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# Experimental Seismic Performance Evaluation of Bridge Piers Constructed In Low Grade Concrete

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***Abstract:*** *Sometimes very low strength concrete is encountered in bridges especially in developing countries. One of the reasons for such situations is that various processes, such as the preparation, placing, compaction, etc, is supervised by non-engineering staff. Such type of bridges performs poorly during seismic events. It is, therefore, important to study the seismic performance of such bridges and quantify the energy dissipation characteristics. Two scaled (scaling factor 1:4) bridge columns were fabricated for this purpose with target strength of 12.4 MPa. The columns were tested by subjecting them to reversed quasi-static cyclic loading. Hysteretic energy dissipation curves were plotted with the load-displacement data recorded during testing. The energy dissipated in each cycle and cumulative dissipated energy was calculated for establishing the seismic capacity. The study also provided the ultimate displacement capacity of these columns which is useful for designers to keep limits on target ductility while designing new columns or calculating safety margins of existing bridges.*
***Key Words:*** *Hysteresis, bridges, columns, quasi-static cyclic testing, energy dissipations, low strength.*

## I. Introduction

The earthquakes cause ground motion and these ground excitations impart inertial forces to bridge system. The ground motion results in significant lateral loading [1] on the bridge which is to be resisted by columns. Single column bridges have only one load path and are very vulnerable due to lack of redundancy [2]. The plastic hinge results due to cracking of concrete and yielding of reinforcement. For economical design of a bridge against an earthquake, yielding and cracking is permitted [3]. The energy dissipation requires sufficient ductility without which the energy dissipation through the plastic hinge cannot be achieved [3]. The cracking and yielding occur in the plastic hinge zone of columns, where energy dissipation occurs through hysteresis [4], [5]. The motion is generally of reverse cyclic nature causing inelastic deformation [6]. In single column bridges having flexural dominance, plastic hinge is usually formed at the base of column [6].

This paper presents laboratory testing of two scaled very low strength RC bridge columns that have circular section. The columns were prepared after detailed field survey and it was seen that many bridges in northern part of Pakistan had strength below 17.2 Mega Pascals (MPa) and some even had strength as low as 13.8 MPa [2], [6]. Study of such bridges is important as Pakistan lies in highly seismic active area with potential of large seismic events [7]. The scaled columns of 12.4 MPa target strength [2] were fabricated to test them using the reverse quasi-static cyclic loading in the laboratories of Earthquake Engineering Center of University of Engineering and Technology Peshawar.

## II. Description Of Test Columns

The two columns represented the typical hammer-head bridge columns found in study areas in northern part of Pakistan and also found globally. The typical test setup is shown in Figure 1. The salient features are presented in Table 1. The features of test columns were deduced from the extensive field survey [2], [8] [9], [10], [11], [12].

**Table 1:** Identification of columns, target strength and mix design of concrete used for test columns.

| Item | QSCT-4-005 | QSCT-5-006 |
|---|---|---|
| Target concrete strength (MPa) | 12.4 | |
| Proportion by weight; Cement: Sand: Coarse Agg. | 1:2.15:4.3 | 1:2.15:4.3 |
| Water/Cement ratio | 0.58 | 0.58 |
| Average cylinder strength achieved (MPa) | 12.7 | 12.3 |
| Modulus of Rupture (MPa) | 3.6 | 3.6 |
| Modulus of Elasticity (MPa) | 16,816 | 16,527 |

*Fig. 1. Scaled RC bridge columns*

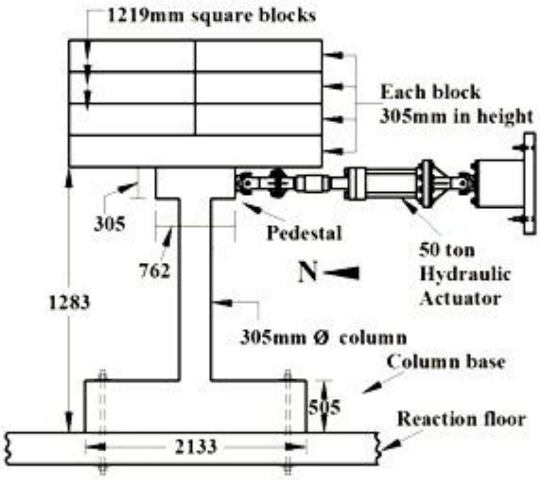


*Fig.2: Side view (Elevation) of the test bridge column*

**2.1 Scaling, Materials and Dead Load**

The scale factors were decided after similitude analysis and results are presented in Table 2. The side view of test column is presented in Figure 2 in which geometric details can be seen.

**Table 2:** Summary of scale factors used for test columns.

| Item | Scale Factor | |
|---|---|---|
| | Required | Provided |
| Length, $l$ | 4.0 | 4.0 |
| Area, $A$ | 16.0 | 16.0 |
| Moment of inertia, $I$ | 64.0 | 64.0 |
| Linear displacement, $D$ | 4.0 | 4.0 |
| Angular displacement, $\theta$ | 1.0 | 1.0 |
| Modulus of elasticity, $E$ | 1.0 | 1.0 |
| Stress, $\sigma$ | 1.0 | 1.0 |
| Specific mass for column only-static case, $\rho$ | 0.25 | 1.0 |
| Poisson's Ratio, $\nu$ | 1.0 | 1.0 |
| Strain, $\varepsilon$ | 1.0 | 1.0 |
| Concentrated load, $Q$ | 16.0 | 16.0 |
| Shear force, $V$ | 16.0 | 16.0 |
| Moment, $M$ | 64.0 | 64.0 |
| Mass on column top, $m$ | 16.0 | 16.0 |
| Gravitational acceleration, $g$ | 1.0 | 1.0 |
| Energy, $e$ | 64.0 | 64.0 |

From Table 2 it can be seen that scale factor for material properties $\lambda_E$ for concrete and rebar was taken as unity; this means no scaling of mechanical properties was done. This is generally recommended for inelastic testing [13]. The two columns QSCT-4-005 and QSCT-5-006 had target concrete strength of 12.4 MPa. The mix design for micro-concrete is presented in Table 1 and the mechanical properties of reinforcing steel used in test columns are provided in Table 3. The reinforcement detail of test column is shown in Figure 3, whereas Figure 4 shows the cross section of column. The required dead mass in test column was 19.24 tons and it produced the same level of dead load stresses as found in a typical prototype bridge column, it cab seen in the Figure 1.

**Table 3:** Mechanical properties of rebar used in test columns.

| Parameter | Value Rebar | Value Confinement |
|---|---|---|
| Type | Deformed | Plain |
| Diameter | 7.4 mm | 5 plain wires, each having 1 mm diameter |
| Number | 26 | |
| Spiral Pitch | - | 37.5 mm |
| Yield strength | 365 MPa | - |
| Ultimate strength | 485 MPa | 614 MPa |
| % elongation | 20.1% | - |

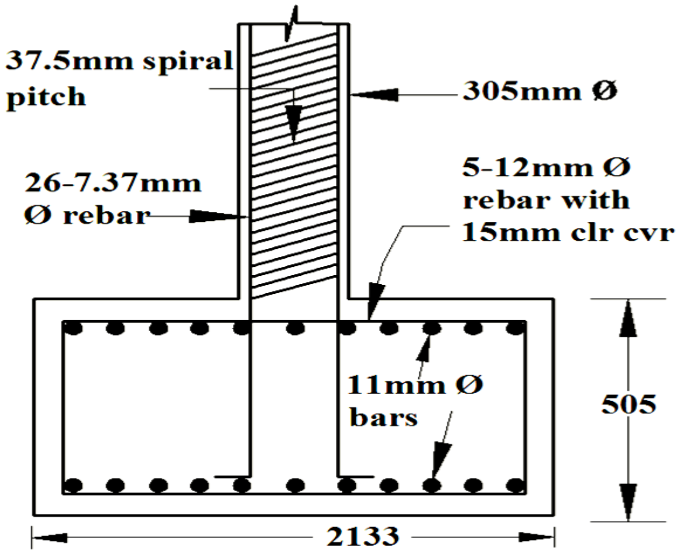


*Fig.3: Reinforcement details of bridge column*

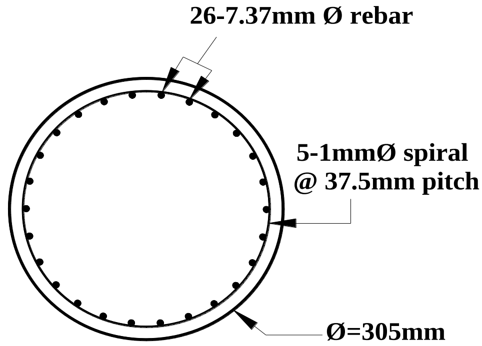


*Fig.4: Cross section of test column showing*

## III. Experimental Program

The reverse quasi-static cyclic testing was conducted in this study. Hydraulic actuator of 50 ton force capacity was used for lateral loading in longitudinal (North-South) direction. The corresponding displacements were measured at the midpoint of pedestal on column top as seen in Figure 2 and it is the centerline of lateral load applied by the hydraulic actuator.

### 3.1 Testing Rig, Instrumentation and Data Acquisition

The testing was done on reaction floor and reaction wall used for anchoring the test specimen and hydraulic actuator respectively as shown in Figure 1. The maximum stroke of the actuator was 305 mm. Two data sets were recorded; one was lateral force and second was displacement of the end of hydraulic actuator. The data was recorded using UCAM-70 data acquisition. In this testing, the data was sampled at frequency of around 1.5 Hz whereas the frequency of cyclic testing was around 0.0067 Hz, which shows that the sampling frequency was well above the Nyquist-Shannon sampling frequency [14].

### 3.2 Testing Protocol

The tooth-saw loading waveform in this testing was used as shown in Figure 5. Testing was to be done till at least 20% reduction in strength was observed, which means that during the test the maximum force was monitored for each cycle until a cycle experiences a maximum force that is 80% of the maximum force in the preceding cycles and is considered as failure point [4], [5]. In this scheme 2 cycles per drift were applied till the failure at 4% drift.

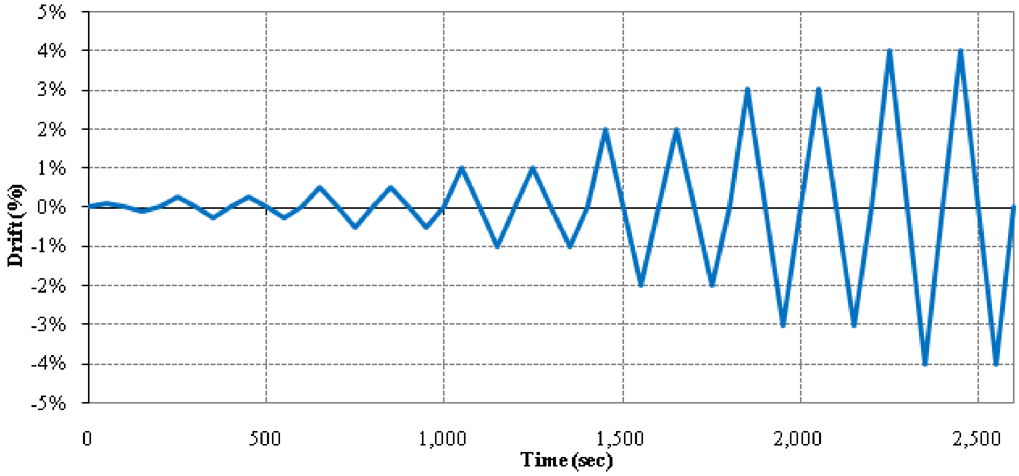


*Fig.5: Loading protocol used for testing the columns*

**3.3 Sign Convention**

A positive force is used to describe push of actuator in north direction on the column whereas negative force is for pull acting in south direction. In similar way, positive displacement is for movement of column in north direction and negative displacement is used for displacement in south direction.

## IV. Experimental Results

The two test columns are discussed here one-by-one.

**4.1 Column QSCT-4-005**

This column had 12.7 MPa cylinder strength when tested as per ASTM C39 [15] as described in Table 1. Refer to Figure 6 for the hysteresis curves for this column.

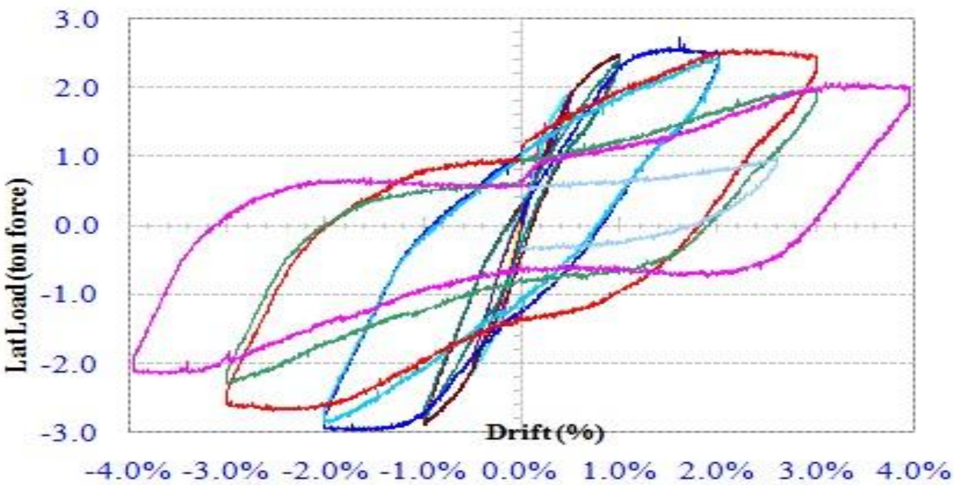


*Fig.6: Cross section of test column showing*

Due to reverse cyclic testing, hair line cracks appeared around 0.25% drift and were not visible. From the analysis of hysteresis curves it is seen that initial yield started at around 0.75% drift. Further from the analysis it is observed that for north direction initial cracking of concrete occurred around 0.25% drift, initial yield at 0.71% and yield at 0.82% and for the force applied in south direction the cracking occurred at 0.22%, initial yield at 0.78% and yield at 0.87%. The values for cracking, initial yield and yield are provided in Table 4. It is noticed that energy dissipated per cycle increased with the increase in drift. The maximum energy dissipated was in first cycle of 3% drift. It is further noticed that energy dissipation per cycle is more in first cycle than second cycle. The values of energy dissipated per cycle are presented in Figure 7. Here it is important to note that the numbers of cycles are 12 before failure at 4%, the second cycle of 4% drift was stopped due to significant damage that occurred in the plastic hinge region. The total energy dissipated in this column up to failure was 984.7 ton (force)-millimeter (tf-mm).

**Table 4:** Values for cracking, initial yield and yield for column QSCT-4-005 and QSCT-5-006.

| | **QSCT-4-005 Value α** | **QSCT-5-006 Value α** |
|---|---|---|
| **Item** | **North / South Direction** | **North / South Direction** |
| *$P_c$ | 3.30 kips / -3.40 kips | 2.50 kips / -2.90 kips |
| *$U_c$ | 0.25% (4.8 mm) / -0.22% (-4.2 mm) | 0.25% (4.8 mm) / -0.25% (-4.8 mm) |
| *$P_{yo}$ | 4.90 kips / -5.75 kips | 4.90 kips / -5.95 kips |
| *$U_{yo}$ | 0.71% (13.5 mm) / -0.78% (-14.8 mm) | 1.0% (19.1 mm) / -1.0% (-19.1 mm) |
| *$P_y$ | 5.92 kips 2.69 tf / -6.23 kips | 5.62 kips / -5.86 kips |
| *$U_y$ | 0.82% (15.6 mm) / -0.87% (-16.6 mm) | 1.05% (-16.6 mm) / -1.05% (-16.6 mm) |
| *$U_u$ | 3.43% | 3.40% |

* $P_c$ = Force at initial cracking; $U_c$ = Displacement at initial cracking; $P_{yo}$ = Force at initial yield;
$U_{yo}$ = Displacement at initial yield; $P_y$ = Force at yield; $U_y$ = Displacement at yield;
$U_u$ = Ultimate displacement at 80% of maximum restoring force
**α** tf = ton force; mm = millimeters

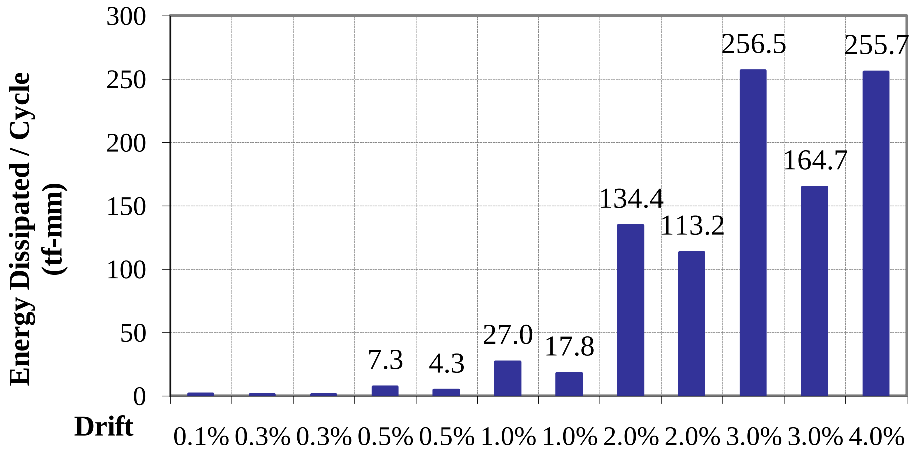


*Fig.7: Hysteretic energy dissipation for each cycle in column QSCT-4-005.*

### 4.2 Column QSCT-5-006

This column had 12.3 MPa cylinder strength when tested as per ASTM C39 [15] as described in Table 1. Hair line cracks appeared around 0.25% drift and were hardly visible. From the hysteresis curves it is observed that at around 1.0% drift the point of initial yield occurred. Further it is observed that for north direction initial cracking of concrete occurred at around 0.25% drift, initial yield at 1.0% and yield at 1.05% and for the force applied in south direction the cracking occurred at 0.25%, initial yield at 1.0% and yield at 1.05%, the values for cracking, initial yield and yield are provided in Table 4. Similarly like previous columns it is noticed that energy dissipated per cycle increased with the increase in drift. The maximum energy dissipated was in first cycle of 4% drift. It is further noticed that energy dissipation per cycle is more in first cycle than second cycle which is typical in both columns. The total amount of energy dissipated up to failure is 1,002.9 tf-mm. In this column the numbers of cycles are 12 before failure at 4% drift. The second cycle of 4% drift was not started due to significant damage that occurred in the plastic hinge region.

## V. Discussions On Results

In this paper reverse quasi-static cyclic testing of two very low strength concrete columns is discussed. The columns are tested using 2 cycles per drift. The column QSCT-4-005 had concrete strength of 12.7 MPa. The column had undergone 12 cycles of loading until failure at first cycle of 4% drift. The total energy dissipated was 984.7 tf-mm. The cycle of maximum energy dissipation was first cycle of 3% drift with 256.5 tf-mm energy. The ultimate displacement in this column was 3.43%.

The other column was QSCT-5-006 and had concrete strength of 12.3 MPa. The column had undergone 12 cycles of loading until failure at first cycle of 4% drift. The total energy dissipated was 1,002.9 tf-mm. The cycle of maximum energy dissipation was first cycle of 4% drift with 297.7 tf-mm energy dissipation. The ultimate displacement in this column was 3.40% which is very close to other column.

## VI. Conclusions

This paper discusses the hysteretic energy dissipation in very low strength concrete columns with strength of 12.7 MPa and 12.3 MPa. From this study the following conclusions are derived:

- The hysteretic energy dissipation starts at around 1% drift in both columns which are onset of yielding.
- More energy is dissipated in first cycle of any drift level than subsequent cycles.
- Both columns give comparable results thus supplementing each others results.

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