Short Term Creep Tests of Low Strength Rectangular Concrete Members
Jacketed with Carbon FRP Sheets

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ABSTRACT

Usage of low strength concrete is common in many developing countries all around the World. For example, in Turkey, the approximate average concrete compressive strength of existing reinforced concrete buildings constructed before 1990s is around 10 MPa. Since the concrete strength is foreseen higher during structural design, the sustained axial stresses of columns of such existing buildings may be remarkably high (70–90% of axial capacity). These high axial stresses sometimes cause collapse of columns or overall structure due to effects of creep of concrete. The service life of such structures can be enhanced through external jacketing of columns with FRP sheets. The efficiency of such a rehabilitation is higher in case of low strength concrete. In this study, the short term creep behavior of carbon FRP sheet jacketed low strength (~7 MPa) rectangular concrete prisms is investigated under varying levels of sustained axial stresses. The safe lifetime of the specimens are extrapolated considering the variations in axial and transverse strains measured during short term creep tests (48–96 hours). In addition, the residual capacities of carbon FRP jacketed rectangular prism specimens are investigated after being subjected to short term creep tests.

KEYWORDS

carbon fiber, confinement, low strength concrete, rectangular cross-section, retrofit, creep, sustained loading
1. INTRODUCTION

Many structures built with low strength concrete exist all around the world, particularly in the developing countries. In the case of Turkey, the average concrete compressive strength can be assumed to be around 10 MPa for buildings constructed before 1990s [1 and 2].

Although, majority of these structures lack engineered design procedures, even the engineered ones frequently suffer from low concrete quality. Consequently, when the actual concrete strength used during the construction is lower than that of foreseen at the structural design phase, the sustained axial stresses of columns may be remarkably high (70–90% of column axial capacity). These high axial stresses sometimes cause collapse of columns or overall structure due to creep effects on concrete. Along with the low concrete quality, reinforcement detailing problems and inadequate utilization of transverse reinforcement negatively affect the load bearing and ductility performance of these structures. The service life of such structures can be enhanced through external jacketing of columns with FRP sheets.

Although significant number of experimental studies exists for investigation of the behavior of fiber reinforced polymer (FRP) confined concrete members under short-term loading, limited number of studies has targeted the behavior under sustained axial loads [3-6].

In this paper, results of short-term creep tests and residual capacity tests performed on Carbon FRP (CFRP) confined specimens with square cross-sections are presented. In order to investigate the case of extremely low concrete quality, that can be encountered for an average compressive strength of 10 MPa, eleven prisms with the unconfined standard cylinder concrete strength ($f'_{cu}$) of 5.3 MPa at 28 days are included in the study. Eight of the specimens were externally confined with three layers of CFRP sheets and three unconfined specimens are tested as unconfined reference specimens. Main parameter of the study is the ratio of sustained axial stress to the axial capacity of the specimen using low strength concrete. Cement, water, sand, gravel, crushed stone weights used in the concrete mix were 197, 231, 563, 852, 272 (kg/m$^3$), respectively. Portland cement with a 28 days compressive strength of 32.5 MPa was used in the mixture and maximum aggregate size in the mixture was 15 mm. Concrete prisms with dimensions of 150x150x300 mm were removed from the steel molds one week after casting and were cured for seven days. Corners of all specimens were rounded to 30 mm radius. Eight of the specimens were wrapped with three plies of CFRP sheets in transverse direction. CFRP sheets were bonded with epoxy adhesive and 150 mm overlap was formed at the end of the wrap. During the wrapping phase; a spacing of 10 mm was left at the top and bottom ends of the specimens to avoid direct loading of the CFRP sheets. Finally, all prisms were capped with sulfur and graphite. Views from the preparation phases of the specimens can be seen in Fig. 1.

2. EXPERIMENTAL PROGRAM

2.1 Specimen Preparation

Square cross-sectioned prism specimens were cast
compressive strength of concrete ($f_{cun}^\prime$) that was obtained as 6.8 MPa from S0A and S0B reference prisms. These stress levels respectively correspond to 90, 83 and 73% of the confined concrete strength ($f_{cc}^\prime$) obtained from S3A and S3B CFRP confined reference specimens. The single unconfined SRI specimen, which was subjected to a much lower sustained stress level than the confined specimens, aims to establish a comparison with respect to the retrofitted ones. It should be noted that, the short-term creep tests were carried out at a time span of 48 hours, except the SRE and SRF prisms whose loading duration was extended to 96 hours.

The short-term creep tests of specimens were ceased only when failure occurred, or upon reaching the targeted loading duration. After completion of the sustained loading duration, the specimens were subjected to monotonic loading until failure was achieved.

<table>
<thead>
<tr>
<th>Specimens</th>
<th>Retrofit (plies)</th>
<th>Sustained stress</th>
<th>Sustained load duration (hours)</th>
<th>Failure during sustained loading</th>
</tr>
</thead>
<tbody>
<tr>
<td>S0A, S0B</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>S3A, S3B</td>
<td>3</td>
<td>3.37 $f_{cun}^\prime$, 0.90 $f_{cc}^\prime$</td>
<td>48</td>
<td>No, Yes</td>
</tr>
<tr>
<td>SRA,SRB</td>
<td>3</td>
<td>3.13 $f_{cun}^\prime$, 0.83 $f_{cc}^\prime$</td>
<td>48</td>
<td>No, Yes</td>
</tr>
<tr>
<td>SRC,SRD</td>
<td>3</td>
<td>2.76 $f_{cun}^\prime$, 0.73 $f_{cc}^\prime$</td>
<td>96</td>
<td>No, No</td>
</tr>
<tr>
<td>SRE,SRF</td>
<td>3</td>
<td>0.85 $f_{cun}^\prime$</td>
<td>48</td>
<td>Yes</td>
</tr>
<tr>
<td>SRI</td>
<td>-</td>
<td>0.85 $f_{cun}^\prime$</td>
<td>48</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Data acquisition was maintained via a 50 channel TML ASW-50C switch box and a TML TDS-303 data logger. During the short-term creep tests, the displacement, strain and load data was collected at every one second automatically until target stress level was reached, then continued at 20 seconds intervals until the end of sustained loading test.

3. RESULTS AND OBSERVATIONS

3.1 Monotonic Tests

Two unconfined square cross-sectioned prisms (S0A and S0B) were tested under 0.002 strain/min loading rate yielding to an average compressive strength of 6.8 MPa. Average axial deformation corresponding to peak stress was 0.0023 mm/mm. In addition to these two unconfined specimens, two identical prisms wrapped with 3 plies of CFRP sheets (S3A and S3B) were also tested under the same loading rate.

Axial stress-strain diagrams obtained by these reference tests are presented in Fig. 3. The strain values in this figure are obtained from the LVDTs since most of the vertical strain gauges were not operational until the end of the tests. As also observed in [7], the enhancement in strength and deformability for FRP confined specimens was significantly high for the low strength concrete.
Comparison of CFRP confined specimens tested under monotonic loading with the unconfined ones reveals that the average confined concrete strength and the strain corresponding to strength increases to 25.5 MPa and 0.0527 mm/mm, respectively.

The lateral deformation data presented in Fig. 4 for lateral strains of CFRP confined specimens were collected by using the strain gauges at mid-heights of the specimens. Although the maximum lateral strains could reach 0.0132 and 0.0129 for S3A and S3B specimens, respectively, the average value was approximately 0.0112. This corresponds to 72% of the ultimate tensile strain given by the manufacturer.

3.2 Short-Term Creep Tests
Two confined specimens for each of the three different sustained axial stress levels were subjected to continuous axial load for targeted time durations. Sustained axial stress levels chosen for the CFRP confined prisms become equal to 73, 83 and 90% of the confined concrete strength ($f'_{cc}=25.5$ MPa). Lowest sustained stress level (0.73 $f'_{cc}$) corresponds to 2.76 $f'_{cun}$, which is much higher than the axial load capacity of an unconfined concrete member. Apparently, the 0.83 and 0.90 $f'_{cc}$ stress levels were even higher, leading to axial stresses of 3.13 and 3.37 $f'_{cun}$, respectively. The single unconfined concrete prism (SRI) was tested under short-term creep load that corresponded to 0.85 $f'_{cun}$.

During sustained loading tests, as expected, the behavior up to the target sustained stress level was identical to monotonic loading tests. However, one specimen from each of the specimen couples (SRB and SRD) that targeted 0.83 and 0.90 $f'_{cc}$ (3.13 and 3.37 $f'_{cun}$) sustained stress levels, unexpectedly failed in the vicinity of the target stress levels (Table 1). Similarly, the unconfined SRI specimen failed three minutes after reaching the 0.85 $f'_{cun}$ stress. The premature failures of the CFRP confined specimens are shown in the lateral strain-loading duration diagram (Fig. 5). The premature failures of the specimens SRB, SRD and SRI are attributed to the possible variation in concrete compressive strength and workmanship errors, which might have led to non-uniform stresses and strains of external FRP jacket.

In case of specimens that could reach the target stress level, the lateral strains initially exhibited a tendency to increase (Fig. 6). This increase was more remarkable for the SRA and SRC specimens that were subjected to higher stress levels than the SRE specimen. However, later on the lateral strains became stabilized and none of these three specimens reached failure during the short-term creep loading phase.

In order to predict the life-time of the specimens subjected to sustained loading, a power type regression analysis was performed on the curves
presented in Fig. 6. Similar power type relationships for creep-time behavior were also reported by [8-10] for plain concrete and [3, 4, 6 and 11] for FRP confined concrete. Analysis on lateral strain-time curves of SRE and SRF with lowest sustained stress level (0.73 $f'_c$ or 2.76 $f'_c$un) showed that the specimens were unlikely to fail in practical duration. However, specimens with 0.83 $f'_c$ (SRA) and 0.90 $f'_c$ (SRC) addressed service life durations that can be easily exceeded in actual conditions. These results are also supported with the premature failure of two other specimens (SRB and SRD) loaded to these stresses. During the analysis it has been assumed that the specimen fails when the trend line, generated by using lateral strain-time data shown in Fig. 6, reaches the FRP effective ultimate lateral strain (rupture strain). The FRP rupture strain was taken as 11000 microstrain, which was determined to be the average rupture strain during the monotonic compression tests. As an exception, since the specimen SRA exceeded 11000 microstrain during the sustained loading and identical SRB specimen prematurely failed at a lateral strain of 10400 microstrain, its service life can be considered as practically short.

![Fig.6 Lateral strain variation with time](image)

Failure modes of the monotonic compression tests (S3A and S3B) and residual capacity tests were similar. The sudden rupture of the external CFRP jacket generally initiated near the center of a side and extended along the 1/3 of the specimen height. In few cases, as also observed in SRA specimen, FRP rupture was close to one of the corners.

The axial stress-strain curves obtained from residual strength tests are shown in Fig 8. In this figure, it is also possible to compare these curves with the monotonically loaded confined and unconfined prisms.

Despite the utilized extremely high sustained stresses, it can be observed that sustained load did not have negative effects on confined concrete strength and deformability characteristics. All short-term creep test specimens, which were reloaded to failure, achieved greater axial and lateral strain values than specimens tested under short-term monotonic loading (Figs. 8 and 9). Surprisingly, the increase in strength and deformation capacities was even more pronounced for higher sustained stresses (Table 2). This observation may be attributed to the creep characteristics of the CFRP sheets, which resisted higher tensile strains with respect to CFRP sheets, wrapped around members, which are directly tested under monotonic loads.

3.3 Residual Capacities

Although some of the CFRP confined concrete prisms failed at higher creep loads, the remaining ones were virtually undamaged after creep tests. In order to investigate the residual load capacities of remaining specimens, sustained loads were removed and the specimens were left unloaded for thirty minutes. In the next step, the specimens were reloaded monotonically under 0.002 strain/min loading rate, until failure. During unloading and reloading phases, data acquisition was continued. View of the SRA and SRF specimens after the residual capacity test is presented in Fig. 7.

![Fig.7 SRA and SRF specimens after testing](image)
It is very important to note that while it was observed that FRP confinement played an important role for the creep performance of the tested members, the efficiency of confinement was remarkably less than reported by [3] for the circular specimens. It is thought that, this difference mainly stemmed from the distribution of the stresses in the cross-sections. In the case of circular cross-sections, the distribution of the stresses is uniform, whereas in the case of square cross-sections, the distribution of stresses is quite irregular due to concentrations at the corners. So, it is very important to approach the results of creep tests of FRP confined circular specimens carefully before generalizing the obtained results for noncircular specimens.

4. CONCLUSIONS

(1) External FRP confinement of low strength rectangular members is efficient to increase the service life under extremely high axial stresses with respect to their axial strength.

(2) The enhancement in the creep performance is relatively less for rectangular specimens with respect to circular ones.

(3) The specimens tested under sustained loading exhibited a slightly better performance during residual strength tests in terms of strength and deformability with respect to their counterparts tested directly under monotonic compression.

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REFERENCES


