The sea defence built with synthetic macro fibres

Blackpool sea defences are being built to protect 1500 properties and the seafront tramway from flooding. The new sea wall being constructed is the first of its kind to include synthetic macro fibres, namely STRUX 90/40, instead of steel. This concrete reinforcement solution is beginning to make inroads in the field of sustainable marine defences.

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(Photos: Grace Construction Products UK Ltd/SLP Precast.)

Figure 1: Vacuum machine lowering precast unit in front of toe beam.

The complete £62m reconstruction of the Blackpool seafront was always destined to be an impressive feat of maritime civil engineering. The new sea defences being built along 3.2km of Blackpool's shoreline are rapidly becoming a benchmark for the rest of the world. Grace Construction Products was called upon to supply its Strux 90/40 synthetic macro fibre technology to reinforce much of the concrete that is being installed along the length of Blackpool's promenade. It is the first time in the world that this technology has been employed for major reinforced concrete elements in marine coastal defences.

The project

The project began in September 2005, will take four years to complete and is designed to prevent shoreline erosion. The Central Area Coast Protection Scheme is a major part of Blackpool Council's ambitious regeneration master plan, which stretches from the Sandcastle Waterworld, near Blackpool's South Pier, to beyond the North Pier.

Grace's synthetic macro fibre reinforcement is being used in two main areas of the Blackpool project. It is being cast in-situ to create a 3.2km-long toe beam, which will hold 10,000 steel sheet piles firmly in place and act as a 'stop' to the sea defence steps, or revetment units, which rise from the toe beam to the promenade. It is also being used in the revetment units, which are being precast off site by SLP Precast, at a purpose-built factory near Blackpool.

The project is funded by the Department for Environment, Food and Rural Affairs. The main contractor, Birse Civils, commissioned Tarmac North West to supply the ready-mixed concrete and consultant designer, Halcrow Group, approved the choice of Grace's synthetic macro fibre to provide the reinforcement, following some innovative problem-solving by SLP Precast.

Trials

Following research and laboratory-based proving trials, full-scale production trials were initiated. In addition to steel reinforcement being replaced by the Strux 90/40 technology, other constituents were included in the concrete mix. These were:

- Grace's Adva Flow 410, a superplasticising admixture, which is added to reduce both the water demand and hence the water:cement (w/c) ratio of the concrete.
- Concrete 'Fylde Buff' colour, added so that the exposed surfaces of the precast concrete closely match the colour of the Blackpool beach sand.
- Polypropylene micro fibres, which are added to control the bleeding of water while the concrete is in the plastic state.

The addition of these four components, alongside CEM I, ground-granulated blast-furnace slag (ggbs) cement replacement, limestone-based aggregates and water, presented the concrete supplier with a challenge in repeatedly producing and supplying a consistent quality of ready-mixed concrete to SLP Precast from a dry batch concrete plant. Nevertheless, the initial trials paid dividends towards achieving a remarkable level of consistency early in the programme.

Project challenges

The use of synthetic macro fibres presented a fundamental challenge for SLP Precast in the production of the revetment units. With the absence of a steel cage, there were no lifting eyes present to enable the straightforward demoulding and lifting of each 20-tonne revetment unit. Therefore, the concrete revetment units were lifted out of the mould by suction. A Dutch firm was commissioned to build bespoke vacuum lifting machines, capable of lifting the units from the mould, turning them 180° for storage while curing and then relifting and lowering them onto lorries for transportation to the construction site. A vacuum seal could still be achieved when the concrete surface had been shot-blasted to provide a non-slip surface. These machines, which have a 20-minute failsafe lock in the event of a vacuum failure, are also being used on site to lift the steps and lower them into position.

Figure 2: Revetment unit being vacuum-lifted out of the mould.

Figure 3: Load testing of the revetment units.

Figure 4: Some of the first revetment units in place.

Figure 5: Loading frame to measure creep of cracked-fibre-reinforced concrete beams.

The revetment units sit four or five deep behind the toe beam, acting as both a seating area for holiday makers and a barrier to the sea – where each step gradually dissipates the force of the incoming waves. Each unit contains 8m³ of fibre-reinforced concrete. In total, approximately 2900 step units will be cast, equating to approximately 23,000m³ of concrete. SLP Precast produces five revetment units per day.

With regard to the in-situ concrete, the fibre-reinforced concrete is poured into steel formwork to create the 3.2km toe beam. One of the main concerns for Birse was to ensure that maximum efficiency was achieved in view of the restrictive tidal windows. The omission of steel reinforcement cages has proved to be a significant benefit. Working times vary considerably according to the height of tides and level of the beach, giving an average working window of only 8 hours per day. Birse has been pouring about 15 linear metres per day of the toe beam, compared with approximately 10m per day on previous jobs where steel has been used.

Using Strux 90/40 also removes the logistical problems of transporting and storing tonnes of steel fabric on site. Pouring the concrete into precast moulds off site, without the problems surrounding the placement of steel cages, has also speeded up that side of the operation.

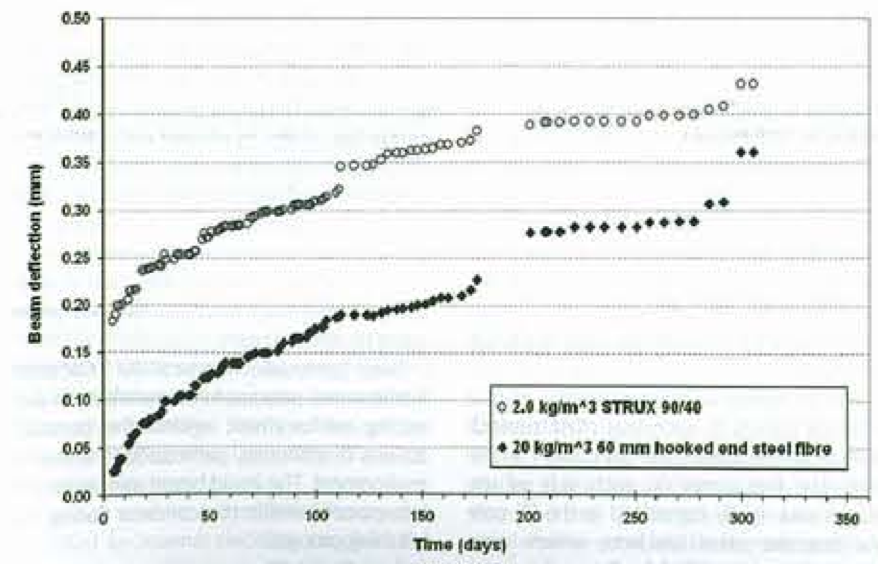

Figure 6: Increase of beam deflection under sustained load (without elastic part).

Long-term behaviour of Strux 90/40 reinforced concrete

In the past, there was limited information available about the long-term behaviour of Strux 90/40 reinforced concrete; neither steel-fibre-reinforced concrete nor macro-synthetic-fibre-reinforced concrete has been tested extensively to determine the creep coefficient of cracked FRC. Recent studies conducted by Bernard[1] on pre-cracked round fibre-reinforced panels, which he subjected to various amounts of sustained loading, showed that the creep coefficient of steel and Strux 90/40 reinforced sprayed concrete were comparable.

In 2005, an initiative was started to revise the existing guideline *Fibre Reinforced Concrete* published by the Austrian Society for Concrete and Construction Technology[2]. It was agreed to evaluate a standardised test procedure to measure the creep behaviour of steel and synthetic macro-fibre-reinforced concrete. With the financial support of several fibre suppliers, a testing programme was undertaken. In order to further investigate the difference in creep behaviour between steel fibre and Strux 90/40 fibre-reinforced concrete, W R Grace started a test programme to compare the creep of both materials based on the recommendations of the Austrian fibre committee.

Beams were cast at the Grace research laboratory in Cambridge, MA, USA. A typical floor mix design was used with a cylinder compressive strength between 35 and 40MPa, dosage rates were 2.0kg/m³ of Strux 90/40 and 20 kg/m³ of a 60mm-long hooked-end steel fibre. Since these were the first tests of a larger series, the dosage rates were not selected based on obtaining similar residual load-carrying capacities, but starting the tests with the lowest recommended fibre dosage rates. The 150mm × 150mm × 550mm beams were cured for 28 days in lime-saturated water before being tested in four-point bending. Instead of a final beam deflection of 3.0mm, the test was stopped at a beam deflection of 1.75mm. In addition, the relaxation of load response of the cracked-fibre-reinforced concrete specimen was recorded to determine the amount of the elastic energy stored in the specimen at a deflection of 1.75mm. The specimen was then carefully removed from the testing machine. Three specimens of each fibre type with approxi-

mately the same residual flexural strengths were selected and placed in a specially designed loading frame shown in Figure 5. The frame was loaded with weights until 50% of the residual flexural load-carrying capacity was reached.

This value was chosen by the Austrian Fibre Committee as a starting point for the evaluation of the creep behaviour of cracked-fibre-reinforced concrete, because this stress represents the maximum stress that will occur in a concrete section at the serviceability state, according to the current Austrian design guidelines for fibre-reinforced concrete. The load is applied in four-point bending and the beam deflection is measured with a mechanical dial gauge. Figure 6 shows the average deflection (in mm) under sustained load over time of the two fibre-reinforced materials.

The elastic part of the deflection, which was measured earlier, was subtracted from the long-term creep measurement. As can be seen from these results, both fibre materials exhibit similar long-term creep behaviour. The deflection of the Strux 90/40 reinforced concrete beams increases more in the first couple of hours compared to the steel-fibre-reinforced concrete beams. After that the slope of the curves are nearly identical. Creep measurement of these samples has been ongoing for one year and will continue. In the meantime, a second creep frame has been constructed so more tests can be conducted at the same time.

Contrary to the common belief that steel-fibre-reinforced concrete cannot creep since steel has a low coefficient of creep, the results obtained so far show that cracked steel-fibre-reinforced concrete does creep. This is not caused by creep of the steel itself but by slow pull-out of steel fibres from the concrete matrix and the interface which creeps. For synthetic macro fibres, a combination of creep of the fibre material as well as the creep of the fibre/matrix interface determines the overall creep behaviour of cracked concrete. Since Strux 90/40 has a high elastic modulus, which is achieved by stretching the film nearly to its limit during the extrusion stage, the creep coefficient is much smaller than that of synthetic macro fibres with a lower elastic modulus, which have not been stretched as much.

All the test results indicate that the creep behaviour of cracked concrete reinforced with STRUX 90/40 loaded up to 50% of its residual flexural strength will be similar to that of steel-fibre-reinforced concrete.

Conclusion

The design life of the new sea defences at Blackpool is 100 years and because Strux 90/40 has none of the potentially corrosive qualities of steel, which could have been a problem in the aggressive marine environment, the project for Blackpool Council will achieve this requirement. ■

References:

1. BERNARD, S. Creep of cracked fibre reinforced shotcrete panels. *Shotcrete – more engineering developments*. Bernard (editor), Taylor and Francis Group, 2004, pp. 47–57.
2. AUSTRIAN SOCIETY FOR CONCRETE AND CONSTRUCTION TECHNOLOGY. *Fibre reinforced concrete*. 2005.