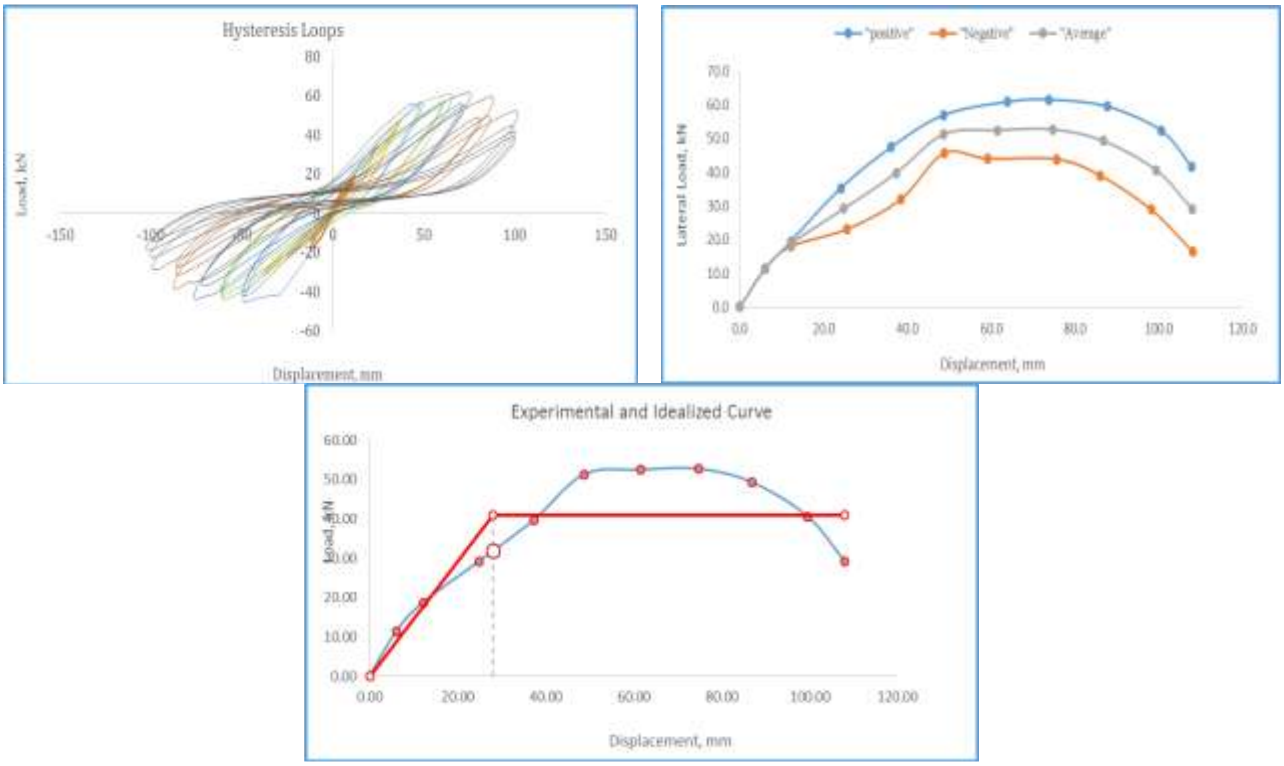

Figure 6: Hysteresis loop, back bone curve and bi-linear idealized plot for specimen-1

The following conclusions and recommendations were made from the testing of the specimens:

1. Mode of Damage Pattern in beam-column joint region does not change even though the change in compressive strength of the concrete.
2. This research model force deformation curve shows better load carrying capacity and initial stiffness as compared to EJ-IA Model which was casted for 2000 Psi compressive strength of the concrete (Previous Research Model).
3. The determination of the ductility factor from the back bone curve does not show the failure type either it will be in shear joint or beam hinging.
4. It has been concluded that Scatter value of R exists as compared to a single value of R= 8.5 being adopted in BCP SP-07.
5. Minimum requirement of the column depth 15db as per SMRF requirements should be increased to 20db to ensure beam hinge mechanism during Earthquake.

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