New hybrid promises smaller crack widths

On the West section of London's Tideway tunnel, a brand-new type of hybrid tunnel segment will be under trial: one that is reinforced with a combination of steel fibres and glass fibre reinforced plastic (GFRP) rods.

Full-scale tests carried out by Professor Alberto Meda at the University of Rome Tor Vergata have already shown that segments reinforced with high-strength steel fibres and GFRP experience significantly smaller cracks when subjected to bending moments and thrust forces.

In bending tests, on metro tunnel-sized segments, the SFRC-GFRP segments reached a peak load 63 percent higher than the SFRC ones and the crack widths for the hybrid version were 60 percent narrower than the fibre-only ones. For point-load tests, crack widths were reduced by 37.5 percent under a load equivalent to the TBM shove load.

In a paper given to the Joint ACI-fib-RILEM International Workshop, Meda comments that these hybrid segments could be useful in situations where bending moments are higher. This could be at cross-passage locations or where cover is shallow.

Professor Colin Eddie, managing director at CECL-Global and a consultant to fibre manufacturer Bekaert Maccaferri, believes that the hybrid solution could help counter the biggest threat to the long-term serviceability of tunnels: cracking due to the TBM thrust force.

A study carried out by a major infrastructure programme revealed that the average rate of damage on any segmental lining tunnel is that one segment will be cracked every six rings, says Eddie. "They are cracked 99% of the time during shoving, the transient load case," he says. "Often, it's the rings on the outside of the curve that are damaged."

Even a small lip of 1mm between segments can cause uneven forces and hence cracking, says Eddie. Cracks close up once the thrust force is removed and the rings are acting in compression, but the bigger the crack, the less it closes up.

"Putting steel bar into underground structures is bonkers because if there are any cracks, it's difficult to demonstrate any design life," says Eddie. "Instead, we can put GFRP in the zone where it's doing the most work, that is in the perimeter of the gauge."

Meda's research was sponsored by GFRP rod manufacturer ATP Construction Composites and Bekaert Maccaferri. ATP has been making composite products for tunnelling for 30 years and its GFRP bars already go into many soft eyes. A patented technological breakthrough – the ability to manufacture a hook or stirrup in one piece – is what enables the segments to withstand high bending moments.

Prior to the hybrid tests, ATP had already carried out comparative testing between steel bar reinforcement and GFRP with the help of European funding. Broadly, these tests showed that the GFRP performed similarly to steel - exhibiting measurable ductility - but cracked at lower ultimate loads. It is the combination with steel fibres, specifically Bekaert Dramix 4D 80/60BG which show strain-hardening behaviour and crack width control, that has turned this technology into a really promising one, says ATP's general manager Nello Giamundo.

Hybrid segments will be used on the West contract for the Tideway wastewater tunnel in London, albeit in a temporary situation. Around 80 rings will be used at the launch and at junctions with side tunnels.

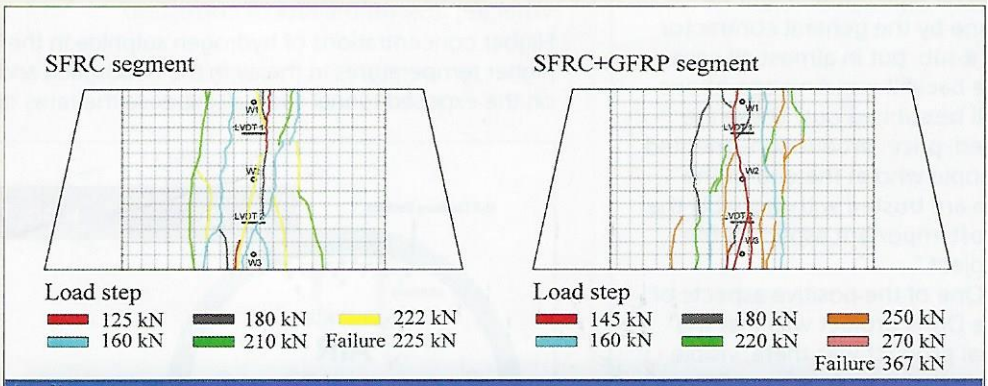
One factor blocking the uptake of the hybrid fibre and GFRP technology is the lack of codes. In the UK CIRIA has recently published a guide, but this is more relevant to structural applications such as bridges, with factors of safety for permanent rather than temporary (shove force) loads.

"The important thing now is to work on some standards," says Giamundo. "We have already developed a guideline, but that is just a start."

Meanwhile, design assisted by testing is permitted in Europe, says Eddie, under EN 1990: "We would argue that the tests that have already been done are a starting point. The performance of these materials is quite predictable."

ATP is also undertaking fire tests. The SFRC-GFRP material looks promising when looking at the fire loading required for rail and metro tunnels. The next step will be to carry out tests for the more onerous performance demanded for road tunnels.

Using a hybrid of high-strength steel fibres and glass fibre-reinforced plastic rods to reinforce tunnel segments leads to better crack control than using steel fibre reinforced concrete only



Loading							
Load [kN]	125	160	180	210	222	250	270
Crack width							
SFRC	<0.05	0.25	0.35	0.60	1.00	n/a**	n/a**
SFRC-GFRP	<0.05	0.10	0.15	0.19	0.35	0.45	0.70