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REPORT ON:
Testing of Garford Bulb Tendons
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MINING RESEARCH AND CONSULTING GROUP

1.0 INTRODUCTION

A series of tests were conducted to determine the load transfer characteristics of twin strand Garford Bulb Tendons with different bulb spacing.

Parallel testing was conducted with 14 wire birdcaged tendon over 380mm and 500mm embedment as part of an existing research programme. Previous testing of 10 wire birdcaged cable was also used in the comparative assessment of the Garford Bulb.

The results obtained have enabled a preliminary relationship between bulb spacing and the deformational characteristics of the system to be determined.

2.0 EXPERIMENTAL METHOD

The test procedure is described in AMIRA Project Report No. 4 - Quantitative Measurement of the Behaviour of Grouted Tendons Subject to Axial and Shear Displacement.

The tendon is grouted into two joined thick wall steel cylinders. The cylinder wall thickness is designed to exclude yield occurring within the testing cylinder. The internal surface of the cylinder is machined to a standard light thread to prevent failure on the grout/cylinder interface.

The tendons were grouted using a commercially available high strength and stiffness grout. The strength and stiffness of the grout were obtained from test cylinders poured during sample preparation.

The prepared grouted tendons were placed in a servo controlled testing machine under strain control and the load deformation characteristics measured. Table 1 outlines the (half) embedment lengths, grout properties and bulb spacing for the tests.

TABLE 1. TESTING DETAILS

Tendon	Grout Properties UCS (MPa) / E (GPa)	Embedment Lengths (mm)	Bulb Spacing Bulbs/Strand/M
Garford	61/23	380	3.9
Garford	61/23	380	3.9
Garford	55/23	380	5.3
Garford	55/23*	500	6.0
14 Wire B/Cg	55/23	500	N/A

* U.C.S. estimate only as test cylinder had high air entrapment.

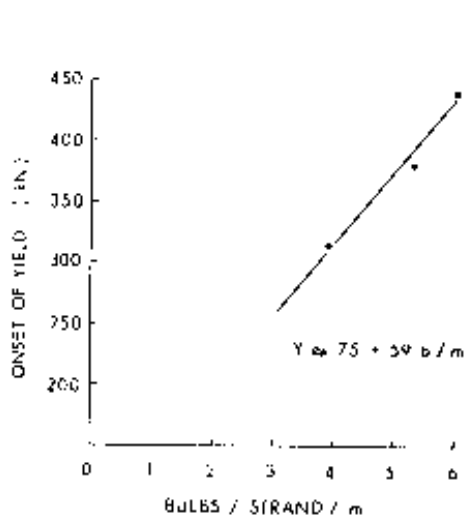


Figure 2(a) ONSET OF YIELD v's BULB DENSITY.

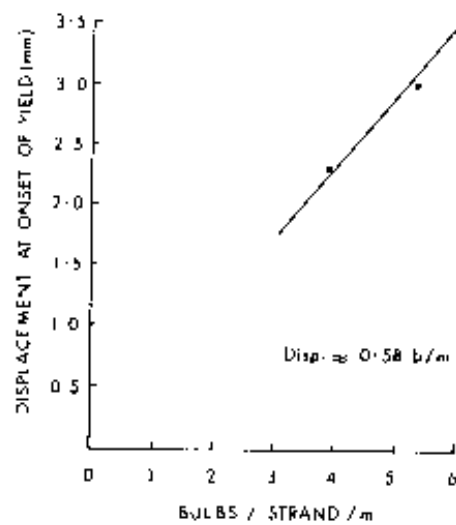


Figure 2(b) DISPLACEMENT AT ONSET OF YIELD v's BULB DENSITY.

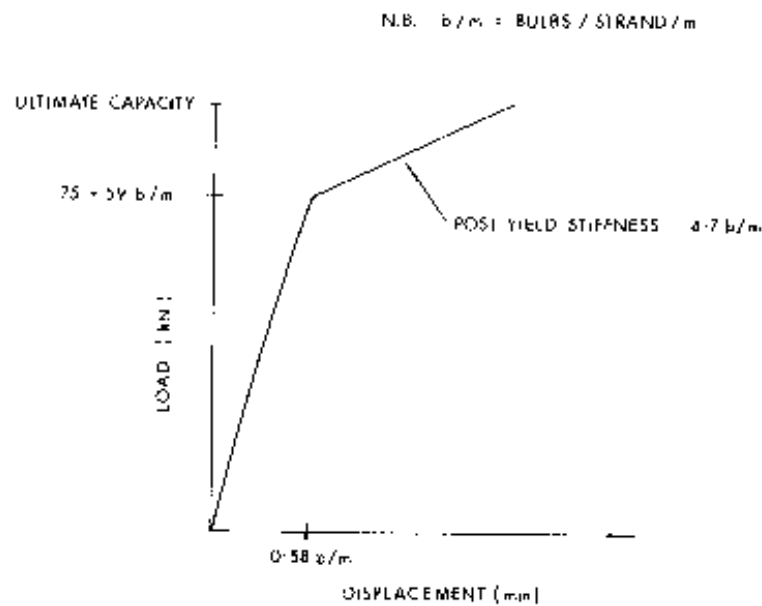


Figure 3 GENERALISED FORM OF LOAD / DISPLACEMENT PLOT IN TERMS OF BULB DENSITY.

3.0

TEST RESULTS

The load displacement plots for each test are shown in Figure 1. The Garford Bulb tests have an approximate bi-linear shape consisting of a stiff portion up to the onset of yield in the system, followed by a softer portion up to the ultimate capacity of the system. The onset of yield is defined as a point of significant change in the stiffness of the system.

The shape of the load/displacement curve is considered to be related to the bulb spacing. Figure 2 shows the load at the onset of yield in the system and the displacement at this load, plotted against bulb spacing. Although within our existing standard it is not normal to compare the behaviour of tendons grouted at different embedment lengths, it has been found that the number of fully grouted cages or bulbs has an overriding effect on the system performance. For this reason the summary of the results presented in figure 2 are normalised in terms of the number of bulbs per strand per metre.

The number of data points does not allow a rigorous mathematical relationship to be established at this stage. However, on the basis of the results obtained to date, the load/displacement curve as a function of bulb spacing has the general form shown in Figure 3. The figure indicates that:

1. The onset of yield occurs at a higher load with more bulbs/strand/m.
2. The displacement at this load is marginally higher with more bulbs/strand/m.
3. After the onset of yield the stiffness of the system is also a function of bulb spacing. The approximate equation for post yield stiffness is $4.7 \times \text{bulbs/strand/m}$.

3.1 Load History

3.1.1 Initial Displacement (<1mm)

Inspection of the load/displacement plots indicates that the stiffness of the tendons with a low bulb density was marginally higher than tendons with a higher bulb density. This is contrary to initial expectations, however it is considered to be related to the behaviour of the grout within the bulbs.

The pullout resistance in a birdcaged or bulb system is considered to be generated from crushing of the grout within the bulbs. Prior to confinement being generated within the grout bulb, the system may undergo a "seating in" stage. Where the tendon has a lower bulb spacing, the greater length of plain strand requires less "seating in" and subsequently is marginally stiffer.

3.1.2 Up to Onset of Yield

After the initial seating in of the system, the resistance to pullout is increased due to the generation of confinement within the bulbs. A higher bulb density results in an increase in stiffness. Above the initial seating in displacement, the stiffness is higher for a higher bulb density.

The inflexion point in the load/displacement plot is referred to as the onset of yield in the system. This is considered to be related to crushing of the grout within the bulbs.

3.1.3 Post Onset of Yield

After the grout within the bulbs has failed, the additional confinement is reduced and the system softens significantly as the tendon pulls through the grout column. There is an approximate linear dependence of post yield stiffness on bulb spacing.

As the tendons with a higher bulb density have a higher load at the onset of yield, the post-yield portion of the load/displacement history up to the ultimate capacity is reduced. On the basis of the results obtained, a bulb density of over 7.5 bulbs/strand/m may not reach the onset of yield before the ultimate capacity of the system was reached. The stiffness of this system may be higher than currently available long tendons.

4.0 COMPARISON WITH 14 WIRE BIRDCAGED CABLE

Two 380mm embedment and one 500mm embedment pullout tests were conducted on 14 wire birdcaged cable.

The ultimate capacity of the cables was not achieved in the 380mm tests due to the effective encapsulation of only one birdcage, the second cage was poorly formed which resulted in pull through of the wires rather than the generation of confinement of the grout. The encapsulation length was increased to 500mm to ensure full encapsulation of two birdcages per sample cylinder. The encapsulation achieved in the 500 mm tests was two full cages together with an approximately 100 mm section of splayed wire which based on previous tests would have a small effect on the system behaviour

The load/displacement plot for the 500mm embedment test approximately overlays the 500mm embedment test for the Garford Bulb with 6 bulbs/strand/m up to the onset of yield.

After this point the performance of the 14 strand birdcage is exceeded. Within the working range of the Garford Bulb, a bulb density of less than 6 bulbs/strand/m was not as stiff as the 14 wire birdcage. Although the 5.3 bulbs/strand/metre tendon had a higher onset of yield its lower post yield stiffness would make it less effective

after 3mm of deformation.

Although no tests of the shear behaviour characteristics have been conducted by SCT, variation in the distribution of wires in the hole may lead to minor variation in the stiffness in shear. The variation is however considered to be small (similar or less than the variation between node and antidote of the birdcage system). The capacity in shear would be the same as birdcage, as it will be dependent on the cross sectional area of the same number of wires.

5.0 SUMMARY

The Garford Bulb tendon fulfils the basic criteria of *Reinforcing tendon* as delineated by the AMIRA P207 Project. When used with a high strength grout, the following performance criteria of the tendon were measured:

1. The tendon with a bulb density of approximately 3.9 bulbs/strand/m is similar to that of 10 wire birdcage but with a higher ultimate capacity.
2. The performance of the tendon with a bulb density of 6 bulbs/strand/m is comparable to a 14 wire birdcage cable and exceeds the performance of 14 wire birdcage in the range of 1.5mm to 5mm
3. With an increase in bulb density and the potential for additional strands to be included without significant increases in hole diameter, the Garford Bulb is considered to have the potential to provide a stiffer and higher capacity system than currently available long tendons.

The results have indicated that a rigorous relationship between stiffness and bulb density may be obtained with further testing. A general relationship is provided in this report.

The results indicate that the Garford Bulb system can be trialled in the field with both two and three strand configurations, in any application currently using birdcage cables. The use of the three strand configuration may provide the capability to achieve opening stabilisation in areas where 14 wire birdcage systems have been marginal in their effectiveness.