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HEAD TO HEAD

Design and construction of head structures at Hinkley Point C

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RESEARCH AND DEVELOPMENT

Reducing the carbon impact of sprayed concrete

HEAD TO HEAD

Graham Booker and **Lorna Johnston** of **Balfour Beatty Major Projects** report on the design and construction of six concrete head structures – part of the cooling-water system at Hinkley Point C, the UK's new nuclear power plant.

Despite the outward appearance, the six concrete head structures constructed at Avonmouth Port for EDF's Hinkley Point C (HPC) project are among the most (if not *the* most) complex, concrete structures ever constructed in the UK. They form the critical inlets and outlets for the water-cooling system that is required for the two new nuclear reactors being constructed in Somerset. These are the first in a new generation of nuclear power stations in the UK providing low-carbon electricity for approximately six million homes. Marking a significant milestone in the revitalisation of our nuclear power industry, HPC will make a major contribution to the UK's move to net zero by 2050. The electricity generated by its two reactors will offset 9 million tonnes of CO_2 emissions a year over its 60-year lifespan. Construction and operation of HPC will create 25,000 employment opportunities and up to 1000 apprenticeships and 64% of the project's construction value is predicted to go to UK companies.

KEY DIMENSIONS

The six head structures consist of two designs – intake and outfall head – with two heads placed above each of the three cooling-water tunnels. The four intake heads placed above the two water-intake tunnels are circa 41 × 17m and weigh approximately 4500 tonnes each, containing approximately 100,000 individual steel bars weighing 725 tonnes. The two outfall heads placed over the outfall tunnel are somewhat smaller, at 16 × 16m with a weight of approximately 2600 tonnes, each with 55,000 bars weighing 240 tonnes.

DESIGN

HPC is the first nuclear power station to be built in the UK for over 30 years and a heightened resilience for design is expected. While the geometry was determined by EDF, Jacobs, as the lead designer for this design-and-build project, undertook the complex task of designing the heads over a period of six years. Their bespoke geometry is unique due to their placement in the Bristol Channel, which boasts the second largest tidal range in the world. For this reason, the intake head structures' elongated nosing design creates a laminar flow of water, reducing the risk of foreign objects from entering the cooling system.

As a safety-critical element of the nuclear power station, the heads

Close-up of the complex geometry of the nosing and exterior of screen chamber.

(Photos: John Zammit/Absolute Photography Ltd.)

Within the 43.6m-long intake head screen chamber. Water from the Bristol Channel will enter the structure between the 2m-high concrete slot walls and baffle screens formed of a copper–nickel alloy, shown on the left. These screens are designed to direct a laminar flow of water into the structure along the length of the screen chamber. The water will then drop into the lower screen chamber on the bottom of the photo, before entering the shaft from where it will head along the tunnel towards the onshore ponds within Hinkley Point.

hold heightened safety factors and load cases for all eventualities, such as ship impacts and a 1-in-10,000-year seismic event. A finite-element model was created for each structure, which combined over 27,000 nodes and 6000 load case combinations creating two terabytes of data, with the largest analysis taking two and a half days to run.

The cooling-water intake design includes a fish return system and low-velocity side-entry water intakes. The low-velocity side-entry intakes reduce the speed of the water being taken into the cooling pipes and are installed sideways to the tidal flow. This reduces the risk of fish entering the pipes. In addition, filtration systems called drum screens and band screens will be fitted in front of the cooling-water pumps to protect the power station from clogging with seaweed or marine debris. These have been designed to carefully transfer fish to the return system and back to sea.

CONSTRUCTION

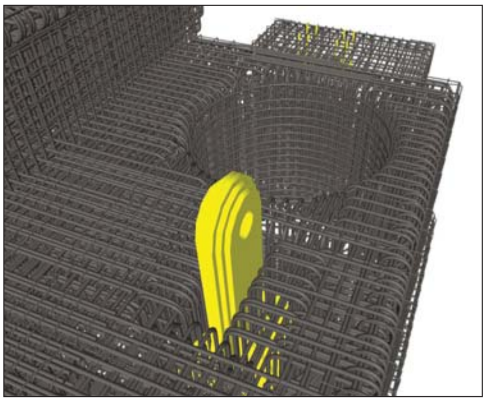
The heads boast an exceptionally complex reinforcement design with an abnormally high steel density. The average reinforcement density in the heads is 550kg/m^3 with areas that peak at 872kg/m^3 in the foundation chamber; this is two to three times more than a general civils build. Unique challenges were created, requiring detailed sequencing as the steel fixers struggled physically to fit their hands between bars to tie the reinforcement together.

With a nuclear specification and tight positional tolerances, every single bar in each of the heads was checked with a quality process involving four separate parties. Constant collaboration from the client, designer, subcontractor and supplier was vital for this process. To aid the process, an electronic check sheet was developed, which streamlined the quality process and contributed significantly to the lifetime record requirements, as well as reducing resources and time.

MODEL

To assist with the complexities of constructing such a feat, specialist consultant ADDA developed a 3D model. Combining over 900 reinforcement drawings into a 3D model was an extensive task, which proved vital for the construction of the heads. Initial analysis identified over 100,000 clashes, which prompted a repositioning and redesign process to mitigate risk and ensure complete buildability; effectively all clashes were removed.

ABOVE:
The reinforcement placed around the lifting lug and pile sleeve.



ABOVE:
Extract of lifting lug and pile sleeve reinforcement from 3D model.

During construction, the 3D model was paramount to success and was constantly in use by the steel fixers, engineers and wider site teams. The model was used as a virtual reality tool in the early stages of the project to visualise the works and upcoming sequencing. In terms of quality, the model was used to track construction progress and ensured every bar in the heads was checked and signed off.

An added benefit of this modelling emerged during the Covid-19 pandemic when it assisted in the review of social distancing measures to enable safer working. The site stayed operational during the pandemic and with the reduced team on-site, many site walk arounds and visualisation were undertaken using body camera technologies alongside the model.

MOCK -UPS

To facilitate the construction of the heads, several full-scale mock-ups were built to replicate complex areas such as the intake head nosings and central shaft. The construction and learnings taken from the mock-ups prompted several design iterations and resequencing works. The process enabled confirmation of concrete placing practices, including compaction, and ensured that the concretes were able to flow satisfactorily around the congested reinforcing bar, as well as confirming poker positions.

In a number of critical areas, miniature inspection cameras linked to on-site iPads were used to monitor concrete supply and behaviour around reinforcement and encased items. This was key for ensuring both the lifting points were fully encapsulated and adequate concrete flow during the nosing pours, which were fully obscured by formwork.

CONCRETE

Each intake head consisted of 11 individual pours, ranging from base pours of 600m^3 to smallest pours of 2m^3 for the slot walls. The geometry of the major pours was such that there was concern that the temperature profiles could exceed the specified maximum limit of 65°C imposed by the specification to prevent delayed ettringite formation. A second specification requirement limiting the core-exterior temperature differential to below 25°C was also challenging. The mix design was optimised to enable the use of high proportions of GGBS within the cementitious content and this assisted in controlling the rate of rise of temperatures. The 25°C differential temperature presented a challenge during the winter months when temperatures dropped below 0°C. During temperature extremes in winter and summer, the thermocouples were monitored closely and provided justification of timely application of further insulation and when to remove it.

The application of CIRIA 766(1) was key to controlling the temperature risk by influencing the pour size, placement temperature of concrete and requirements for post-pour curing. To manage this aspect of the project, Balfour Beatty engaged Dr Phil Bamforth, author of C766, to assist in the planning of each pour. These plans were regularly reviewed and updated throughout the programme to take account of ambient temperature conditions expected for each pour. On-site temperature monitoring was undertaken by the Balfour Beatty UKAS-accredited laboratory, requiring the installation of thermocouples in key strategic locations in each pour. This enabled Dr Bamforth's modelling to be validated and provided the as-built evidence essential to a nuclear project. Due to this extensive modelling and good site practice, there were no exceedances of peak temperature limits.

LEFT:
Two of the intake heads nearing completion at Avonmouth Port.

CONCRETE MIX DESIGN

The specification requirements for the mix design process are comprehensive, consisting of several stages for trials prior to acceptance for use. The main stages can be summarised as:

- development trials – undertaken in a laboratory to identify suitable mix designs
- nominal mix trials – formal laboratory trials to demonstrate that the preferred design is robust and can be replicated several times
- sensitivity trials – formal laboratory trials where the cement and water fractions are changed by the batching tolerances to give wet and dry concretes
- suitability trials – these are formal plant trials where several batches are produced and tested to demonstrate that the laboratory trials can be replicated at the industrial scale.

Before the formal trials could be progressed, over 100 development trials were undertaken within the Balfour Beatty laboratory, or at the Hanson Chipping Sodbury or Sika laboratories. These ensured that the constituents could be optimised for the two main concretes, both of which are C45/55 strength class, with a maximum water:cement ratio of 0.40. The two mixes consisted of one to be placed and compacted conventionally and the other as a self-compacting concrete for the areas of congested reinforcement. Both concretes contained 10mm Mendip limestone aggregate due to the congested reinforcement, as well as a blend of tightly controlled limestone crushed rock fines and land-based natural sand.

CONCRETE SUPPLY

As with the rest of the HPC project, concrete was batched by Hanson Concrete under a partnership arrangement to operate the site plants. The on-site batching plant at T-Berth (the site location at Avonmouth Port) was specified to ensure that consistent high-quality concrete could be provided to both the heads and the adjacent factory producing the precast tunnel segments, including several admixture dosing lines. To address the risk of back-up supply during the concrete pours, Hanson erected a second dedicated plant within the area of its cement terminal at Avonmouth Port. This second plant was used as the primary source of concrete for the heads, while the T-Berth plant was reserved for supplementing supply for the larger pours and as a back-up in case of breakdown, as well as the routine supply to the precast segment factory.

The temperature elements of the concrete deliveries were assisted by the installation of both water heating and chilling equipment, as well as experimentation with the addition of dry ice in peak summer conditions.

TECHNICAL SUPPORT

To provide the technical support required for the project, Balfour Beatty established an on-site materials team with a dedicated UKAS-accredited laboratory equipped to undertake a large scope of testing methods for the concretes and their constituents. This facility supported both the heads construction and the segment production in the adjoining factory, operating on a 24/7 basis. Among the range of constituent tests undertaken on deliveries to the batching plants, the laboratory achieved the distinction of being one of only four organisations accredited by UKAS for a range of cement and GGBS testing, including fineness, prism strength, soundness and setting time. Each delivery to the plant was inspected prior to discharge and modifications were made to the silos to enable samples to be obtained during the unloading process, as well as being visually checked.

THE FUTURE

Now that the heads are constructed at Avonmouth Port, the engineering complexities are not over, with the immediate commencement of the 'Phase 2' Offshore Campaign. This campaign involves the installation of the handling alignment frames, which will tower above each head, doubling their height to approximately 23m. These combined structures will then be transported using self-propelled modular transporters onto a barge and taken to their installation site in the Bristol Channel. Using two of the largest sea cranes in the world, the heads will be tandem lifted and lowered into position on the seabed to exacting tolerances.

Many lessons have been learned from the construction of the head structures and these will be taken forward to future projects by all parties. The use of 3D-modelling processes on such a large scale will enable future designs to be undertaken with zero clashes and massively reduce the amount of rework and changes required. The industry need never be the same again. C

Reference:

1. BAMFORTH, P. *Control of cracking caused by restrained deformation in concrete*. C766, CIRIA, London, December 2018.