DRAINAGE CONCRETE PIPES WITH HYBRID REINFORCEMENT

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Abstract

Brazil is passing through an economic growing process where basic infrastructure systems are highly demanded. Among them there is the need of water and sewage collecting systems production. In order to provide a low cost alternative for concrete pipes production, an experimental study was developed focusing the analysis of hybrid reinforcement, combining steel wires and steel fibres. It was demonstrated in previous studies that fibres alone can provide a strain hardening behaviour for concrete pipes with diameters of 600 mm or 800 mm. But for pipes with diameters of 1000 mm and greater wall thickness, there is no fibre alignment enough to provide such behaviour. The alternative of hybrid composition of the reinforcement was chosen by the fact that fibres provided a better performance for low level of deflections, although steel wires increase the post peak strength at higher levels. On that purpose, concrete pipes with nominal diameters of 1000 mm and 1500 mm length were produced using three different kinds of reinforcement: steel fibres, steel wires and hybrid. The pipes were submitted to the full scale crushing strength test with continuous control of the diameter displacement. The tests were carried out using the cyclic procedure proposed by Brazilian and European standards for steel fibre reinforced concrete pipes. In that situation it was possible to compare the behaviour of the components at the pre-crack and post-crack stage. The results show that the single reinforcement provided a typical softening response of the pipes. On the other hand, the hybrid reinforcement provided a strain hardening behaviour, which generates a better response at low and high displacement levels.

1. INTRODUCTION

Brazil is passing through an economic growing process where basic infrastructure systems are highly demanded. Among them there is the need of water and sewage collecting systems production. In the particular case of sewerage systems, there is a need of that correspond to provide this basic public service to about 31% of total Brazilian houses and buildings. In some cases, there is a higher strength requirement due to the high level of embankment. In this particular case, the strength of pipes has to be higher in order to meet the requirements even for the post-peak strength. In some situations, the hardening behaviour could be of interest. Some previous studies [1][2] had shown that a fibre content of 40 kg/m³ could
provide this kind of behaviour for pipes with 600 mm and 800 mm of inner diameter, respectively. However, the fibre performance seemed to be higher when applied in pipes with smaller diameters due to the best alignment provide by the thin thickness of the pipe wall. So, for higher inner diameters of the pipe, the increase of fibre content necessary to achieve the hardening behaviour could turn this kind of reinforcement less competitive due to the increase in costs. In order to provide possible solutions for this demand, some technological possibilities must be studied in order to verify if these alternatives are feasible. It was already demonstrated that steel fibres and wires provide different patterns of reinforcement for concrete pipes [1]. The fibres presented higher intensity of strengthening for low levels of displacement and cracking. On the other hand, steel wires provide higher bearing capacity for higher levels of displacement and cracking. This behaviour is characteristic for concrete pipes with reduced diameters, less than 1000 mm, because, in this particular case, there is only one layer of wires at the centre of the pipe wall. In this case, steel wires are mobilized when higher level of displacement and cracking is reached. So, a study focusing the combined capacity of fibres and steel wires seems to be interesting in order to achieve an enhanced behaviour for the pipes with a lower overall steel consumption.

2. METHODOLOGY

All the pipes used in this experimental study were produced in one single day using the same equipment with a vibro-pressed compactation system. That condition was established with the intention of diminish the influence of intervening variables in the pipes production. In that sense, the same features and basic materials that were being regularly used by the company were applied for the pipes fabrication. The demanded amount of fiber was added directly on the aggregates conveyor belt. A hooked end cold drawn steel fiber was used with a fibre consumptions of 20 kg/m^3. The length of fiber was 35 mm and the diameter was 0.55 mm. The fibre was provided glued in bundles as presented in Figure 1. The main steel wire reinforcement (transverse reinforcement) was assembled and welded by means of an automatic machine with cold drawn steel wires (yield strength of 600 MPa) with a diameter of 6 mm, and spaced each 85mm. The main reinforcement was positioned at the center of the pipe wall with equal distance for both inner and outer surface, which is provide by means of use of plastic spacers (Figure 2). A support reinforcement (longitudinal) made with 16 wires of the same type of steel was also used. Three pipes were produced for each kind of reinforcement: fibres, steel wires and hybrid reinforcement combining fibres and steel wires.

![Figure 1. Fibres used in the experimental program.](image)

It was observed that the pipes produced only with fibres or steel wires presented a very good final finishing of the surface. Initially, when the hybrid reinforcement was used some finishing problems were observed (Figure 3). So, some adjustments were made in the concrete feeding rate in order to avoid these problems.
The mechanical performance of concrete pipes is normally evaluated through the crushing test method as specified in the standards ABNT NBR 8890 [3] and EN 1916 [4]. The set up of this test, also known as three-edge bearing test, is schematic presented in Figure 4. These standards prescribe two different test procedures for the qualification of pipes, one for steel wires reinforced concrete pipes (SWRCP), and the other for fibre reinforced concrete pipes (FRCP). As the continuous test was previously used for the comparative performance analysis of steel wires and fibres, the cycled loading test was chosen for this particular study. So, the test method procedure recommended for FRCP was used for both kinds of reinforcement in order to turn possible the comparative performance analysis in the same basis.

The standard crushing test method for FRCP is characterized by a double cyclic loading [3 and 4]. The first cycle consists of loading the pipe until the proof load, which is the load associated to the pipe strength class. At this point, the load is maintained for one minute and the pipe is rejected if any crack or other damage is observed. Once approved at this stage, the loading of the pipe is continued until reach the maximum load. When the load start to decrease and achieve the value of 95% of the maximum load the pipe is unloaded, finishing the first cycle of the test. On the second loading cycle, the pipe is reloaded up to a load equal to the proof load and held for one minute. The pipe has to withstand this post-peak proof load in order to be approved. The test procedure established by the Brazilian standard [3] prescribes that the second loading cycle is continued up to the moment that the pipe reach the maximum measured post-peak load. The maximum post-peak load shall to exceed the proof load by a minimum of 5% of the established value for the strength class.
In order to improve the evaluation of pipes mechanical behaviour during the tests, LVDTs were positioned at the pipes providing a continuous acquisition of diametric displacement together with the load value. A similar test set up was used in previous studies [5 and 6], where LVDTs were positioned against the upper part of the inner surface of the pipe and attached at supports fixed at the bottom part of the pipe as shown in Figure 5a. The displacement measurement system used permits to eliminate the interference of external strains or dislocations in the results. A plastic sheet was fixed between the LVDT and the pipe surface in order to avoid the LVDT rod entrance in a possible crack that could appear at that position during the test (Figure 5b).
3. RESULTS AND ANALYSIS

The load versus diametric displacement curves obtained with the fibre reinforcement are presented in Figure 6. The results obtained with the steel wire reinforcement alone are presented in Figure 7, while, the results obtained during the crushing test of pipes with hybrid reinforcement are presented in Figure 8.

![Figure 6: Load versus diametric displacement curves obtained with pipes reinforced with 20 kg/m³ of fibres.](image)

Observing the results presented in Figures 6 to 8 is possible to figure out different behaviour patterns. The type of reinforcement interferes in both cycles in different ways. Basically the FRCP presented a softening behaviour, with a reduction of the resisted load with the increase of diametric displacement. It occurs due to the fact that fibres have been pulled out with the increase of crack opening that occurs together with the displacement increase. On the other hand, the SWRCP presented a lower strength in the first cycle, but a typical hardening behaviour in the second cycle. This SWRCP behaviour can be attributed to the fact the steel wires reinforcement does not strengthen the outer wall layer of the pipe where there are major tensile stresses for small levels of displacement [7]. The strengthening capacity of the steel wires starts with an increase of displacement and cracking, which allowed this reinforcement to work due to the steel mobilization in the section. The hybrid reinforcement had coupled the strengthening capacity from both kinds of reinforcement. So, there is a light hardening behaviour increasing the strength in both cycles.

The maximum load obtained for the first cycle of loading and its respective level of diametric displacement are presented in Table 1 in order to achieve a better analysis of the results. The first loading cycle correspond to the matrix work in the process and shows how the reinforcement could provide an enhancement in this performance. When the fibre was used, the load reached the maximum value when the diametric displacement was around 1.2 mm in the first cycle. The lower level of strength was obtained with the steel wire reinforcement at a low level of displacement. Fibres helped to control the cracking initialization and thus increased in the resisted load in the first cycle and the respective diametric displacement. When the hybrid reinforcement was used, the higher level of resisted load was achieved, as expected. However, the increment in the strength capacity was not
associated to continuation in the diametric displacement level. This result may be related to the small number of specimens tested. With the objective of achieve a better analysis of the pos-crack behaviour the curves correlating the average load and diametric displacement for the second cycle is presented in Figure 9. The pipes with fibre reinforcement presented a typical softening behaviour. In this particular case, the load stays always under the level achieved in the first cycle. The maximum load in the first cycle was approximately 90 kN, and the maximum load in the second cycle stays under 60 kN. The pipes reinforced with steel wire have the same level of strength presented by the pipes with fibres at the first level of diametric displacement. However, after this initial part, the behaviour became clearly a hardening one, but could not exceed the level of strength of the first loading cycle. Differently, the post-peak strength of pipes with steel wire reached close level of first cycle around 80 kN. The hardening behaviour in the post-crack strength was obtained with the pipes with hybrid reinforcement. Naturally, is possible to interpret the behaviour of the hybrid reinforcement as the sum of single reinforcements.
Table 1: Results obtained for the maximum load and respective level of diametric displacement for the first cycle of loading.

<table>
<thead>
<tr>
<th>Type of reinforcement</th>
<th>Maximum load at the first cycle (kN)</th>
<th>Diametric displacement (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fibre</td>
<td>82 91 103</td>
<td>1.20 1.23 1.21</td>
</tr>
<tr>
<td>Average value</td>
<td>92.0±10.5 1.21±0.02</td>
<td></td>
</tr>
<tr>
<td>Steel Wire</td>
<td>83 92 82</td>
<td>1.04 1.09 1.15</td>
</tr>
<tr>
<td>Average value</td>
<td>85.7±5.5 1.09±0.06</td>
<td></td>
</tr>
<tr>
<td>Hybrid</td>
<td>99 107 98</td>
<td>1.21 1.22 1.03</td>
</tr>
<tr>
<td>Average value</td>
<td>101.3±4.9 1.15±0.11</td>
<td></td>
</tr>
</tbody>
</table>

Figure 9: Average load versus diametric displacement curves obtained with pipes in the second cycle of the tests.

The consumption of wire steel was approximately 26 kg/m³ and the total steel consumption of the hybrid reinforcement was around 46 kg/m³. This consumption was around 0.6%, which was under the 1% normally expected for critical volume of fibre consumption. So, the hybrid reinforcement could lead to a hardening behaviour using a reduced total volume of steel in the matrix. More than this, the hybrid reinforcement could provide an enhanced performance for the lower and higher level of displacement and cracking, helping the serviceability conditions and ultimate strength simultaneously.

4. CONCLUSIONS

The results show that the single reinforcement provided a typical softening response of the pipes. On the other hand, the hybrid reinforcement provided a strain hardening behaviour, which generates a better response at low and high displacement levels. Although, the
hardening behaviour was obtained in previous studies using 40 kg/m$^3$ of fibres only, this performance was achieved with pipes with 600 mm of inner diameter [2]. Pipes with greater diameter will demand higher fibre content to guarantee the same performance, as demonstrated by the new developments in numerical analysis of FRCP [7]. Nevertheless, the hybrid reinforcement could provide a hardening behaviour using a slightly higher total volume of steel in the matrix. In addition, the hybrid reinforcement provided an enhanced overall performance for the lower and higher level of displacement and cracking.

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REFERENCES


