Tech Excellence

POWER OF CONSISTENCY

Hinkley Point C is the UK's first new nuclear build since the 1990s. For operator EdF it is a crucial chance to prove it can build a mega nuclear scheme to time and budget. Innovation is vital, reports **Emily Ashwell**.

Much more rests on the £19.6bn project to construct the Hinkley Point C nuclear power station in Somerset than the ability to power 6M homes.

Everyone is bearing the pressure to get it right – from the shovel drivers at a nearby Somerset quarry who wash the wheels of their vehicles to ensure the quality of the raw materials being delivered to Hinkley is as pure as possible, to the team of 48 planners painstakingly mapping out each element of work on the construction site.

This is because the political, economic and historic context of the construction of Hinkley Point C, means that successful delivery could pave the way for more nuclear new builds in the UK and overseas.

Some UK politicians are doubtful about Hinkley Point C's economic case. French energy giant EDF is delivering the scheme in conjunction with the China General Nuclear Power Group (CGN). Going over budget or time could damage EDF's plans for another nuclear power station, Sizewell C in Suffolk.

In France, where more than 70% of electricity generated comes from nuclear power, the energy firm needs investment to overhaul the country's ageing fleet of reactors. The Flamanville 3 new build in Normandy is now notorious for having been delayed by several years and has gone over budget by hundreds of millions of pounds.

So it comes as no surprise that EDF and its contractors are under more than the usual amount of pressure to get Hinkley Point C right.

"One of the biggest challenges we had was take best practice from the industry and some of the key lessons learned from other projects and make sure that they were embedded here," says EDF Hinkley Point C delivery director Nigel Cann (*see interview p18*).

In detail, this means looking carefully at what triggered the delays and cost increases on Hinkley's predecessors and heading them off. The result is a series of construction innovations that have so far resulted

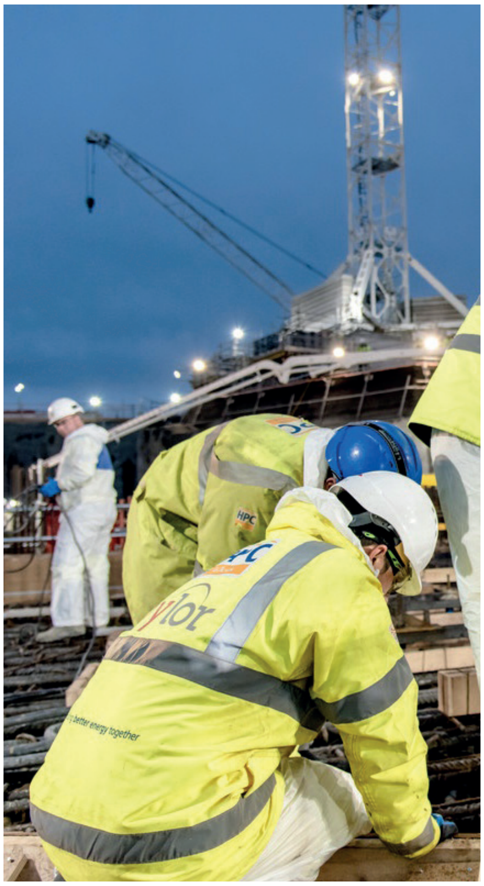
KEY FACTS

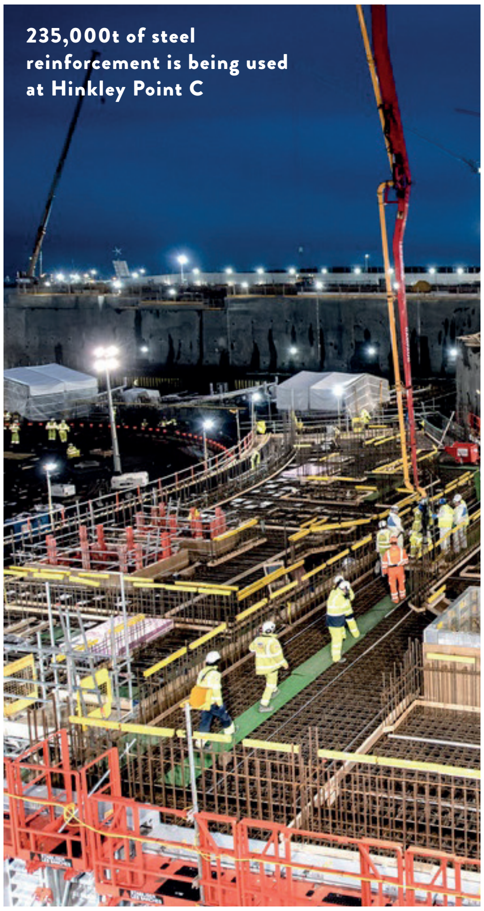
3M.t
Amount of concrete required

£2.8bn
Value of main civils contract

4,500t
Weight of Unit 1 base

> "One of the biggest challenges we had was to take some of the key lessons learned from other projects





235,000t of steel reinforcement is being used at Hinkley Point C

Concrete for the 4,500t nuclear island was poured in 30 hours

in the project having a 97% right first-time rate.

Hinkley Point C is on the north Somerset coast. The 176ha construction site for two European Pressurised Water Reactors (EPRs) – Units 1 and 2 – sits alongside an operating nuclear power station, and one being decommissioned.

Construction of the new power station started at the end of 2016. Enabling works are substantially complete and excavations for Unit 2 are nearing the finish line. A Kier Bam Nuttall joint venture (JV) has the £203M enabling works contract, which involves excavating over 5.5M.m^3 of material, building terracing structures and creating a road network. Costain is due to finish the 500m long jetty, which will handle raw materials delivered by ship in March, while Balfour Beatty has the marine works contract to build the three tunnels needed for water intake and outfall.

Milestones for the main civils construction work are now being ticked off – December's concrete pour on the first part of Unit 1's 4,500t base was a major one. The Bylor contractor JV of Bouygues and Laing O'Rourke has the deal worth over £2.8bn for the reactor buildings and main civils works.

So where is EDF and its tier 1 teams looking to learn lessons and what is being done differently?

Huge importance has been placed on concrete production – 3M.t is needed. Problems with concrete at other nuclear power station builds have caused costly delays. Flamanville suffered from cracking or poorly compacted concrete. Finland's Olkiluoto 3 – not an EDF project – had too much water in some of its concrete mix impacting strength.

Consistency and quality are the two key drivers for concrete production at Hinkley Point C. Engineers have been working on mixes since 2012, with testing at the Bouygues lab in Paris resulting in a 150 page technical report for each. An 18 month programme to mock up and test the batching plants was also undertaken.

"What we're trying to develop is a product that's so consistent, that when the [workers] on site are placing it, compacting it, finishing it, they do the same over and over again over the next six years," says Bylor chief materials engineer Peter Abel. "So, if there's a change, for instance if we're losing workability too quickly or it's a bit sticky or heavy, [the workers] might change the way they're placing and curing it, which is

> **"Consistency and quality are the two key drivers for concrete production at Hinkley Point C**

exactly what we don't want."

Aggregates come from Hanson quarries, many of them local. Abel says that it is less the mix of concrete that makes it suitable for nuclear, and more the way it is handled. "What is nuclear concrete? Nuclear concrete is everyone involved knowing what they're doing, why they're doing it and maintaining it. The actual mix design isn't that special, but it's the way it's handled and treated and tested and maintained which is the nuclear bit."

There are simple tests and surveillance methods throughout the process. "One of the biggest things you can do wrong is put the wrong powder in the wrong silos," says Abel.

In addition, high performance microwave moisture probes are used to monitor water content. There are also probes within the mixer, and the mix is controlled by a machine, not an operator.

The batching plant operator normally uses experience and judgement in the final mix, tempering adjustments before completing the batch, but at Hinkley Point C the adjustments are by a specially calibrated machine.

"You lose a little bit on output, but you gain massively on consistency," says Abel.

The result is that the plants at Hinkley Point C are producing the lowest standard deviation concrete in the UK, according to Abel. He says a good UK batching plant will produce concrete with deviations of about 5, but at Hinkley it is typically producing concretes below 2.

Standard deviations are the result of tests on the ingredients, and strength of the concrete. Higher values indicate changes in the composition of the concrete.

"All the quarries know what they need to produce because we treat them as the same team as here. If we didn't have that control, there would be variability. I have never had such good control over the inbound aggregates," he says.

Alongside the base of the structures, Bylor's concrete work

> **"We've planned our pour timings like an orchestra**


Construction on site in August 2018, showing the Unit 1 base in the foreground

will include the housing for the two reactors and prefabricated components for the fuel buildings, which sit adjacent to the reactors. Prefabrication of elements for the fuel buildings aims to cut 18 months off the construction programme and reduce insitu welding by 45%.

The 57m diameter cylindrical reactor buildings are designed with a 1.8m thick reinforced concrete domed roof and will be around 64m tall. The reactor buildings have a double-wall containment structure and a reinforced concrete foundation slab. A cross section of the reactor design shows the outer concrete wall, and then a gap which will be maintained at sub-atmospheric pressure to enable radiation leaks to be collected, within an inner containment wall with a leak-tight steel liner.

The team has developed an app for delivering the concrete to site that produces a running order for concrete production each day. These timings are cascaded across the project, so everyone can see what concrete is being delivered where and when.

All this has contributed to the successful first pour for the foundation slab or nuclear island for Unit 1. The pour was undertaken continuously over 30 hours requiring just under 2,000m³, forming a maximum 3.2m thick slab, reinforced with steel from south Wales.

The main concrete was a C40/50 mix with a cem3b low heat cement.

Workers poured a specially developed low heat concrete mix which could be revibrated up to six hours after placement.

"We've planned our pour timings like an orchestra, so by the time we placed this layer and stepped back to put the next layer on top, the concrete is in tune with that movement," says Abel.

One of the key elements of Hinkley Point C's concrete mix is ground-granulated blast-furnace slag (GGBS) from Port Talbot in south Wales. A by-product of steel manufacturing, It helps to lower and control adiabatic heat generation in mass concrete.

While GGBS is commonly used in concrete, at Hinkley it will be the first time it has been used in an inner containment building.

Although most of the mixes used in the various Hinkley Point C structures contain constituents from local quarries, the particular mix for the containment building also includes a special low heat cement from the South of France. It has taken five years to fully develop and samples are currently undergoing load testing at the University of Dundee.

"We need 10,000t, which is a smallish volume, but this concrete is the most important concrete on the project. The cement is very pure, very consistent, and has a natural low heat. By blending with GGBS, it helps to manage heat and hydration," says Abel.

The concrete for the reactor buildings must be able to withstand everything from a tsunami to an aeroplane collision.

It is with the construction of the reactor buildings that the team is also learning from the steel construction problems at Flamanville. On that project, the reactors' containment buildings were fabricated on site and comprise 150 steel panels. There, workers were hampered by bad weather and welds

TIMELINE – OTHER EPR PROJECTS

The two Hinkley Point C reactors are European Pressurised Water Reactors (EPRs). Each will produce 1.6GW of power. They have been designed by EDF and Areva.

Engineers spent 850,000 hours studying the design for the third-generation pressurised water reactors for Hinkley. Assessment of the EPRs by the Office for Nuclear Regulation (ONR) took four years.

At the end of 2018 the first EPR nuclear power station went into operation at Taishan in China. This was another EdF and CGN project.

Construction of what was supposed to be the first nuclear power station using the this technology began in Olkiluoto, Finland in 2005. It is not expected to go into full operation until 2020, 11 years late.

Flamanville C in France was due to come into service in 2012, after construction started in 2007. The opening date has been pushed back to 2020.

Hinkley Point C is due to come into operation in 2025, construction started in 2016.


Taishan nuclear power station

were deemed substandard. This caused delays and cost hikes as they were re-done.

As well as concrete, Hinkley Point C's containment liner includes a 6mm thick steel plate, which will be prefabricated in six major components. These include four huge rings to line the cylindrical reactor building, as well as the dome. Prefabrication will be undertaken at steel manufacturer Tissot's works near Bordeaux in France. It is there that Tissot hopes to do as much of the welding as possible.

Some welding will still have to be done insitu, and a huge temporary works shelter is being built, so that this work can be done under cover.

"At Flamanville, welding was disrupted by wind and weather. The impact of weather can cost two months per year," says Bouygues services director Jean-François Persegol.

At Taishan in China, another EDF/CGN nuclear new build, the first four liner rings were also prefabricated, with the results boding well for Hinkley Point C. Engineers there found they took 25 days to construct a ring, compared to 40 at Flamanville.

Persegol explains that offsite prefabrication is vital at Hinkley as it enables work to be done in a more controlled, less time stressed environment.

When it moves to the mechanical, electrical and heating, ventilation and air conditioning installation stage, contractors will have to co-ordinate cabling and pipework in 2,500 rooms throughout each unit of the power station. The MEH Alliance of Altrad, Balfour Beatty Bailey, Cavendish Nuclear and Doosan Babcock is in charge of this work and EDF is again drawing on lessons from Flamanville. Given 235,000t of steel reinforcement bars have to be set in concrete, the Hinkley Point C team does not want to repeat clashing problems at Flamanville, where some of the steel had to be moved to make way for other components later in the project.

To avoid this at Hinkley Point C, there is an extensive 4D modelling programme, showing in detail where every component goes – what Bechtel 4D team manager at Hinkley Point C, Andy Codd, describes as a "Russian doll of Rubik's Cubes". Workers can access the full design on tablets and although this has been done before, the team at Hinkley Point C says it has never been done to this scale.

"You'll have more than [a total of] 4,500 rooms just in the main nuclear island units, which are mainly replicas of each other with some differences. So, if you take that grand scale of the universe looking down, we did a calculation on how much data we're really handling and it is approximately 1,700 items to be fitted in each of those rooms," says Codd. "I have never been on such a complex project in terms of the amount of numbers and data there is. We're trying to organise a digital twin to predict the issues that will come out in the future."

It is this digital twin of Hinkley Point C, with all the de-clashing undertaken, which will wipe out massive time issues and aims to create 20% in cost savings for the building of Sizewell C. N

CONCRETE BATCHING PLANT

With names like Batts Combe, Masters and Gurney Slade, the constituents used at Hinkley sound more like the list of craft ales you would find at a local Somerset pub than concrete constituents.

But these constituents will be delivered via the Severn Estuary, on to the temporary jetty and into one of the site's three concrete batching plants. These plants do not just supply the Bylor JV building the reactor, they also supply concrete for earthworks, marine works and the jetty.

Each plant has an aggregate ground storage capacity of 50,000t and each overhead aggregate storage bin capacity of 100t. The mixer capacity is 140m^3 per hour. Each concrete batch must comply with nuclear regulations.

Teka TPZ 4500 planetary mixers were specified for the plants, with each having special automatic cleaning equipment fitted to remove residue from previous mixes. ConSpare CDX mixer dust extraction systems were specified to manage dust containment.

> "Hinkley Point C is a 'Russian doll of Rubik cubes'"

Artist's impression of Hinkley Point C

DATA TALK

Digital images can improve asset inspections, so why is the industry adoption so slow? **Emily Ashwell** reports.

Collecting tunnel condition data using a digital camera

Increasing the use of digital imagery in asset condition surveys has game changing potential.

Technology which can collect data about the condition of, for example a tunnel, using arrays of digital cameras fixed to moving vehicles, is already available.

The digital images can be processed to produce visualisations of the tunnel's condition. Machine learning tools can be trained to automatically identify defects, particularly through object recognition technology.

It initially sounds like a simple route to huge savings in time, increased health and safety and increased assessment accuracy. But as with many new technologies, the headline benefits belie the complexities of getting industry adoption.

A new study undertaken by Arup has been examining the barriers to greater uptake of computer vision technology.

With funding from industry innovation group i3P, the consultant was commissioned to investigate the potential of integrating computer vision techniques with current and future asset management processes.

Arup associate director Mike Devriendt led the study. "If you go back 10 or 20 years it was all very manual – an engineer with a clipboard would stare at things," he says. "We found that when you then go back in successive years it is very difficult, for example, to look at a tunnel after construction works have been carried out close to that asset, and see whether the condition of that asset changed with time.

"The record keeping is notoriously not great in terms of being able to tell how things have changed."

Of course, digital imagery is already in widespread use in the industry through mediums such as laser scans, mobile sensors and thermal scans. However, the study wanted to examine the potential for use of digital images combined with machine learning, getting to a point where a physical inspection would only be used in the event of an anomaly.

In the UK 40% of construction expenditure goes on repair and maintenance, with infrastructure brining in a £8bn bill. Inspections are key to making decisions about how this money is spent.

The Arup team decided to examine the barriers to adoption with a particular focus on the tunnels sector, undertaking interviews with clients such as London Underground, High Speed 1 and Network Rail.

The advantages of this technology are clear. From a health and safety point of view, using this technology means fewer engineers have to set foot into the potentially dangerous environment of tunnels. In addition, there is a level of automation which, if managed, can be a basis for planning maintenance.

"Rather than taking the odd photo of different defects, you capture entire images over however many kilometres

KEY FACTS

40%
Amount of construction spend that goes on repairs and maintenance

> **"Record keeping is notoriously not great in terms of being able to tell how things have changed**

> Rather than taking the odd photo of different defects, you capture entire images over however many kilometres of tunnel you're looking at

of tunnel you're looking at. So, you always have a source of truth of what the condition of the asset is at any given stage.

"It could be video, it could be a sequence of images which you then stitch together, which you can then the present in an immersive Google Streetview type view, or in CAD based view – there are various different softwares that can do that. This helps if you're trying to develop augmented reality-based models or want to use it as part of a building information model," says Devriendt.

Although using the technology initially sounds like a no-brainer, to Arup's surprise, the study found many major clients are still undertaking asset inspections in a very physical way. And the barriers to adopting inspection technology are complex.

The first issue to overcome was the perception of "black box" technology.

"As soon as I mentioned machine learning, peoples' eyes glazed over," says Devriendt. "But what asset owners want is 100% surety. Some of the interviewees had had suppliers turn up saying 'we can run these algorithms through', but when the client has compared the outcome to manual inspection, it has not been favourable."

Devriendt is concerned that if clients get a poor first experience of using this technology it will damage take up of computer vision technology and ultimately mean its benefits are not realised.

Some of the interviewee replies might suggest the technology is not quite ready if the clients said physical inspections were better, but this also might suggest there is a need for an industry bench test of the technology, according to Devriendt.

The goal is to automate data collection in previously dangerous environments

A benchmark test could involve an asset owner or supplier providing thousands of images, which are all fed into an algorithm.

The asset owner already knows what the asset's defects are (based on previous detailed manual inspection), so the technology supplier's claims and trained machine learning algorithms can be tested against this knowledge. If the technology comes up with the same answer, the asset owner can be sure of the effectiveness of the technology.

Arup is now keen to continue working with i3P to get more funding to take the project on to develop benchmark tests for the industry.

"We are trying to work to set industry standards. Otherwise there is a risk of undermining the potential in the industry with asset owners putting their toe in and having bad experiences. I fear unless these things are set up properly, you'll get a loss of confidence," says Devriendt.

The work to set up a benchmark test also raises the issue of intellectual property (IP). How willing would clients be to share their images and data with the industry to bring about industry-wide benchmark tests?

If a contract says that all background and arising IP is owned by the client, that may limit the supply chain's willingness to offer up machine learning algorithms they have developed. This is particularly so considering the algorithms will naturally develop arising IP from the training process.

The study found that interviewees thought getting agreement about IP would be challenging, particularly if rigid and non-collaborative contractual terms are used. Using terms that allow arising IP to be commercialised by all parties or use of preferential licence agreement was mooted.

Adopting new technology does not automatically happen when the software is developed. As Arup's study found out, if the industry is to innovate, there must be discussion and collaboration to ensure that take-up works for everyone. N

OUT OF THE ASHES

Engineering consultancy Clarkebond has spent the last decade rebuilding itself into a firm which sticks to its core competencies, but works entrepreneurially wherever these competencies are needed. **Emily Ashwell** reports.

Based in Bristol's docklands, in the shadow of one of the world's greatest engineers, consultant Clarkebond embodies the engineering and entrepreneurial spirit of the city's forefathers.

The office is just yards from Brunel's *SS Great Britain*, which when it was launched in 1843, was the world's largest and fastest ship.

Today Clarkebond – which recently undertook the structural engineering for the city's new Being Brunel museum – also has its eyes on far horizons. It is now delivering engineering projects globally, including gearing up to help rebuild Caribbean communities recovering from hurricane damage.

Clarkebond may be helping to rebuild other countries, but it has also recently emerged from an extensive rebuild itself.

During the 2009/10 financial crisis the firm went into administration, getting severely burnt Carillion-style from unpaid overseas contracts and some regional under-performance while getting into debt after buying another practice. As a result of the administration, staff numbers went down from 200 to 45.

KEY FACTS

£6M
Clarkebond turnover

1946
Year Clarkebond was established

Commercial director Neil Marks reflects: "As the financial markets tightened, so the overdrafts were reduced as we owed more money. In the end we had no headroom to operate."

The team tried to do a management buyout but was outbid by an Irish entrepreneur, recognising a good core business. The firm is still owned by the same holding company today.

It has been a long and challenging journey rebuilding the firm. It was unable to bid for public sector work for three years after administration, but it had some clients – including local property developers such as Deeley Freed – who kept a steady income coming in.

> **"We positioned ourselves anywhere because we had to rebuild**

"We positioned ourselves anywhere, because we had to rebuild," admits Marks.

"We had to grub up work, as my old boss used to call it. We used to get work wherever we could, although we still had some long-term clients who looked after us."

Today it is a different picture for the firm, which was set up in 1946 to help rebuild Bristol and the surrounding area after the War. It is now heading towards 100 employees and has cautiously built itself back up. The firm's longevity is apparent in a walking tour of the centre of Bristol. On almost every street where there is an iconic building, Clarkebond, has at some stage over the last few decades, worked on it.

Clarkebond focuses on its core disciplines of civil and structural engineering, although it also covers geotechnical engineering, has a traffic and transportation department, and undertakes some flood risk and hydrology. There is a rough 50:50 split between structural and civil engineering and the firm has

Marks channels the spirit of Brunel

> We look to do what we do well, in more markets and over a wide geographical area

a turnover of around £6M. It says its reputation put it in good stead through the difficult times.

"We're not embarrassed about making money, we have got to survive. We just want to do what we're supposed to do and get paid what we're supposed to get paid for. I have a very simple view in life; if everybody does what they're supposed to do, generally things work out quite well. It's only people that make it complicated," says Marks.

The business strategy is to stimulate growth by throwing its geographical catchment area wider. With the experience of administration still raw, it is looking for steady, organic growth, slowly building up the business while staying stable.

"We are into diversity in everything we do except for our core discipline. We look to do what we do well, in more markets and over a wide geographical area," says Marks.

Through this strategy, it has a number of overseas projects on the horizon and has been working with the Department for International Trade to gain new opportunities, including winning a grant to research new markets.

On the tiny Caribbean island of Dominica, which was devastated by Hurricane Maria in 2017, Clarkebond has plans to work with architecture charity Article 25 to support the delivery of 1,700 new homes as part of the recovery effort.

Given its past experience with payment problems from overseas work, this time round Marks says Clarkebond is "going in with its eyes open" and prefers opportunities funded through established institutions such as the World Bank or the Caribbean Development Bank.

Back in the UK, it has just won its first place on a Network Rail framework for the London North Western route, which Clarkebond – whose management has rail experience – describes as a "foot in the door" after two years of knocking.

Other projects it is currently working on reflect the locations of its three offices. The Exeter office is working on a new accident and emergency department at the city's hospital. The Bristol team is working on new structures at Hinkley Point C nuclear power station and the London office is working with Wates on a huge £1bn regeneration site in the London Borough of Havering, where it will deliver civil and structural engineering.

Marks says that staff numbers are fed by graduates and apprentices, with students coming from its links with education institutions including the University of the West of England and Surrey University.

In Bristol, where many of the multinational consultants have offices, the competition for staff is tough, though it currently sponsors students ranging from those undertaking entry-level apprentices through to those studying for masters degrees as a way of encouraging them to join when qualified.

"There are big outfits everywhere. With the big corporates' slick machine, they can go in and get the graduates because the students probably perceive that is where they will get the best training and career moves. But it is not necessarily the truth. We want engineers who can span a broad area of technical expertise and sectors and our projects are very diverse," says Marks.

He cites the example of an engineer who started at its Exeter office as an apprentice, did an HNC degree and has been out to work in Myanmar where Clarkebond is undertaking civil, infrastructure and drainage expansion for its largest public hospital, the Yangon General Hospital.

Clarkebond's strategy is one of steady growth, with a clear strategy of sticking to what it knows. But when it comes to the actual engineering, the firm is keen to show the world that it punches above its weight. N