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Naj Aziz

University of Wollongong

Ali Mirzaghobanali

University of Southern Queensland in Dubai, am001@uowmail.edu.au

Matthew Holden

Jenmar Australia, mholden@jenmar.com.au

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THE EXTENT OF SHEARING AND THE INTEGRITY OF PROTECTIVE SLEEVE COATING OF CABLE BOLTS

Naj Aziz¹, Ali Mirzaghobanali² and Matthew Holden³

ABSTRACT: Long term integrity of cables installed around tunnels for ground reinforcement can be influenced by ground movement. This paper reports on the laboratory study of the influence of shearing on damaging the encapsulated plastic sleeves leading to exposure of the cable surface to a hostile environment. Two experimental studies were carried out to assess the extent of shearing displacement and damage to the sleeves. Various shear displacement tests were carried out. In the first test a sleeved cable was encapsulated in a plastic tube and single sheared up to 43 mm vertical displacement and the same procedure was repeated with the second sleeved cable being subjected to double shearing using a double shear testing Machine MKII. In both tests it was found that the corrugated plastic sleeves started to be sheared at a maximum displacement of greater than 20 mm, without damage, it was inferred that the corrugated sleeve can withstand shearing displacement without tearing up to maximum of 33 mm. The experimental procedure and the variation in the testing method are described.

INTRODUCTION

Increasingly tunnels are being introduced into metropolitan transport systems to provide links in urban areas where surface routes become congested and are preferred to conserve surface facilities of particular merit. Tunnels provide safe, environmentally sound, very fast and unobtrusive transport for all walks of life. In urban areas they are also built or constructed at shallow depth and pass through different rock structures of varying competence. Construction of tunnels in urban areas requires effective reinforcement and regular monitoring. Failure to address reinforcement integrity may have severe consequences including;

- Damage to the tunnel structure caused by excessive tendon corrosion,
- Interruption to traffic flow,
- Excessive tunnel maintenance cost,
- Damage to surface facilities, and
- Costly litigations

The most widely used reinforcement system now-a-days is by tendons (both rock bolts and cables) and their effectiveness and long term performance is dependent on the nature of ground formation that the tunnel is driven through. Long term stability of the tunnel requires long term integrity of the reinforcement elements anchored into the surrounding rock formation. Steel corrosion represents the most important factor that undermines the long term integrity and stability of the constructed tunnels. The incorporation of plastic sleeves to tendons provides this element of protection as long as cables are encapsulated in the plastic sleeve and that the used sleeves have long term durability. Ground movement and deformation surrounding the tunnel may cause the sleeves to crack and exposure of the tendons to groundwater. The extent of the ground movement and tendon shearing may be

¹ School of Civil, Mining and Environmental Engineering, University of Wollongong, NSW, Australia Email: naj@uow.edu.au Tel: +61 2 4221 3449

² School of Civil Engineering and Surveying, University of Southern Queensland, QLD Australia Email: ali.mirzaghobanali@usq.edu.au Tel: +61 7 4631 2919 Visiting academic staff at the School of Civil, Mining and Environmental Engineering, University of Wollongong, NSW, Australia Email: amirzagh@uow.edu.au

³ Mining and Civil Engineer, Jennmar Australia Email: mholden@jennmar.com.au Tel: +61 2 4648 7539 Mob: +61 409 072 202

evaluated by regular monitoring for ground movement from the surface. Better understanding of the extent of ground deformation that may contribute to the demise in the integrity of the installed sleeves represents a challenge that is being addressed and is the subject of study in this paper.

A challenge associated with incorporating a protective plastic sleeve over the reinforcing tendon is ensuring effective load transference between the tendon, the grout annuli and the ground. A smooth plastic sleeve relies heavily on the skin friction between the sleeve and the grout annuli to transfer load from ground movement to the tendon and ultimately reduces the load transference capacity of the system. To overcome this, many ground support standards and guidelines specify that the geometric profile of the sleeve should be corrugated and sinusoidal in shape. For instance, the British standard code of practice for ground anchorages, BS 8081: 1989, as well as the Roads and Maritime Services (RMS) quality assurance specification for soil nailing (R64) both specify sinusoidal corrugations with a pitch between six and twelve times the sleeve wall thickness and amplitude not less than three times the wall thickness as shown in Figure 1. The idea is to create a mechanical interlock between the inner and outer grout annuli through the geometric interference introduced by the corrugations in the plastic sleeve. This relies on the shear strength of the cement grout as opposed to the mechanical properties of the plastic sleeve. Figure 2 shows a typical flexible corrosion protected ground anchor which incorporates the protective plastic sleeve.

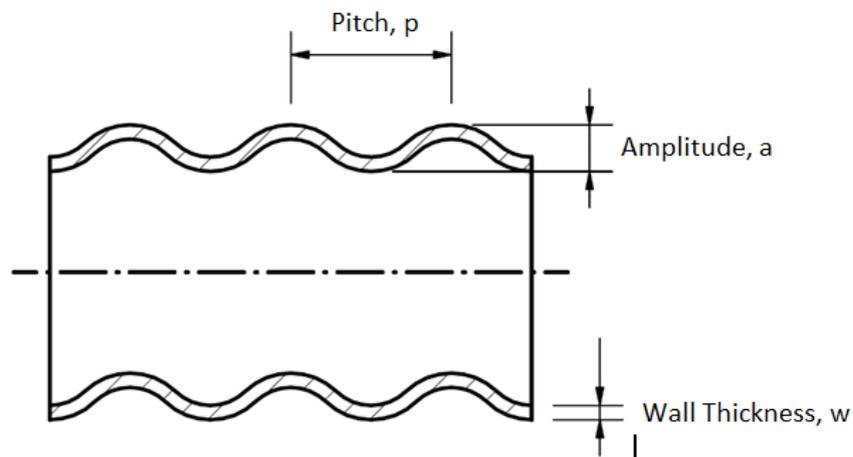


Figure 1: Cross-section of corrugated plastic sleeve

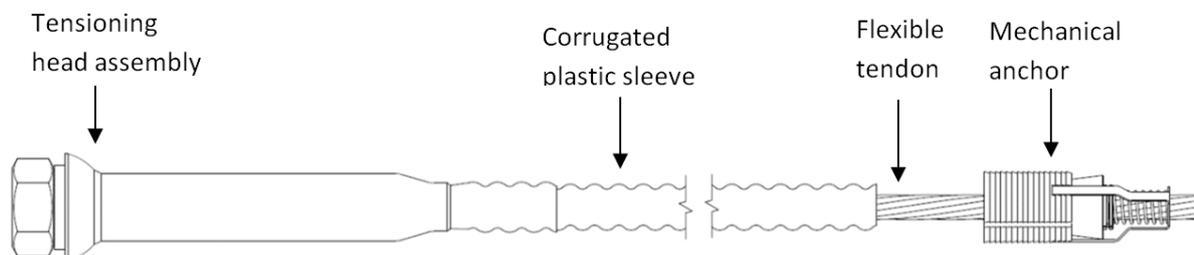


Figure 2: Typical flexible corrosion protected ground anchor

THE PROCEDURE

For evaluating the integrity of encapsulating sleeves on cable bolts, two methods of testing the sleeved cable sections were undertaken. The aim was to determine the maximum shear displacement of the cable that would cause the plastic sleeve to crack during shearing. Initially sleeved cable sections were subjected to a single shear test method and this was followed by the standard large scale double shear test methods. 21.7 mm diameter 19 wire (9x9x1) construction designation Superstrand cable was used in the study. BluGeo HS400 grout was used to encapsulate the steel

cable with corrugated plastic sheathing. The corrugated plastic sheath is manufactured from High Density Polyethylene (HDPE) with a wall thickness of 2.0 mm, pitch of 22 mm and amplitude of 6 mm (refer to Figure 1). A close up view of the cable and corrugated plastic sleeve is shown in Figure 3.

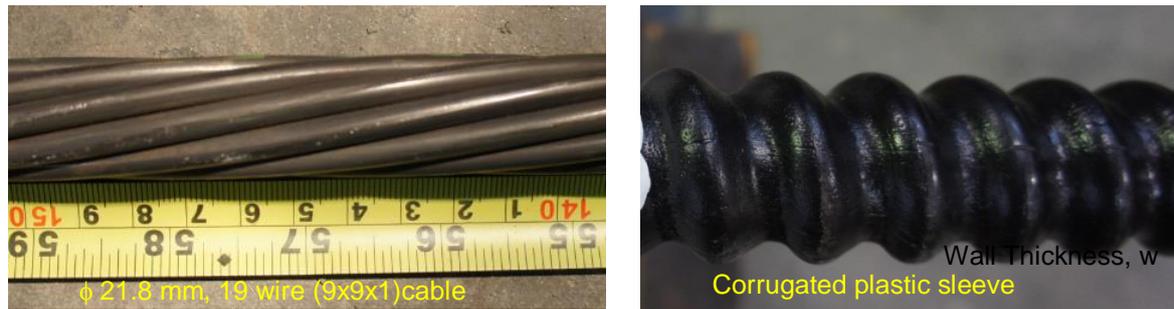


Figure 3: A close up view of the 21.7 mm diameter steel cable and corrugated plastic sleeve

Single shear test

A guillotine type single shear apparatus as shown in Figure 4a was used to carry out the preliminary shear tests. The encapsulated cable was grouted in a 5 mm thick smooth wall plastic tube using a cementitious grout to act as the outside protection layer. A 12 mm ring strip of the plastic cover was removed from mid-section of the encapsulated cable section to expose the corrugated tube, shown in Figure 4b, to allow the bare corrugated plastic sleeve to be visually inspected when sheared. Shearing of the cable was carried out in four displacement steps, until cracks appear in the corrugated sleeve.



Figure 4a: Single shear apparatus:



Figure 4b: Cable section with corrugated sleeve installed in 45 mm plastic tube

Figure 5 shows the shear load and shear displacement of four tests. The final test was terminated at shear displacement of 43 mm. The test was stopped at the end of each predetermined displacement step shown in the graph and the cable sleeve was physically examined for any damage. Four shear displacement step ranges were made. They were 6, 12, 24, and 40 mm ranges. As seen in Figure 5 the displacements range step of 24 mm represented, the critical shear travel for plastic sleeve failure. The shear displacement of the cable after 6 and 12 mm was recovered once the sheared load was taken off the cable. Figure 6 shows the ultimate cable shear travel and the condition of the damaged sleeve respectively. The final view of the damaged sleeve may have occurred, when the shear displacement was beyond 24 mm. An audible cracking sound was heard at the vertical displacement of around 33 mm. Therefore it is reasonable to suggest that cracking of the corrugated sleeve occurred at the vertical shearing movement of 33 mm.

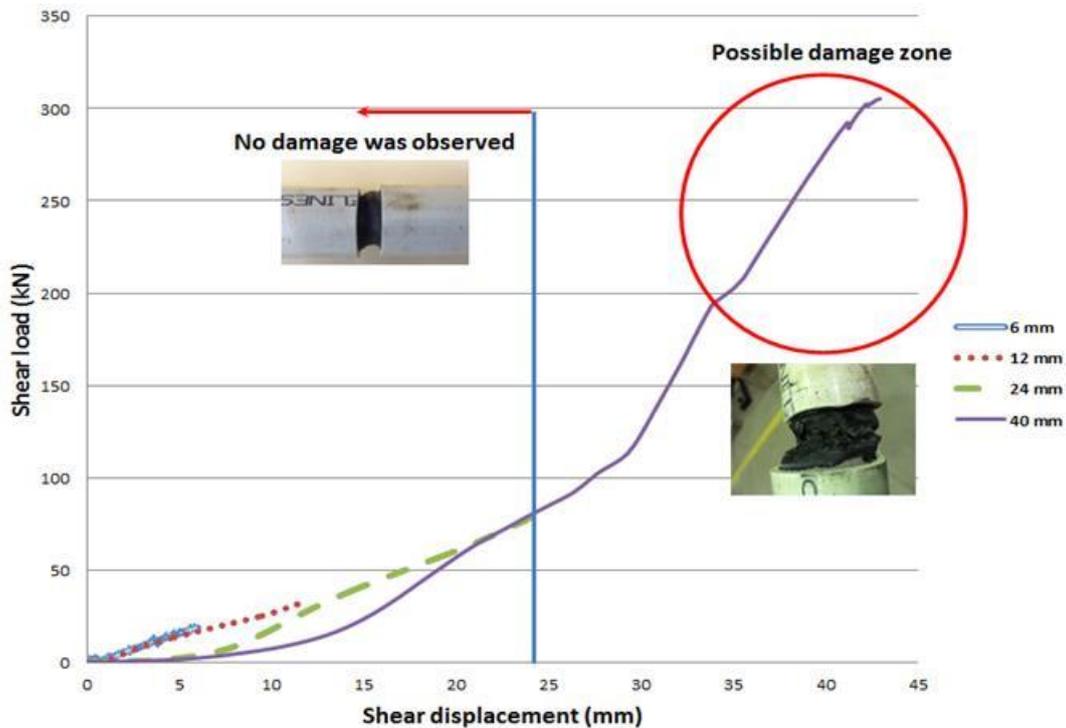


Figure 5: Shear load and displacement graphs



Figure 6: Damaged corrugated sleeve at the end of the shearing test

Double shearing method

The aim of this investigation was to determine the possible damage on the sheath of the corrosion protected cable bolt upon subject to 15 and 20 mm shear displacements. Testing was carried out in accordance with the double shearing methodology reported by Aziz *et al.*, (2015 a and b). In this study the contact between concrete medium joint surfaces were allowed, by using MKII double shear apparatus. The double shear testing process requires three concrete blocks with two outer 300 mm side cubes and a central rectangular block 450 mm long. The strength of the concrete used was relatively weak at around 20 MPa as specified for the investigation. The casting of the concrete blocks was carried out directly in the confining steel frame of the double shear apparatus. A plastic conduit

wrapped with 8 mm PVC tube and set through the centre of the mould lengthways, creating a centralised hole for cable installation in the concrete blocks. The plastic conduit was gently pushed out once the concrete block was set. The concrete blocks were left immersed in a water tank to cure for a minimum period of 28 days. The Uniaxial Compressive Strength of concrete was determined as 21 MPa, after the period of curing, by testing three cylindrical samples.

The cured blocks were then mounted in the double shear confining steel frames and the sleeved cable bolt specimen was inserted into the borehole. The annulus section between the sheath and cable was grouted and left for setting prior to cable bolt installation. Two 100 t load cells were inserted onto each end of the cable followed by the typical cable bolt end fitting. The load cells were connected to the data logger during tensioning. Once the cable was pretensioned for 5 t of axial load as specified, the grout was injected into the annulus between the cable and borehole through the intersecting small holes on top of the block. The whole assembly was then left undisturbed for the duration of seven days for the grout to cure. 50 mm cube samples were cast from the same grout as used for encapsulation and then tested for strength, yielding 45 MPa of UCS after seven days of curing. The top of the concrete blocks were covered by the bolted steel plates and the whole assembly was then mounted on the carried base platform. The whole double shear assembly and the base frame was then positioned on to the 500 t compression testing machine for shearing process at the rate of 1 mm/min as shown in Figure 7.

RESULTS AND ANALYSIS

Figure 8 shows the shear load and axial load profiles against shear displacement for two tests conducted in this study. The maximum values of shear load attained during double shearing, were 20 t and 24.3 t for 15 mm and 20 mm of shear displacement respectively. These correspond to maximum axial load of 7.3 t and 8.9 t. At the end of the test, the double shear assembly was dismantled and the tested cable was extracted and examined for the extent of damage to the protective sheath. Figure 8 shows pictures that were captured once the concrete blocks were gently dismantled.



Figure 7: Double shear testing apparatus in 500 t compression testing machine

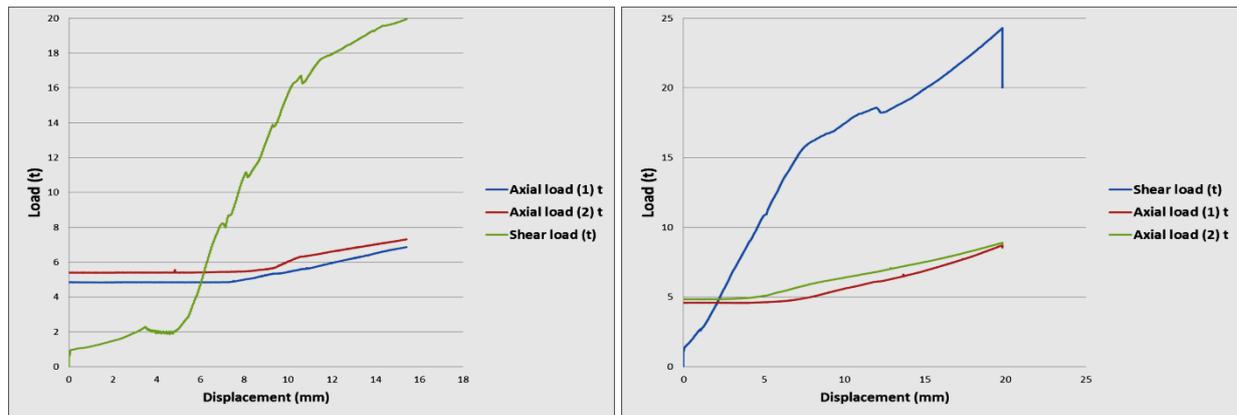


Figure 8: Shear and axial load profiles against shear displacement, left at 15 mm of shear displacement and right at 20 mm of shear displacement

For 15 mm of shear displacement;

- No damage was observed cable bolt sheath ,
- Deformation shear displacement of the cable bolt was recovered once the sample was dismantled,
- Cracks were observed on top of the concrete blocks once the steel cap was opened.

Figure 9 shows post-test picture of the second test where the maximum shear displacement set to 20 mm. The following main conclusions were obtained:

- No damage on sheath of cable bolt was observed,
- Permanent deformation of the sheathed cable was noted once the sample was dismantled,
- Cracks were observed on the top and side of the concrete blocks once the steel box was opened.

Clearly the vertical shear displacement of 20 mm appeared not to have caused any detrimental damage to the sheath, which entails that the enclosed cable inside the plastic sheath would not be exposed to an adverse environment. Triggering of the plastic deformation and cracking would be likely to occur at shear displacement beyond 25 mm as indicated from the initial single shear testing.



Figure 9: Post-test pictures of double shearing for 20 mm of shear displacement

CONCLUSION

No damage was noted on the protective sheath of the cable bolt when the double shearing assembly was subjected to 15 and 20 mm of shear displacement at the rate of 1 mm/min. Permanent deformation was observed on the protective sheath after 20 mm of shear displacement. The position of permanent deformation corresponds with the location of the concrete blocks joint. Triggering of the plastic deformation and cracking would likely to occur at shear displacement beyond 25 mm as indicated from the initial single shear testing.

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