CONNÆCT

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First Edition 2007

North extremities

Rock anchors secure Kjøllefjord Wind Project, Northern Norway

World LNG consumption soars

Post-tensioning technology meets demand for storage

Speedy solution

PT systems expedite Shopping Centre Expansion in Salzburg

Second longest & environmentally friendly

Stay cables suppport the Green Bridge, Brisbane, Australia

MSS helps Bangkok beat congestion

Industrial Ring Road Project, Thailand

THE MAGAZINE OF THE GLOBAL BBR NETWORK OF EXPERTS

A Global Network of Experts

www.bbrnetwork.com

BBR is recognised as the leading group of specialised engineering contractors in the field of post-tensioning, stay cable and related construction engineering. The innovation and technical excellence, brought together in 1944 by its three Swiss founders – Antonio Brandestini, Max Birkenmaier and Mirko Robin Ros – continues, more than 60 years later, in that same ethos and enterprising style.

From technical headquarters in Switzerland, the BBR Network reaches out around the globe and has at its disposal some of the most talented engineers, technicians and the very latest internationally approved technology in the world.

The Global BBR Network

Within the Global BBR Network, established traditions and strong local roots are combined with the latest thinking and leading edge technology. BBR grants each local BBR Network member access to the latest technical know-how and resources – and facilitates the exchange of information on a broad scale and within international partnering alliances. Such global alliances and co-operations create local competitive advantages in dealing with, for example, efficient tendering, availability of specialists and specialised equipment or transfer of technical knowledge.

Activities of the Network

All BBR Network members have established and strong local connections in their respective regions. They are all structured differently to suit the local market and offer a variety of construction services, in addition to the traditional core business of post-tensioning.

BBR Technologies

BBR technologies have been applied to a vast array of different structures – such as bridges, buildings, marine structures, tanks, towers – and used in all types of geotechnical applications. The BBR brands and trademarks – CONA, CMM, BBRV, HiAm, DINA and SWIF – are recognised worldwide.

The BBR Network has a track record of excellence and innovation – with thousands of structures built using BBR technologies. While BBR's history goes back over 60 years, the BBR Network is focused on constructing the future – established traditions are blended with the latest thinking and leading technology.

BBR VT International Ltd is the Technical Headquarters and Business Development Centre of the BBR Network, located in Switzerland. The Shareholders of BBR VT International Ltd are: BBR Holding Ltd (Switzerland), subsidiary of Tectus Group (Switzerland); BBR Polska Sp. z.o.o. (Poland), subsidiary of BBR Holding Ltd (Switzerland); BBR Pretensados y Técnicas Especiales, S.L. (Spain), member of the FCC Group (Spain); KB Spennteknikk AS (Norway), member of the Kongsvinger Betongindustri Group (Norway); VORSPANN-TECHNIK GmbH & Co. KG (Austria / Germany), member of the Porr Group (Austria).

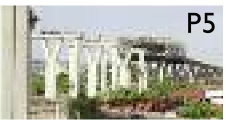
This first edition of CONNÆCT, the Magazine of the Global BBR Network of Experts, brings inspiring and informative stories about construction achievement which has been realised with BBR Technologies and the people of the BBR Network throughout the world.

With environmental and financial expectations to the fore, international communities are demanding ever more technological advancement and skill from engineers and technicians. Within the Global BBR Network, we are proud to have a pool of the most talented professionals, as well as a wide range of leading edge products and services, all focused on meeting those challenges by creating innovative solutions.

Knowledge management and knowledge sharing is key to continued technological progress. Our people have access to the very latest internationally approved technology and information and have the opportunity to share and exchange information within the BBR Network. By having a strong global dialogue within the construction technology arena, the BBR Network is at the very forefront of the construction industry and will always be a step ahead.

Bruno Valsangiacomo
Chairman
BBR VT International Ltd

Marcel Poser
CEO
BBR VT International Ltd



P5 How a Moveable Scaffold System helped to keep traffic moving during construction in one of the world's most congested cities.

contents

At Austria's highly successful Europark shopping centre, BBR post-tensioned flat slab technology delivered what the client wanted and reduced construction time.

contents
continued

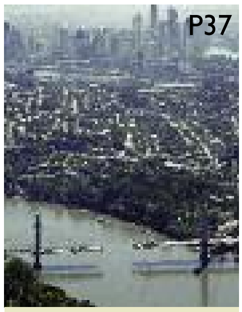
BUILDINGS CONTINUED

TANKS & SILOS

A look at the market place and how construction technology has contributed to meeting increased consumer demands for natural gas – on land and offshore.

SPECIAL APPLICATIONS

STAY CABLES



Completed at the end of 2006 and the second longest cable stayed bridge in Australia, Brisbane's Green Bridge – which is closed to private vehicles – is supported by BBR CONA stay cable technology.

MMR

Innovative application of BBR external post-tensioning has strengthened twin motorway bridges near Deventer in the Netherlands.

LANDMARK STRUCTURES

Past, present and future

Marcel Poser, CEO of **BBR VT International Ltd,** answers some leading questions about European Technical Approvals, the BBR product range and the Global BBR Network, whilst sharing some thoughts about the recent past and looking into the future. →

BBR Technologies have national approvals and are well established and proven in the respective markets, however in the last twelve months the most significant accreditation in the history of BBR has been for a completely new set of products – the BBR VT CONA CMX range.

Why is European Technical Approval (ETA) so important?

Well, you have to understand the history of these things to really appreciate the value of ETA today. In the past, there were a lot of national approvals for technical products – some were very detailed as a result of local experience and others were not so detailed. Some countries adapted and adopted specifications running in other countries. But the net result was that systems were not easily comparable internationally because of the differing requirements of the various national certification and approval processes.

In effect, what has been created within the European Approval for Post-tensioning Kits is an "international passport" – the most up-to-date method of comparing like-with-like, from which it is clear exactly what specifications your product fulfils. ETA provides a clear, independent review, testing, Quality Assurance and auditing system for the componentry. Every product is tested to the same standards and, afterwards, an independent auditor ensures that what you deliver to and install on site fully complies with what you have actually tested. But more than this, ETA delivers a "recipe book" for designers on how to use the system, as well as a gold-plated guarantee – the CE Label or Certificate of Conformity – of the quality and suitability of the product which gives confidence to owners of the structures to which the system is applied.

How do you get ETA?

The procedure can be a lengthy process because it requires a number of stages and it thus requires a substantial investment – in both time and money – on the part of the applicant!

Guidance for the whole process is contained within ETAG 013 – *Guideline for European Technical Approval of Post-Tensioning Kits for Prestressing of Structures* – which details a clear set of testing procedures which have to be fulfilled to obtain ETA. These include static tests, fatigue tests, load transfer, electrical resistance, cryogenic tests and so forth.

Throughout Europe, there are a number of laboratories which are certified to conduct the testing process in accordance with the ETAG specifications. Once completed, an approval body then evaluates the test results, drawings and the complete system. Next, the whole set of information is sent to the "European circulation" – to all member states of the EU. These are designated specialists who review and comment on the application – or indeed have the authority to request more tests or seek further clarification. Only when this whole cycle has been successfully completed do you get European Technical Approval for your product or system. Full details of the ETA for the BBR VT CONA CMX range can be downloaded from our website – www.bbrnetwork.com.

The new BBR VT CONA CMX range was launched at the 2006 fib Congress in Naples.

So, what is the new BBR VT CONA CMX range?

The BBR VT CONA CMX is a new range of post-tensioning systems. So far we have ETAs for:

- CONA CMI – Internal Bonded Post-tensioning System
- CONA CMM – Unbonded Post-tensioning System

In a way, you could say that this range was just like any other system – except that we have gone a stage further. Instead of adapting an old system to conform to new requirements, our engineers have created totally new systems.

If you compare, for example, the CONA CMI system with other similar approved systems, you would see that – technically – we really do have the competitive advantage. Specific features of the new system include:

- 20-40% less space needed in the anchor zone – thus, less concrete, slimmer structures, less eccentricity in the anchors
- significantly lower concrete strength prior to stressing – thus, shorter construction cycles
- less reinforcement in the anchor zone – thus, cost and time savings

Furthermore, the environment in which we live has changed significantly and we now have to consider issues, such as increased corrosion from pollution, when designing a product from a durability viewpoint – and the needs of more advanced technical inspections of a structure during its lifetime.

BBR VT CONA CMI
– Internal Bonded
Post-tensioning System

How did this new product come about?

The process really started several years ago, when we first discussed the possibility of producing something new. It takes a long time to consider the needs of various markets – it's all very well developing something on paper, but we wanted to make sure we understood what those needs really were and then to deliver a solution which met these requirements, along with those of ETAG!

We had a committed team of engineers who spent endless hours working on this development – Michael Schreiner, Piotr Krawczonek, Manfred Damoser, Juan Manuel Linero and Robert Danzl – and they were not afraid of pushing back the technological boundaries in optimising our new systems. They took all of the knowledge we have gained over the past 60 years and combined it with feedback from around the world, about what our Network members and their clients need, to produce a completely new system. The end result is a high quality, up-to-date product which will ensure that the BBR Network is one step ahead of the pack in being able to deliver a superb technological solution.

BBR VT CONA CMM
– Unbonded Post-
tensioning System

Why go to the trouble and expense of creating a new product?

OK, we could have taken any old system and modified it to meet the requirements, but we have taken this opportunity to respond to the market with something truly state-of-the-art. We wanted to go the extra mile.

Once in a while you need to create something completely new. It's a bit like that old car you bought ten years ago – whilst at the time it was the highest possible spec, the new car you can buy today gives you the benefit of all the technological advances in the intervening years. Of course, you could adapt the old car, but so much has changed – in terms of environmental influences and manufacturing techniques – that it will never really have that leading edge technology seamlessly fused into it – post-tensioning products are just the same.

When can the BBR Network start using the new product?

It's available immediately in Europe – and the EC requires these products to be used. In fact, it is available to the whole BBR Network worldwide and our commitment to the highest quality products means that there will be a high level of demand for construction projects all around the world in the short-to-medium term.

PT Specialist Company

The installation of Post-tensioning Kits has to be performed by certified companies. For a complete list of all countries where BBR certified PT Specialist Companies can be found, please visit the BBR Website: www.bbrnetwork.com

How do BBR Network members learn how to use a product?

Within BBR, we are committed not only to selling components, but also to the appropriate installation of our products – in fact, this is as important as the quality of the product itself. We certify all of our Network members – annually – as PT Specialist Companies. We arrange internal training sessions which ensure that the systems are installed in the correct way – it makes no sense to have the best system if it's poorly installed. ➔

First cable-stayed bridge in New Zealand goes BBR – artist's impression of Ormiston Road Bridge.

If there is an implementation of a specific application, all members are encouraged to benefit from this experience by sending technicians to that site so that they can observe and learn. Equally, members have access to information and other members – that's really the beauty of such an active network, as knowledge can be transferred internally and with great ease.

At least once a year, we organise a global media conference – where knowledge exchange happens on a broad scale. In 2006, representatives from the whole Global BBR Network met in Dubai. The meeting took place at the Jumeirah Emirates Towers where, some 16 years earlier, BBR Network member Structural Systems had been heavily involved! This year, we are looking forward to getting the BBR Network together at our Global BBR Conference in Singapore.

Recent months have seen some excellent collaboration between Network members. There has been great work between teams from the UK and Spain in the transfer of specialist skills related to LNG tank construction projects. Meanwhile, skills in flat post-tensioning for heavy load slabs have travelled from Australia to New Zealand and then around the globe to Poland. Cable stayed bridge construction has prompted close liaison between Network members in Spain and Australia, while co-operation between the teams in Jordan and Saudi Arabia has supported the construction of the Jamarat Ramp Bridges project, in Mina, just to the east of Mecca.

The 2006 Global BBR Network conference took place in Dubai – at the Jumeirah Emirates Towers where, some 16 years earlier, BBR Network member Structural Systems had been heavily involved!

It is not just knowledge which is passed around the world, but also the more tangible things – like equipment and tooling – where individual investment would simply not be not justified.

This strength of know-how, combined with excellent products and the tools for the job, means that every Network member has the opportunity to tender for any type and size of project – in the secure knowledge that they can rely on the experience of the entire Network, particularly for the eventual execution of the work. The BBR Network enjoys a great competitive advantage and ensures effective usage of equipment and specialists.

What's on the cards for the next twelve months?

Looking at projects we are likely to be involved with throughout the world, there will certainly be some exciting new schemes in the energy sector, including more LNG tanks and wind farms, as well as some high-speed railway systems – plus further residential and industrial development projects, particularly in Eastern Europe.

In Spain, a landmark project will be getting underway – a cable-stayed bridge in Valencia, designed by world famous architect, Santiago Calatrava. Meanwhile, the first cable stayed bridge in New Zealand – the Ormiston Road Bridge in Auckland – will be taking shape and using BBR Technology.

Within BBR, we are always looking for complementary systems for use in specific applications – we never stop studying the market to see where there's a need for a new system. Without revealing too much too soon, we are currently considering energy applications – windmills, LNG, nuclear – as part of our ongoing development process and commitment to a high level of quality and inspectability.

As far as the BBR Network is concerned, over last couple of years it has expanded significantly – we now have a presence in almost 50 countries. In the next few years, we will have our eyes firmly focused on continents where we still see potential – watch out for some announcements in the very near future!

Industrial Ring Road Project, Thailand

BBR Construction Systems Singapore's decision to use a Moveable Scaffold System (MSS), during their contract to build part of the massive Industrial Ring Road (IRR) project, helped to keep traffic moving in and around Bangkok while construction work was underway.

➔

MSS helps Bangkok BEAT CONGESTION

The Industrial Ring Road scheme started as a Royally Initiated Project which was focused on solving the problems caused by the tremendous volume of traffic, both within the city centre and the surrounding areas. The objective was to alleviate traffic congestion, resulting from freight transportation, by providing new bridges to link Bangkok Port with Pu Chao Saming Phrai Road to the South, Suksawat Road to the West and Rama III to the North.

PROJECT OVERVIEW

The project comprises two cable-stayed bridges – back-to-back, over a bend in the Chao Phraya River downstream of Bangkok – with main spans of 398m and 326m respectively, as well as almost 4000m of approach bridges and viaducts.

The massive scale of the scheme and the need to complete it within a relatively short period of time, dictated that the project should be divided into three contracts:

- Contract 1 for the Southern Area
- Contract 2 for the Northern Area
- Contract 3 for the Western Area.

BBR SCOPE OF WORKS

BBR Construction Systems Singapore was awarded the contract for construction of the superstructure works for part of Contract 3 which comprised a 1368m long approach bridge, with 31 spans (Piers W32 – W1).

The Company's scope of works included the design, fabrication and operation of the MSS, formwork, laying of reinforcement, post-tensioning and concreting works.

Span length varies from 36m, to a maximum of 50m for the river crossing. Pier height gradually increases from the abutment area up to a maximum height of 45m above ground level at the interchange.

The width of the viaduct is 23m and consists of a twin box girder which gradually widens to 35m at the bifurcation area, with two additional single box girders at both sides.

CONTRACTUAL CONSTRAINT

One of the major constraints in this part of Contract 3, was that during construction, all major roads had to be kept open at all times – and this was a contractual requirement. Hence the MSS (Movable Scaffolding System) method was the preferred choice for construction of the viaduct. Together with its Consultant, BBR Singapore designed, fabricated and operated this MSS – 1600t of structural steel – over the entire length of this approach bridge.

Facts & figures

The superstructure of the viaduct, including the crossheads, consisted of approximately 30,000m^3 of concrete, 5900t of steel reinforcement and 1200t of 0.6" diameter pre-stressing strands. The post-tensioning system used here was BBR CONA.

The optimum cycle time achieved per span using the MSS was 15 days, with about 110 workers deployed during the peak period. The team completed Contract 3 in May 2006 – after a 3-year construction contract.

The Moveable Scaffold System

This Movable Scaffold System (MSS) was designed to handle not only the longest span of river crossing (50m), but also to tackle the bifurcation area, starting from Pier W12 to W4.

- **Pier W28 to Pier W12**
  These locations were relatively straightforward as the width of the box girder remained constant throughout.
- **Pier W12 to Pier W9**
  From Pier W12 onwards, the width of the box girder gradually increases from 23m – to 35m. At this point, the gantry arms were extended to cover the enlarged width of the viaduct.
- **Pier W9 to Pier W4**
  Here, two additional single boxes were connected to the slip ramps constructed by others.
- **Pier W4 to Pier W1**
  At Pier W4, the slip ramps curve away from the approach bridge. These slip ramps were constructed by others and were completed before the MSS arrived at this location. Therefore, in order to launch past Pier W4, the team completed construction of the previous span, then lowered the side arms and the bottom platform and disconnected them from the hanger bars. The lowered members were then shifted to the next span by using trailers. Next, the gantry was launched to the next span, the lower platforms were raised and re-attached to the hanger bars.

TEAM & TECHNOLOGY

- **OWNER**
  Owner Public Works Department, Ministry of Interior, Thailand
- **CONTRACTOR**
  Kajima-Tokyu-Unique Joint Venture
- **DESIGNER**
  Epsilon Company Ltd, Norconsult Civil Engineering Co Ltd and Mott Macdonald Ltd
- **TECHNOLOGY**
  BBR CONA internal
  BBR CONA flat
  Moveable Scaffold System (MSS)
- **BBR NETWORK MEMBER**
  BBR Construction Systems Pte Ltd (Singapore)

Balanced cantilever construction

The balanced cantilever method is often appropriate and cost-effective for the construction of long spans where bridge height, topography, or geotechnical conditions render the use of conventional falsework uneconomical.

Cost-savings are achieved partly due to the construction method and partly due to the structural system. Previously cast portions of the superstructure can immediately be used to support the construction of new segments, making possible the use of short, economical formwork travellers. Formwork is adjustable and can be reused many times. The regular repetition of identical tasks for the construction of each of the segments substantially reduces the ratio of labour costs to material costs. The use of short segments makes possible an economical prestressing layout that closely matches the moment diagram. In classical cantilever construction, cantilevers are built out symmetrically from pier tables in segments ranging between 3 and 5m in length. The construction sequence for a given segment consists of the following steps:

- Prestress the previously cast segment
- Advance formwork travellers to their new position
- Anchor travellers to the newly prestressed girder end and adjust formwork
- Place reinforcing steel, couple new tendon ducts with empty ducts in the completed portion and pull prestressing steel into ducts
- Cast the new segment

The economical range of span lengths for cast in situ cantilever construction begins at roughly 70m and extends to beyond 250m. For long spans, the ratio of falsework and formwork cost to total superstructure cost ranges between 25% and 35% , independent of bridge height and topography. This represents a considerable saving over conventionally cast in situ bridges for which ratios of 40% are typical.

Postcards from the countryside

MILOWKA FLYOVER, POLAND

Road construction is a very hot topic in Poland. And safe, collision-free traffic means new viaducts, flyovers and bridges. Depending on destination, landscape and – last but not least – the owner's expectation, various technologies are at the disposal of the designer. The specialist construction techniques, employed on this challenging flyover project, are described by site manager Piotr Stasyk of **BBR Polska.**

Our involvement in the construction of the flyover in Milowka – on Expressway S-69 between Bielsko-Biala and Zwardon – was substantial.

SPECIALIST WORKS

The project called for an alternative design, application of the free cantilevering method, installation of 10 RESTON bearings (4300-20,000kN), installation and servicing of cantilevering carriers, prestressing, BBR CONA external and internal cables, as well as assembly and installation of two TENSA Grip expansion joints. A large range of specialist works within the scope of one contract is a logistical advantage. It allows us to optimise the time resulting from the week-by-week rhythm which is offered by the free cantilevering method.

THE TERRAIN

The flyover was situated in a mountainous landscape.

The construction site was located on a slope with a considerable incline. To level it, soil had to be brought in at the very beginning, so that assembly places, which were in any case very limited in size, could be organised.

The approach to the site was a mountain road with obvious level differences, making efficient transportation difficult – especially after rain or during the winter. Extreme conditions in our "backyard" – assembly and storage places and roads – often dictated the way tasks were executed or the kind of equipment used.

In the middle of the site, there was a gorge – the main span carriers were dismantled right above it – on this occasion, ordinary blocks had to be used for lifting during most of the works.

EXTREME WEATHER

The weather provided some distractions, too. After an intense snow fall, we had to find the carriers first and then clear them of snow before the actual work started. After it rained, the site turned into a muddy slide – impassable for heavy machines without the help of special devices. This was a common occurrence at Milowka.

The shape of the structure is quite special too – concrete horizontal arch, with transverse and longitudinal inclination, 7% in the case of the latter. In fact, there were enough complications for several projects! Despite that, completion of the works was on target and prestressing was completed on programme.

HUFTARØY-HUNDVÅKØY BRIDGES, NORWAY

Link to the mainland

Two islands off the west coast of Norway are in the process of being connected to the mainland by two free cantilevered (FC) bridges. Hundvåkøy Bridge is a typical FC bridge with a main span of 233m and two side spans of 112 and 115m. Storholmen Bridge has two main spans of 160 and 172m. To balance these, counterweight boxes of approximately 45m were used on each end. Storholmen Bridge has recently been completed and construction of Hundvåkøy Bridge has just begun.

TEAM & TECHNOLOGY

- **OWNER**
  Statens vegvesen
- **CONTRACTOR**
  Reinertsen Anlegg AS
- **DESIGNER**
  Statens vegvesen
- **TECHNOLOGY**
  BBR CONA internal
  BBR CONA rock anchors
  TOBE Pot bearings
- **BBR NETWORK MEMBER**
  KB Spennteknikk AS (Norway)

BATANG BARAM BRIDGE, MIRI SARAWAK, MALAYSIA

Travelling formwork

This 1040m long bridge across the Batang Baram river at Miri Sarawak in Malaysia creates a new land link between the new Miri Port on one side of the river and the Customs & Immigration Checkpoint to Brunei on the other. The bridge is located approximately two kilometres upstream of the new port and is some 25km from Miri – a major oil and gas centre.

BBR Malaysia's work included the construction of the main river spans – comprising 110m, 180m and 110m cast insitu balanced cantilever single cell pre-stressed box girders. A total of 82 segments – each four metres long – were cast using pairs of formwork travellers. In addition, the 1.5m diameter driven steel tube piles, pile caps and pier columns were constructed by BBR Malaysia. Specially designed precast permanent formwork was used to cast the two pile caps for the main piers in the water.

Dead Sea Parkway Road Project, Jordan

This 11.6km two-lane road, which is part of the Tourism Sector Development Project, runs from the Dead Sea Coastal Road – the lowest point on earth at 427m below sea level – 7km south of the Hotel Development Area. It cuts through the mountainous terrain leading to the Maain Spa Road Intersection where magnificent views of the Dead Sea and the natural scenery can be enjoyed.

BBR Network member **Marwan Kurdi & Partners Co. Ltd** was engaged to construct the two main bridges on the contract – at Wadi Hammara and Wadi Abu Assal.

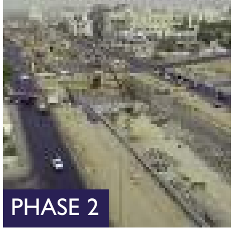
The 36m high and 122m long Wadi Hammara Bridge has four spans of 30.5m each – and is the highest bridge in Jordan. It spans the most difficult part of the route, between the Maain Hot Springs and the Dead Sea. The Wadi Abu Assal bridge has three spans of 30.5m each and is 24m high. It has vertical and horizontal curves to cater for the rough terrain and steep slope.

Due to the challenging terrain, the superstructure was built with pre-cast prestressed T-beams using BBR CONA internal post-tensioning technology and the beam installation was carried out using a launching girder.

Launching in lowest place on Earth

TEAM & TECHNOLOGY

- **OWNER**
  Ministry of Tourism & Antiquities
  Ministry of Public Works & Housing
- **MAIN CONTRACTOR**
  Societa italiana per condotte d'acua spa
- **DESIGNER**
  JV Pacific Consultants International & Yamasit Sekkei Inc
- **TECHNOLOGY**
  BBR CONA Internal
- **BBR NETWORK MEMBER**
  Marwan Kurdi & Partners Co. Ltd (Jordan)



Flying over, under and around Jeddah

KING ABDULLAH ROAD, JEDDAH, KINGDOM OF SAUDI ARABIA

Founded as a fishing village some 2,500 years ago, today Jeddah is regarded as the commercial capital of the Kingdom of Saudi Arabia. Jeddah is also the major gateway for pilgrims to Mecca, the holiest city in the Islamic faith. Currently, major infrastructure investment is underway to improve and extend facilities for the City's rapidly growing population.

King Abdullah Road is one of Jeddah's main avenues, crossing the city from East to West and intersecting with other main streets. This project aims to deliver a road free from traffic control signals.
Already, three phases are either completed or under construction – and will be followed by further phases to allow easy passage across the city to its west coast.

PHASE 1: INTERSECTION WITH KING FAHD ROAD

This interchange was executed on three levels:

- **Underpass for King Fahd Road** - 1km long, 25m wide.
- **Flyover for King Abdullah Road** – double-deck, 160m long and 30m wide bridge over three spans of 45, 70 and 45m. The longitudinal tendons are BBR CONA internal 1906, stressed in two stages while the transverse tendons were BBR CONA 406. The pier heads were stressed by BBR CONA internal 1206.
- **Two rotary bridges** – to recreate the original intersection at ground level, each 30m long and 17m wide, stressed longitudinally by BBR CONA internal 1906 and 706.

PHASE 2: INTERSECTION WITH FOUR STREETS

King Abdullah Road will become a 1km long, 30m wide underpass, crossed over by four bridges. The key components of this phase are:

- Khaled Ibn Waleed Street Bridge – a 42m long, 23m wide bridge, stressed by BBR CONA internal 1906 longitudinal tendons.
- U-turn Grade Bridge – a 42m long, 7m wide bridge, stressed in two stages by BBR CONA internal 1906 longitudinal tendons.
- Telephone Line Grade Bridge – a 42m long, 3m wide bridge, stressed in two stages by BBR CONA internal 1906 longitudinal tendons, will allow the crossing of pedestrians and services (international telephone cables embedded in a concrete mass).
- Madinah Road Bridge – this bridge will combine the intersection of Madinah Road north-and-south bounds with King Abdullah Road. This 30m long and 102m wide bridge will be stressed by BBR CONA internal 1906 and 1206 longitudinal tendons.

TEAM & TECHNOLOGY

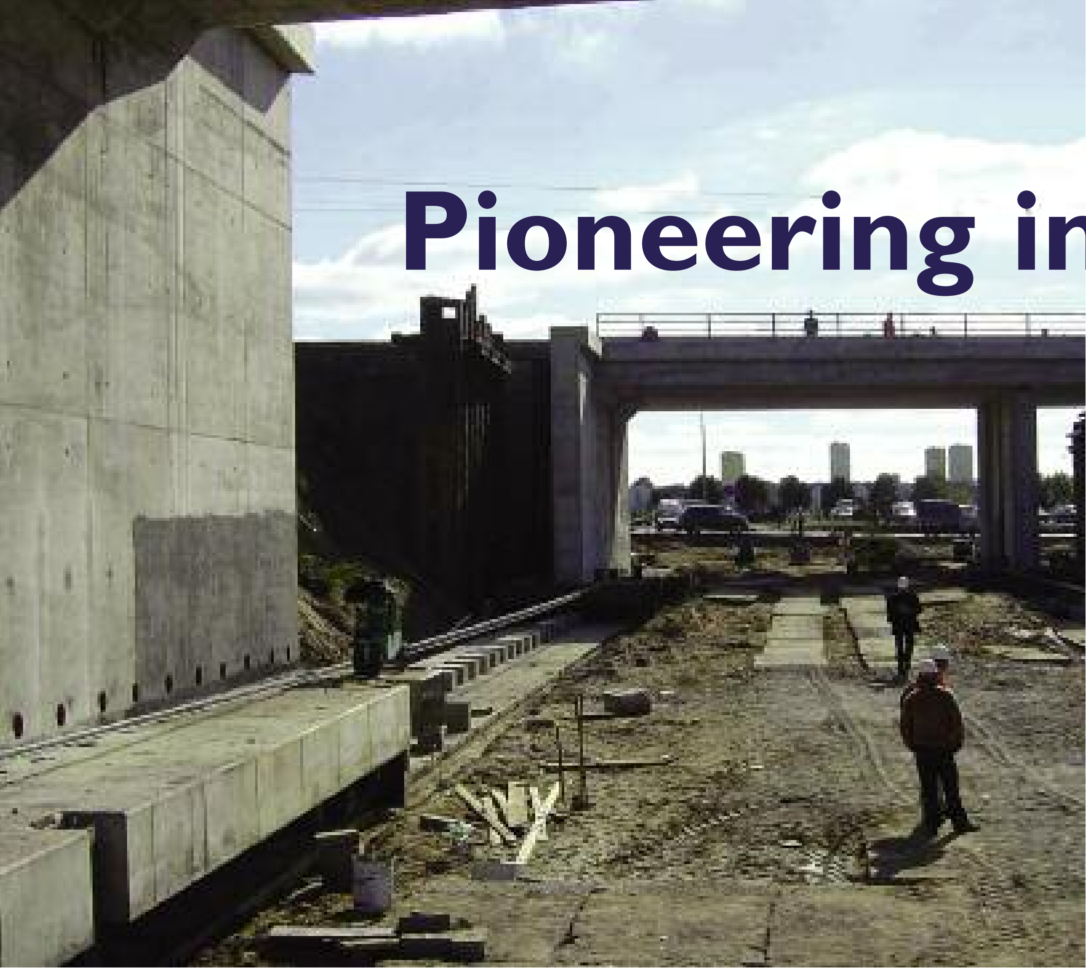
- **OWNER**
  Municipality of Jeddah
- **CONTRACTOR**
  Huta-Hegerfeld Saudia Ltd
- **DESIGNER**
  BBR Systems Ltd
- **TECHNOLOGY**
  BBR CONA internal
- **BBR NETWORK MEMBER**
  Huta/BBR Prestressing Division (Kingdom of Saudi Arabia)

PHASE 3: INTERSECTION WITH HAIL STREET

This is another flyover bridge for King Abdullah Road which involves a double-deck structure, six spans – five of 40m and one 50m over Hail Street – and executed in three stages:

- 2 spans + 5m cantilever (at one end)
- 3 spans + 5m cantilever (at other end)
- middle span over Hail Street

The longitudinal tendons are BBR CONA internal 1906 stressed in two stages – initial and final.



Pioneering in Poland

Technology sequence

- Casting of the viaduct superstructure on fixed scaffolding alongside the final alignment
- Closing of the railway track
- Construction of the earthwork retaining abutments
- Execution of the earthworks
- Placement of prefabricated elements to be used for the slide
- Lifting of the structure, placing of the sliding pads
- Shifting the bridge to the final alignment
- Vertical adjustment
- Restoration of the embankment
- Opening of the railway line

OLSZTYN BRIDGE SLIDE

Early last September, the Programme Three (or Trójka) radio station broadcast news about the pioneering operation involving a bridge slide in Olsztyn. Marcin Ornat, head of **BBR Polska** Regional Office in Gliwice and BBR project manager in Olsztyn, was there to supervise.

"In fact, the whole activity proved to be extremely 'mediagenic'. We have done similar jobs in Poland before, such as our project for the Kutno Bypass, but this time it was the scale of the undertaking that bred such interest. For two months, the new viaduct was being assembled just a stone's throw from the railway line, then – within just four hours – it was moved into position. All that happening in the city centre of Olsztyn – the operation was really quite a show!" Marcin Ornat proudly explained. And, after a pause, he added: "Actually I think that, compared with other tasks that BBR Polska faces everyday, it was an ordinary job, just exceptionally well-executed in the glare of the limelight!"

The most labour-intensive job was securing the excavation, the earthworks, preparation of the bedding and restoration of the railway track. Also the installation of the shifting equipment proved to be quite time-consuming – it took a whole day, but the result provided the optimum solution.

FULLY AUTOMATED SYSTEM

Usually, shifting sets are used – but not this time. The one used on this occasion, BBR SL-402, was a fully automated system of jacks, hydraulic pumps and additional equipment for shifting and lifting. It enables control of a maximum of four shifting (lifting) points and their respective loads with a precision of +/- 1mm difference between them.

SPEED & DISTANCES

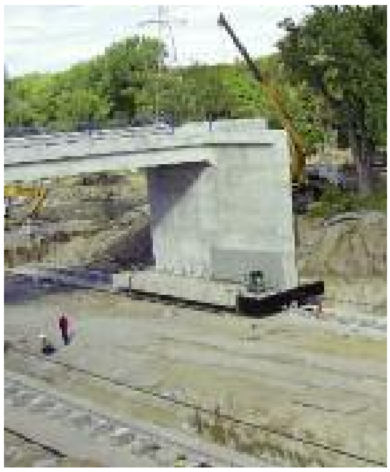
This system enabled us to move objects with a speed of approximately 5m/h – and, on the last viaduct, a speed of around 10m/h!

The following distances were covered during the slide:

- Viaduct WK-3 stage 1 – 28m (the heaviest element – 2427 tonnes)
- Viaduct WK-3 stage 2 – 41m
- Viaduct WK-2 – 42m

The lifting alone took no more than four hours, including time for installation of preparatory equipment!

The method used in Olsztyn has been employed in other countries for a number of years. Its effectiveness will most probably make Polish designers reach for it more frequently in the future – and will make the investors appreciate it!

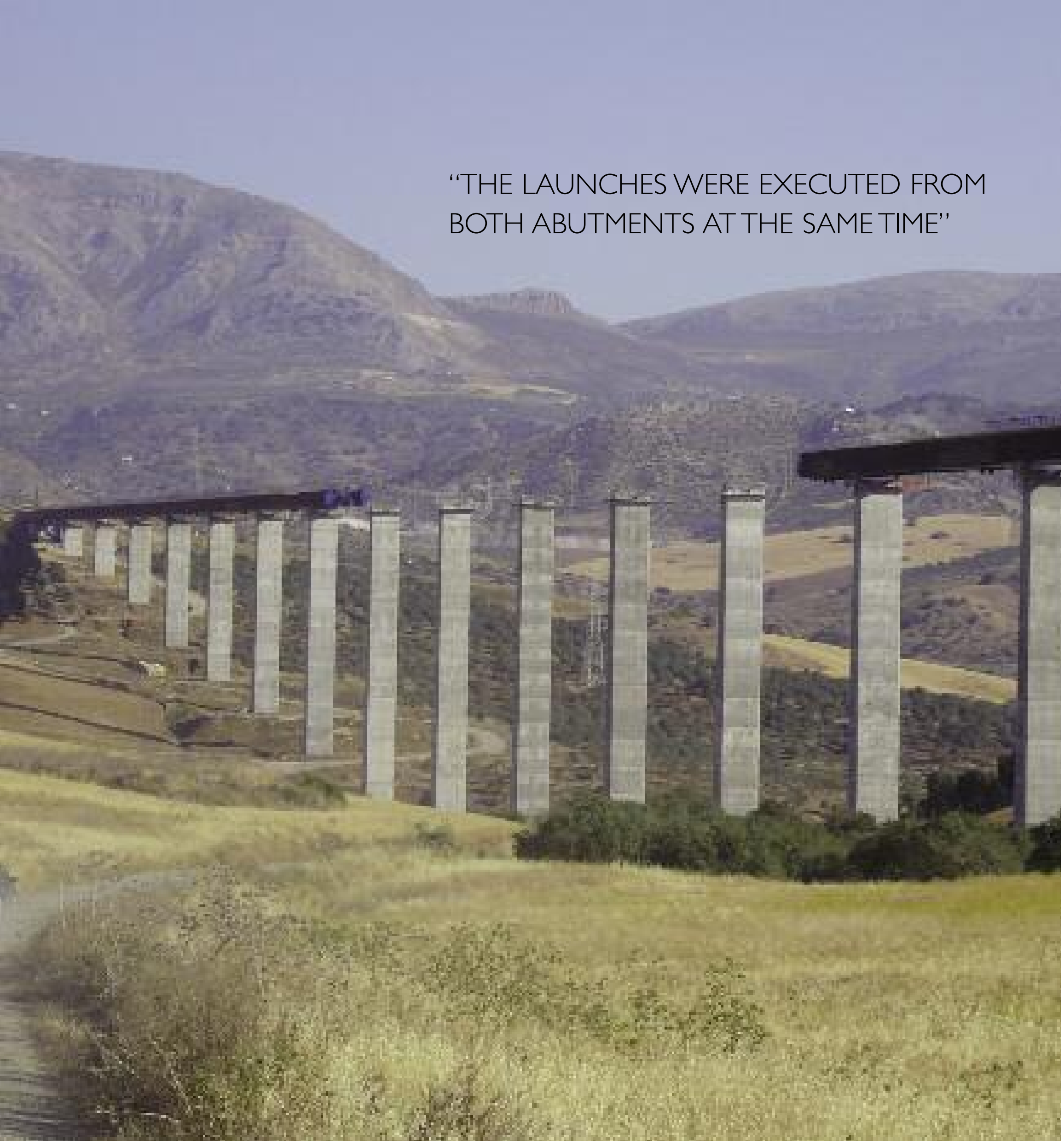


VIADUCTO ARROYO DE LAS PIEDRAS, SPAIN

The Spanish government has allocated a multi-billion Euro budget for the construction of new rail infrastructure – their plan is to bring all provincial cities within four hours' travelling time from Madrid and six-and-a-half hours from Barcelona.

As part of this major investment, the new Las Piedras Viaduct at Alora – 40kms north of Málaga – will carry the AVE high speed railway from Córdoba to Málaga. Diana Cobos Roger from **BBR Pretensados y Técnicas Especiales** describes the heavy lifting techniques employed on this major construction project. →

Incremental launching at Las Piedras



"THE LAUNCHES WERE EXECUTED FROM BOTH ABUTMENTS AT THE SAME TIME"

The Las Piedras Viaduct is a composite structure which has been built using the incremental launching method. It has a total length of 1211m, divided into 20 spans – a single span at 50.5m, 63.5m for 17 spans, then two further spans of 45m and 36m – with a slope of 2.4%.

UP & DOWN LAUNCHING

The launches were executed from both abutments at the same time – upwards launching of 592m and downwards of 619m.

The total weight to be launched upwards was 7300t which required the use of two pulling jacks BBR S-750 with 31 compacted steel strands during the last phase of the launching. For the downwards launches, the total weight was 7650t. Two 230t retaining jacks – both fixed to the abutment – were needed to secure and hold the structure. All of the jacks were synchronized. A retaining force was set and, once the pulling force was bigger than the retaining one, the bridge started to move.

STRUCTURAL INTEGRITY

Each of the 19 piers was passed using a lifting jack with a stroke of 1000mm and 150t capacity. As the tallest piers were 100m high, a security system was installed to ensure that movements at the top of the pier did not exceed the ones defined by the designer. The angle between the vertical and the real position of the pier was

TEAM & TECHNOLOGY

- ***OWNER***
  Administrador de Infraestructuras Ferroviarias (ADIF)
- ***CONTRACTOR***
  ALTEC
- ***DESIGNER***
  IDEAM
- ***STEEL STRUCTURE***
  MEGUSA
- ***TECHNOLOGY***
  Incremental Launching, Heavy Lifting
- ***BBR NETWORK MEMBER***
  BBR Pretensados y Técnicas Especiales (Spain)

BBR S-750 pulling jacks were used during the last phase of launching.

"THE LOAD TRANSFER FROM THE LIFTING JACKS TO THE PIERS WAS A QUITE A CHALLENGE"

precisely measured, so that if the tolerated values were exceeded, the launch process would be stopped automatically.

On the top of each pier, a guiding system was installed. Before passing the first pier, a patch loading test was done on site to assess the behaviour of the structure.

The guiding system consisted of two structures with metallic rollers, positioned on both sides of the top of the pier, which helped to guide the structure whilst allowing for small deviations. In addition, the sliding bearings used on the project incorporated a special design feature which allowed turns to help correct the launching alignment.

During the last phase of launching, deflections and turns at the joint had to be equal at both ends. This task was carried out with the same lifting jacks that were used to pass the piers.

Because of the high daytime temperatures, joint welding between sections had to be done during the night, thus avoiding tensions developing inside the structure as a result of thermal gradient.

EFFECTING LOAD TRANSFER

The load transfer from the lifting jacks to the piers was a quite a challenge because, once the launch was completed, the viaduct was about 75cm higher than the finished level. All groups of jacks on the piers had to be synchronized and worked in several phases until the viaduct reached its correct level.

It took around eight months to complete the entire bridge launch. This section of the new AVE route in South Western Spain is expected to open for passenger services during 2007. ●

TECHNICAL INSIGHT

Heavy lifting systems

In simple terms, "heavy lifting" is a hydraulic lifting technique especially developed for extremely heavy loads. Load handling systems often result in considerable savings of time and costs compared to conventional techniques. This modern and efficient system can largely substitute traditional lifting, lowering or shifting of heavy elements.

The BBR Network offers complete systems for heavy lifting which have been used on many diverse projects around the world. Load handling systems require full consideration at an early design stage for structural detailing, construction planning and selection of the right equipment.

Within the BBR Network, there is extensive experience in the field of load handling and a complete range of services from the planning, engineering, equipment supply and execution of any heavy lifting project can be provided – early involvement of our specialists results in a handling scheme that optimises the project's economy, efficiency and schedule.

A patch loading test was done to assess the behaviour of the structure.

PEPPERS PIER RESORT, HERVEY BAY, QUEENSLAND, AUSTRALIA

Beautiful challenge down under!

The construction of 42,500m^2 of post-tensioned slabs at the Peppers Pier Resort Hervey Bay – a landmark project in Queensland – is described by Justin Hampton of BBR Network member **Structural Systems** as a "beautiful challenge" to its builders.

A striking array of blending curves and angles, the Peppers Pier Resort was always going to challenge the construction team. Undaunted, Structural Systems recently completed the design and construction of the post-tensioned slab and load-transfer system that reduced both construction time and building costs.

FLOOR SYSTEM

This landmark project is the largest post-tensioned building project undertaken on the Fraser Coast and will be Hervey Bay's most exclusive resort facility. With its striking but highly-irregular building shape, one of the keys to a successful project was deciding on a floor system that was both economical and fast to construct and also providing a solution that will benefit the long term durability of the structure. Post-tensioned construction was the obvious solution. The project consisted of a post-tensioned beam raft foundation and seven fully post-tensioned suspended levels, with a total of 42,500m^2 of stressed area. The bonded BBR CONA flat anchorage system, especially designed for post-tensioned slabs, has been used throughout.

COST & STRUCTURAL BENEFITS

Structural Systems was contracted to design, supply and install the post-tensioning system for all suspended and load-transfer structures. Post-tensioning was chosen for both economic and structural benefits, allowing for reduced beam depths in the transfer area and thinner slabs, resulting in reduced transfer loads. This reduction in slab thicknesses also allowed increased floor-to-floor heights achieved in the car park areas.

The deflections of the structure were minimised to reduce associated risks with the finishing trades, thus ensuring long-term maintenance costs are reduced when compared to a conventionally reinforced solution.

Peppers Pier Resort Hervey Bay

Located three hours drive north of Brisbane, Peppers Pier Resort Hervey Bay is set to become one of Queensland's premier beach-side destinations. In keeping with its seaside village lifestyle environment, the resort's distinctive curvature and tiered design is influenced by the form of ocean waves.

It features a landscaped lagoon swimming pool, fine dining restaurant, premium conference and meeting facilities and a health club. Hervey Bay is one of Australia's most popular holiday escapes offering a warm climate, beautiful beaches and a host of land and water-based activities. It is also the best whale-watching destination in Australia.

MTC MULTIFUNCTIONAL SHOPPING CENTRE, CAKOVEC, CROATIA

Competitive alternative design

The MTC site started in October 2005 and is growing into a 14,000m^2 multifunctional shopping centre, with 9,000m^2 of retail space and 150 covered parking places on the roof. Situated in Cakovec, north Croatia, it was the second project completed with post-tensioned slabs and executed by **BBR CONEX** of Croatia. The design of post-tensioned slabs was undertaken in collaboration with Dreibau Ingenieurs Conseils, Switzerland. Originally, the project was conceived as a reinforced concrete three storey framed structure with ribbed slabs made of precast TT girders. The building is around 97x78m with a column grid of 16x10m.

REDUCING TIME & MATERIALS

The original structural solution for the building – ribbed precast girders and beams – was redesigned and replaced with a higher spec solution, based on post-tensioned flat slabs with shallow beams for the larger 16m span. Construction time was cut in half and formwork expenses were reduced by 75%. In addition, the new structure is lighter, with a lower centre of gravity and better seismic properties. Also, floor-to-floor heights were increased by up to 42cm. The floor structure for this project was so advanced that it had to be tested to prove that it could cope with the demands. So, shear testing of critical columns was performed. Testing was carried out according to American Code ACI-318/2002. The slab behaved in a fully elastic manner, with residual elastic deformations of less than 1%.

DEMANDING CANTILEVER

The most demanding part of the structure was a 5.5m wide cantilever section of the slab on the edge of the building – 43m long. On the second slab, there are 18 parking places. It was designed as a waffle slab without additional beams, in order to control the long-term deflections by reducing the self-weight. Again, post-tensioned slabs proved to be a very competitive alternative for any kind of structure, in terms of economy, time and performance.

WHITE CITY SHOPPING DEVELOPMENT, LONDON

Europe's largest retail centre

The White City Shopping Development in West London will be one of Europe's largest when it opens in 2008 and BBR Network member **Structural Systems (UK)** Ltd is on the case. The £700m project is due to create 5000 jobs with an area of 120,000m^2 comprising retail and commercial space, cinemas and public areas. At the start of the project, the site was divided by London Underground's Central Line. A concrete overbuild "tunnel" now hides the railway and work can at last start on the superstructures to the east and centre of the site. Meanwhile to the west, construction is 80% complete.

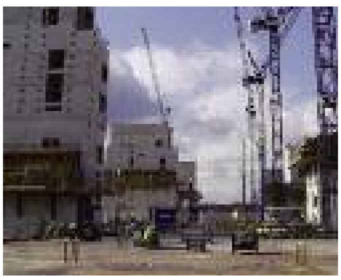
TWO-WAY POST-TENSIONING

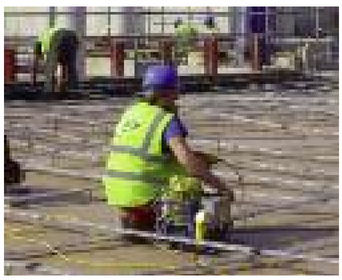
Structural Systems (UK) Ltd has been responsible for the slab post-tensioning work to the level 20 and 30 flat slabs, plus some of the more complex beam areas of level 40. The majority of the level 20 and 30 slabs are on 8x8m grids. The 225mm deep slabs have been two-way post-tensioned using the BBR CONA flat 505 bonded PT system.

MASSIVE SLAB AREAS

Reinforcement is very light, being confined to edge or construction joint reinforcement, top mats at columns and punching shear links at some columns. The slab areas are massive – level 30 alone is 150x200m in total. The total PT slab area is expected to reach 80,000m^2. Whereas the lower levels support car parking, level 40 carries retail loading, mall loading – including maintenance vehicles – and even fire engine loads. Also, a number of the stanchions from the three-storey steel superstructure do not land on grid. The solution is a series of beams including transfers as required. Through the central part of the site, where grids are most erratic, the beam size has been minimised by employing post-tensioning. To date, the largest beam has been a 24m spanning beam – 3000x1800mm deep – and containing seven CONA internal 1906 multi-strand tendons.

Future work includes the five-storey anchor store in the feature corner of the site and more post-tensioned flat slabs across the newly accessible central area.





STOREHOUSE FLOOR IN NEW ZEALAND

Massive milk powder store

As far as post-tensioned floor slabs go, the Fonterra Co-operative Group project that **BBR Contech** recently completed for Haydn & Rollett and Allied Concrete must surely rate as one of the largest, according to BBR Contech's Keith Snow and Jeff Marchant.

This massive system forms the foundation for a storehouse that is nearly 4.5 hectares in area – stretching for almost half a kilometre alongside the railway line in Hamilton's Crawford Street, in New Zealand.

STRINGENT REQUIREMENTS

The rail store is designed to house Fonterra's milk powder exports between their point of origin – the central North Island – and the rail network to their port of departure. Comprising three separate areas and a covered rail siding, it imposed stringent requirements for a high-performing and effective flooring system – admirably met by post-tensioned floor slabs, whose total absence of joints means a smooth, aesthetically appealing appearance, a high resistance to applied loading, easy care and long-term durability.

Facts & Figures

Total area of post-tensioned slab on ground	**50,000m²**
Tendons	**60,000m**
Strand	**300t**
Concrete	**Approx. 10,000m³**

SLAB CONSTRUCTION

The 35,000m², 165mm thick slab was poured in 12 stages, with slabs ranging in size from 2300 to 3345m². Each slab has crossed-over tendons to the adjacent one, which means only a single open joint within each area. The post-tensioned floor slab was designed by BBR Contech utilising a BBR CONA flat 405 tendon configuration.

Allied Concrete's new full delivery concrete flooring division, Conslab Ltd, was responsible for constructing the slab and BBR Contech was again engaged as the specialist post-tensioning contractor. This was a continuation of the same teamwork which has delivered a large number of high performance concrete floors for many clients over recent years.

"The sheer size of the building required meticulous planning, right from the start – this was bigger than anything any of us had ever done before!" said Kim Barrett of Haydn & Rollett, the contractor for the project.

REHIRED FOR APRON SLAB

Following on from the successful completion of the main storehouse slab, BBR Contech was approached to configure a heavy duty post-tensioned apron slab which runs between the main storehouse and the adjacent rail siding. This 15,000m² apron slab is required to deal with closely spaced and fully laden containers, stacked two high. In addition, the slab must also resist loads from large container handling equipment with peak axle loads approaching 100t.

SHARING KNOWLEDGE

BBR Contech worked closely with Australian BBR Network member, Structural Systems Ltd, to configure a slab which would meet all of Fonterra's design criteria. The result was a slab measuring some 500m long and 30m wide, constructed in six separate pours. The slab depth is 270mm with perimeter edge thickenings of 380mm. The post-tensioning comprises BBR CONA flat tendons. Structural Systems Ltd has designed similar apron slabs in Australia and this is the first such heavy duty application for New Zealand. The close collaboration between BBR Network members demonstrates how specialised technical know-how, consulting expertise and local experience can deliver certainty of performance for some very challenging engineering projects.

TEAM & TECHNOLOGY

- **OWNER**
  Fonterra Cooperative Group
- **CONTRACTOR**
  Haydn & Rollett Construction Ltd
- **DESIGNER**
  BBR Contech (New Zealand) / Structural Systems Ltd (Australia)
- **TECHNOLOGY**
  BBR CONA flat
- **BBR NETWORK MEMBER**
  BBR Contech (New Zealand)

SALZBURG SHOPPING CENTRE EXPANSION

Already one of the most successful centres in Austria, the Europark Shopping Centre on the outskirts of Salzburg, underwent a major expansion which has extended the retail sales area from 30,500m^2 to 50,000m^2. Dipl. Eng. Michael Schreiner of Austrian BBR Network member, **VORSPANN-TECHNIK GmbH & Co. KG,** reports on how the use of internal unbonded prestressing – to control the static behaviour of the flat slab – delivered an excellent solution for the client and saved valuable construction time.

POST-TENSIONING SYSTEM

The selected prestressing system was the BBR CONA CMM 406 with bands as tensile elements. A key element of this system is the combination of four strands, with a nominal cross-sectional area of 150mm^2, arranged in a band. The VT-CMM band offers the advantage, in comparison to a monostrand, of easier and faster placing of tendons on site. In addition, tendon cutting and mounting and prelocking of the fixed anchorages can also be carried out off-site, in the factory. The in-situ concrete slab had a thickness of 45cm to 60cm and a span of 16m by 8m. The tendons were placed near the columns, in the direction of the principal axis.

A slab thickness of 45cm permits application of the "free tendon layout" method. This method requires tendons to be fixed only at the upper and lower reinforcement layer – therefore, special spacers for tendons are not required.

PRESTRESSING WORKS

The three post-tensioned slabs had an average area of 16,000m^2 and had been divided in 10 to 15 construction stages. In total, 2615 tendons (400t) with an average length of 32.65m were produced, installed and stressed in 11 months. This project was an excellent demonstration of the benefits of the BBR CONA CMM technology and the client certainly appreciated the expertise of the highly professional and dedicated team from the BBR Network.

SPEEDY SOLUTION

TEAM & TECHNOLOGY

- ***OWNER***
  Europark Errichtungsgesellschaft mbH
- ***MAIN CONTRACTOR***
  Joint venture between Strabag AG, Alpine Mayreder Bau GmbH, Dywidag GmbH
- ***DESIGNER***
  Ziviltechnikergesellschaft Herbrich Consult, Salzburg
- ***TECHNOLOGY***
  BBR CONA
- ***BBR NETWORK MEMBER***
  VORSPANN-TECHNIK GmbH & Co. KG (Austria)

MULTIFUNCTIONAL RESIDENTIAL BUILDING, SLOVENIA

Building the little butterfly

Zelimir Bodiroga and Damir Pavicic from **BBR CONEX** of Croatia report on their third project completed with post-tensioned slabs – in the historic town and growing ski resort of Kamnik on the banks of the Bistrica River.

The building is known as "Metuljcek" – Slovenian for "little butterfly" – and is a very demanding and complicated project which started in March 2006. It comprises two underground parking levels, two commercial and three residential floors, it has a total area of almost 30,000m^2. We undertook design of the post-tensioned slabs in collaboration with Dreibau Ingenieurs Conseils, Switzerland.

ORIGINAL PLANS

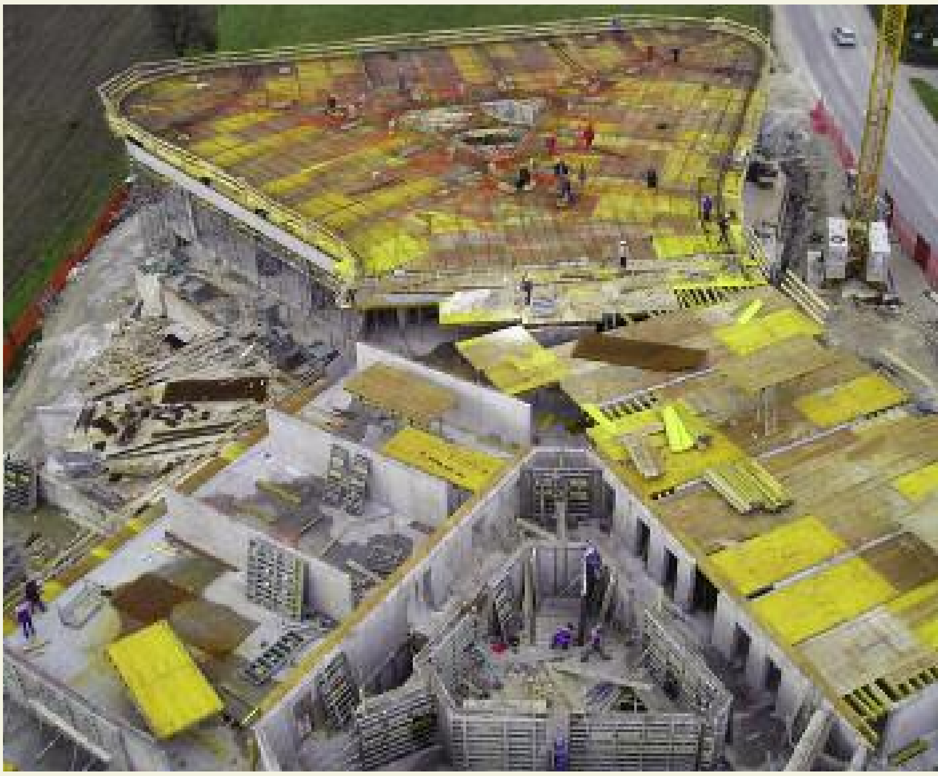
The original concept for the building was an eight storey framed structure with an irregular foot-print. It consisted of two triangular sections which, together, formed an irregular butterfly shape. The vertical bearing structure comprised two triangular cores, with vertical communications, columns spaced at 6 or 7m and retaining walls in the underground structure. Floor construction was of reinforced concrete cast in situ slabs, supported by beams between columns. There was also a circular ramp in one corner of the building for car access to the underground parking levels. Numerous holes and shafts for installation and air circulation had to be incorporated in the slabs. Together with the irregular shape of every part of building, the design was way too complicated – from every aspect!

REDESIGN ENHANCES

BBR CONEX was involved in redesigning the "little butterfly" much more than is usual on a construction project. Floor slabs were redesigned as completely flat and all the beams were removed – thickness of the slabs ranged from 18cm to 22cm. The basement slab is also post-tensioned, with the thickness reduced from 70cm to 45cm – and no water isolation was needed as a post-tensioned basement slab is already waterproof. In the superstructure, columns of complicated cross-section were replaced with RC walls, arranged radially around the cores. This way the construction was simpler, faster – and, more importantly, enabled flying form tables to be used. Economy of the structure was greatly enhanced, whilst stability and seismic properties were also improved. In addition, with new walls instead of the columns, the problem of punching shear was solved and great deal of rebar was spared.

TEAM & TECHNOLOGY

- **OWNER**
  CM Celje
- **CONTRACTOR**
  CM Celje
- **DESIGNER**
  CM Celje with Dreibau Ingenieurs Conseils (Switzerland)
- **TECHNOLOGY**
  BBR CONA unbonded
- **BBR NETWORK MEMBER**
  BBR CONEX (Croatia)



POST-TENSIONING

The slabs and basement slab were post-tensioned using 0.6", greased and PE-coated, 7-wire BBR CONA Single T15SUPER unbonded monostrand tendons with BBR CONA Mono anchors. Tendon cross-sections are 150mm^2, with a tensile capacity of 279kN. Tendons in the elevated slabs had no intermediate anchors, as the slabs were poured in continuously for each "wing" – the average area of one pour was just under 1600m^2 and required about 300m^3 of concrete.

In the basement slab, tendons were parabolic and had one or no intermediate anchors. Tendon layouts were complicated, often with three families of tendons – in three different directions – interweaving with each other.

The total area of post-tensioned slabs is about 27,000m^2 – including seven elevated slabs and the basement slab. Every floor slab is divided into two parts, each cast in one pour.

The basement slab was cast in eight pours. Tendons had to be stressed from above or from inside of the slab, as there was no space for stressing between the edge of the slab and the trench walls – about 1m is usually enough for edge stressing. Demanding and complicated logistics were involved in the project, mainly for the basement slab, as the design was complicated and the site had very little space around the trench.

This project is a perfect example of the variety of enhancements that the post-tensioning of slabs can yield.

AL NUAIMIAH TOWERS, AJMAN, UAE

Prestigious residential development

Warwick Ironmonger, General Manager – Middle East Region for **Nasa (BBR) Structural Systems LLC** reports on how post-tensioned slab solutions are delivering a range of benefits for their customer in the UAE.

Building upon its significant track record in the Middle East, BBR Structural Systems (BBR-SSL) has recently completed the design and construct post-tensioning works associated with a prestigious residential development in Al Nuaimiah for His Highness Sheikh Humaid bin Rashid Al Nuaimi, the Ruler of the Emirate of Ajman.

ECONOMICAL SOLUTION

The complex consisted of 15 apartment buildings, each comprising of 17 suspended flat plate, post-tensioned slabs with a combined total floor area of 180,000m^2. Post-tensioned floors were adopted to permit an economical solution – satisfying the project requirement of thin slabs and minimal use of false ceilings, whilst achieving the earliest possible completion date. The slabs were typically 230mm thick for spans of up to 8500mm and increased locally to 250mm in the vicinity of 10,800mm spans.

MINIMAL FORMWORK

The complex was the first of its type in Ajman and the completion of the suspended floors at a rate of three levels per building per month – using only one set of formwork, made possible through the post-tensioned solution – facilitated the earliest onset of foreign investment in the Emirate of Ajman and offered neighbouring residents of Dubai and Sharjah the earliest opportunity to re-locate to more affordable accommodation in the Emirate of Ajman.

FURTHER CONTRACTS

Following the success of this project, a second complex of 16 residential buildings has been proposed in nearby Al Khor and, despite the fact that contracts have been let to four main contractors, BBR-SSL has managed to secure the post-tensioning works associated with all of these buildings. Post-tensioning site works are currently in progress for 12 of the 16 new buildings.

FRUIT JUICE WAREHOUSE FLOOR, POLAND

Taking the load

For their first slab task, **BBR Polska** was lucky to have the advantage of extensive shared know-how from BBR Contech NZ – the slab post-tensioning giant. That was in 2005 and, with this special technology becoming more-and-more popular in Poland, since then BBR Polska has participated in several projects.

A special industrial slab on grade has been designed for Alpex, a fruit processing company located in Leczeszyce near Grojec. It was destined for the apple juice concentrate warehouse and needed to carry 60 containers, about 14m high, each weighing over 200t.

"This meant that a load of 200kN on each of the 12 feet of the containers had to be taken into account in the design." explained project manager Anna Plusko, "Consequently, the slab on grade required a substantial thickness – from 24 to 35cm – which required over 400m^3 of concrete!"

The 1317.75m^2 slab needed no expansion joints because it was post-tensioned using PE coated unbonded cables.

Through its continuous expansion programme, helped along by BBR Polska, the Alpex plant is now able to produce 24,000t of concentrated fruit juices – 95% of its products are exported to the EU, USA and Japan.

TECHNOLOGY MEETS DEMAND FOR STORAGE

World LNG consumption soars

Over the past few decades, world consumption of LNG – Liquefied Natural Gas – has increased more than five-fold and it is predicted that growth will continue to be very strong. The rising demand from large markets such as China and India, combined with the increasing popularity in a large number of other smaller markets has resulted in the development of many new LNG facilities throughout the world.

A paper on design and construction aspects of post-tensioned LNG storage tanks in Europe and Australasia has been produced by BBR's Hudson Lun, Frank Filippone and Diana Cobos Roger, with contributions from members of the BBR Network, a summary of the key aspects is reproduced here.

NEED FOR STORAGE TANKS

There are significant natural gas reserves globally and exploration companies are rapidly developing facilities for exporting the natural gas, with the corresponding receiving facilities being planned and built in emerging markets. With a timeframe of some 5-10 years for planning and construction, there is currently much activity underway in the LNG supply chain in preparation for current and predicted demands.

The growth in this sector has seen the development of significant LNG storage tank facilities for LNG exporters and importers. These massive storage tanks are essential for reception and safe storage of the liquid gas.

STORAGE CONDITIONS

The storage temperature of LNG is -162°C and is described as "cryogenic" conditions. The liquid occupies 600 times less space than natural gas in its gaseous state, making it practical to ship by ocean tanker. In addition, it is stable and safe because, even though compressed in volume, the liquid remains at normal atmospheric pressure. On land, LNG is stored in specially engineered and constructed double-walled storage tanks. At these temperatures, the requirements for the containment structures are very stringent and post-tensioned concrete tanks are ideally suited to the task.

The large concrete tank structures are extremely robust with significant amounts of prestressing required – all being designed and installed under tightly controlled quality conditions, with hardware requiring special certifications.

DESIGN AND CONSTRUCTION

Design and construction techniques have been specially formulated for LNG tank construction. The outer walls of the tank are most commonly constructed from post-tensioned concrete. The void between the tank double walls is filled with insulation.

Tanks are around 80-90m in diameter and 50m high, with a wall thickness of some 750mm.

The post-tensioning tendons are very large and typically run both vertically and horizontally.

- **Vertical tendons**
  These can either be single directional tendons from the top of the tank, terminating in a recess or socket at the bottom – or "U" tendons starting at the top, coming vertically down through the tank, curving around through 180° degrees and returning to the top.
- **Horizontal tendons**
  Typically, these start at a buttress and travel half way around the tank, terminating at the opposite buttress. Another tendon commences from the same buttress and travels back through the remaining half of the tank, terminating at the original buttress – thus creating a complete "hoop" with the two tendons.
  For efficient use of post-tensioning, adjacent tendons are anchored at alternate buttresses, 90° from the actual buttress.

LNG tanks are generally constructed under design and build arrangements, with the principal contractor being responsible for determining the specific design requirements for the prestressed concrete. The post-tensioning specialist examines the required force profile and details the spacing and tendon size for the post-tensioning.

PT DESIGN REGULATIONS

There is no official standard for the design of these tanks and the first guidelines published were based on pioneering work in cryogenic applications. According to *fip* SR 88/2, testing is required to be carried out on:

- **Prestressing steel** – at room temperature and at cryogenic temperature
- **Tendon anchorage assembly** – at room temperature and cryogenic temperature
- **Load transfer** – at cryogenic temperature

Tests according to these guidelines were completed for the BBR Technology. Subsequently, a new guideline has been published to cover prestressing in cryogenic applications – ETAG 013.

The testing and quality control of prestressing materials used in cryogenic applications is critical to the successful performance of the containment systems.

The BBR CONA post-tensioning system is in full compliance with the testing regime under cryogenic conditions.

EXPERIENCE & EXPERTISE

LNG storage tanks are ideally suited to construction methods employing slipformed or climbing insitu concrete construction combined with post-tensioning. The design and installation techniques are very specialised and require specially certified and tested materials and highly experienced contractors.

A large database of information has been developed during construction of these massive concrete structures and many innovative techniques have streamlined activities associated with the supply and installation of post-tensioning materials and other construction-related engineering. The nature of the typical design and build project delivery method has seen the formation of some strong design and construction relationships and this has seen the rapid development and optimisation of design and installation techniques. ●

The US market

Technological advances and increased competition, thus lowered costs for handling, have made LNG more attractive to US energy suppliers over recent years. Record high receipts of LNG were reported in 2003 – the highest since 1979.

Existing plants are planning expansion which will provide a total additional peak time capacity of 2.440 billion cubic feet per day. Meanwhile, over 20 new import facilities are being evaluated by the authorities and many more are at the planning stage. These new plants include eight offshore and 19 onshore installations which together would bring an additional peak time capacity of approaching 31,500 million cubic feet per day.

Until now, the highest capacity of LNG storage has been close to centres of population in the Eastern United States. By far and away, the majority of current projects, either at the early stages or in construction, are located in the Gulf of Mexico region and, alone, are set to increase US LNG capacity by 55%.

Generally, the demand for domestic LNG is expected to increase as companies make inroads into several niche markets such as vehicular fuel and as a replacement for propane at facilities off the pipeline grid.

UK's largest civils package

SOUTH HOOK LNG TANKS, PEMBROKE DOCK, WALES

This massive infrastructure project is being undertaken by BBR Network member **Structural Systems UK Limited,** in conjunction with the main contractor Taylor Woodrow Construction and involves the construction of the five 92m diameter post-tensioned tanks to provide the outer shell of holding tanks for Liquid Natural Gas (LNG).

When completed, these storage tanks will form an integral part of a new reception terminal to handle LNG into the energy grid, through the port of Pembroke Dock near Milford Haven in South Wales – and this is currently the largest civil engineering package being undertaken anywhere in UK. The total project is being managed by Chicago Bridge & Iron (CB&I), on behalf of the Qatar Petroluem and Exxon Mobil companies. Other works involved in the project include the supply of transport vessels, reinstatement of existing unloading pier, pipe infrastructure, re-gasification plant and the five concrete tanks and associated holding tanks. When complete, each of the post-tensioned concrete tanks will be 35m high and have a 92m diameter, giving a circumference of approximately 290m.

TEAM & TECHNOLOGY

- ***OWNER***
  Qatar Petroleum & Exxon Mobil
- ***CONTRACTOR***
  Taylor Woodrow Construction Ltd
- ***DESIGNER***
  Chicago Bridge & Iron
- ***TECHNOLOGY***
  BBR CONA internal cryogenic
- ***BBR NETWORK MEMBER***
  Structural Systems (UK) Ltd

Project Statistics

Horizontal cables = 670 – 19 x ø15.7 strands
+ High tensile steel strand ø15.7

Horizontal cables = approx 156m long each
+ Galvanized ducting = 105km

Vertical cables = 420 – 12 x ø15.7 Strands
+ High tensile steel strand ø15.7

Vertical cables = approx 70m long each ('U' tendons)
+ Galvanized ducting = 29km

Strand wedges = 38,000
Multi strand anchors = 2,180

Cement for duct void filling = 1,000t

BBR PT FOR PERFORMANCE

Post-tensioned strand for the project is installed and stressed both vertically and horizontally. Vertically, the strand will be stressed through a U-shaped tendon from the ring beam to the base. Horizontally, post-tensioning will be applied through a pre-formed buttress located at the quadrant points of the tank.

The buttress arrangement allows for the hoop tendons, which make up the circumference of the tank, to be stressed in two halves to improve stressing forces and minimise friction losses. Four buttresses are formed to allow alternating tendons to be stressed at 90° to each other, to ensure the loads are uniformly distributed around the tank and reduce both the stressing loading on each buttress and construction issues with the anchor installations.

Post-tensioning was favoured over traditional reinforcement as a result of the cryogenic temperatures needed to keep the gas in a liquid form and the superior ductile characteristics of the high tensile steel strands at low temperatures. In addition, the cylindrical concrete tanks were slip-formed to the under side of the ring beam to speed up the construction programme.

STRAND INSERTION

Once the tank walls have attained the required design strength, the high tensile steel strand to be post-tensioned is fed through the pre-laid ducting. Ducting, within the slipformed tank walls, consists of a series of vertical and horizontal galvanized tubing installed at approximately 300mm centres.

MULTI-STRAND JACKING

Following the placement of the strand which will provide the hoop stressing forces to the concrete tank, stressing is undertaken using a specialist "multi-strand" jacking operation,

thus increasing the tensile capacity of the concrete and ensuring the tank is robust enough to withstand the pressure should the inner tank leak. To complete the operation, the ducts which now contain the stressed strand are filled with cement grout, to both fill the remaining voids and bond the high tensile steel strand into the ducting.

The construction on the project is estimated to run from September 2006 to July 2008 and is being programmed so that three of the five tanks will be online to handle the first delivery of LNG through the port in February 2008. To meet the projected completion dates, operations will require Structural Systems UK to operate two construction crews from February 2007 to December 2007 to satisfy the client's requirements. ●

GASCO LPG TANKS, RUWAIS, UNITED ARAB EMIRATES

Adaptable technique

The nature and form of construction of these large concrete tanks can readily be adapted to the storage of other materials. Another significant facility designed and constructed by Chicago Bridge & Iron (CB&I) has recently commenced in the United Arab Emirates. Warwick Ironmonger, General Manager – Middle East Region for **NASA (BBR) Structural Systems LLC,** describes their project for GASCO.

In this scheme, four full containment LPG tanks for storing propane and butane are being constructed in Ruwais, to the west of Abu Dubai city. Each 34m high tank is 62.8m in internal diameter and has a domed concrete roof.

These tanks generally have 500mm thick walls with a lower taper to 800mm thick at the base and are horizontally post-tensioned only, with vertical actions normally reinforced. The outside face of the concrete wall here is static formed with the inner face cast against a permanent steel liner.

NASA (BBR) Structural Systems' task consists of the design and detailing input, supply, installation site services including the stressing and grouting of around 820MT of PC strand within the walls of the tanks.

Horizontal tendons typically comprise 19 x 15.7mm diameter, 1860MPa UTS strands housed, stressed and grouted within galvanised ducting of 105mm ID have been detailed to satisfy the effective force profile specified by our client. Each tendon is approximately 105m length and is to be stressed from both ends. The cryogenic version of the BBR CONA internal multi-strand anchorages, positioned at the buttresses, were chosen to anchor these tendons as it was specified that the pre-stressing system should be workable at low (cryogenic) temperatures.

Construction of the walls, which are being cast in 3.4m lifts, commenced in July 2006 – with the anchorage castings and ducting already cast into the concrete of the first two lifts – and is expected to be completed in mid-2007.

TEAM & TECHNOLOGY

- **OWNER**
  GASCO
- **CONTRACTOR**
  Snamprogetti (Main) /
  Chicago Bridge & Iron (Tank)
- **ENGINEER**
  Snamprogetti / Bechtel
- **TECHNOLOGY**
  BBR CONA internal cryogenic
- **BBR NETWORK MEMBER**
  NASA (BBR) Structural Systems LLC (UAE)

Floating TERMINAL

ADRIATIC LNG TERMINAL, SPAIN-ITALY

The Adriatic LNG Terminal, which will be operational in April 2008, is being constructed in a large dry-dock facility in Algeçiras in southern Spain. This same dry dock was previously used to build the *fib* award-winning BBR post-tensioned concrete structure for the Monaco Floating Breakwater. Two BBR Network members – *BBR PTE* and *KB Spennteknikk AS* – are both heavily involved.

The Adriatic terminal is a rectangular structure, 180m long, 88m wide and 47m high, with the capability to hold two 125,000m^3 LNG tanks. It is a gravity-based structure, which will be towed to its final destination, 17km off the coast of Italy, where it will be used for receiving, storage and regasification of LNG. Approximately 90,000m^3 of concrete, 30,000t of rebar and post-tensioning steel and 350,000t of solid ballast are being used for the construction of the terminal.

BBR PTE is developing the post-tensioning works in association with two other companies. This project includes both horizontal and vertical post-tensioning utilising tendon configurations of 12 and 19 15.2mm strands.

Left: 53 custom-made TOBE pot bearings are being used as support for four steel topside modules on the GBS concrete top slab. The bearings are designed to withstand blast events and uplift during safe shutdown in case of earthquakes.

FROM BARCELONA TO CARTAGNA, SPAIN

LNG market grows in Spain

The construction of the fifth and sixth LNG tanks in Barcelona, for the project owner, ENAGAS, started in 2003. The two tanks have an inner diameter of approximately 80m and an inner height of 37m – the total overall height of the structure is 49.5m. The outer containment walls are 800mm thick, post-tensioned vertically and horizontally with the cryogenically proven and tested BBR CONA post-tensioning system.

An approximate total of 600t of prestressing steel was required for each tank. There were 140 horizontal tendons, each containing 15 15.2mm strands. The 140 vertical tendons were of a loop configuration containing 19 15.2mm strands. In addition, there were 12 horizontal tendons in the external ring of the foundation slab each with 24 15.2mm strands.

To ensure corrosion protection of the tendons, grouting was carried out using a specially developed vacuum grouting technique with special high-turbulence mixers. All post-tensioning work on these tanks was conducted by BBR Network member, **BBR PTE** (Spain). The fifth tank was finished in 2004 and the post-tensioning work on the 6th tank was completed in late 2006.

Another 150,000m^3 LNG tank is being constructed by BBR PTE (Spain) – in Cartagena – with an outside diameter of 81m and an inner height of 40m. The containment walls are 800mm thick, post-tensioned vertically and horizontally with BBR CONA. Construction is expected to be completed in summer 2007.

Overview of new digestion tank system – front left, digestion tank (DT1) with installed conic prestressing tendons, behind DT2 with inner funnel formwork before concreting, DT3 with rising inner formwork and, rear right, DT4 with circumferential funnel formwork.

GUT GROSSLAPPEN WASTEWATER TREATMENT PLANT, MUNICH, GERMANY

Innovation continues in Munich

Some 30 years ago, BBR supplied and installed its then pioneering HiAm anchored strands for the Olympia Stadium project, the former home of Bayern Munich Football Club. Now, next to the team's new home at the Allianz Arena, engineers from BBR Network member **VORSPANN-TECHNIK GmbH** working on the Gut Grosslappen Wastewater Treatment Plant have again created an innovative new solution.

Dipl.-Ing.(FH) Thomas Weber of **VORSPANN-TECHNIK GmbH** describes his company's success in proposing and using BBR VT CONA CMM unbonded prestressing in the design of digestion tanks for the Gut Grosslappen Wastewater Treatment Plant in Munich.

WINNING WAYS

VORSPANN-TECHNIK won the tender for the execution of the prestressing works thanks to the use of the BBR VT CONA CMM bands. The advantages of the prestressing concept compared to the original design were the determining factors for this decision.

The wastewater treatment plant München I – Gut Grosslappen currently possesses a digestion tank system with six digestion tanks. These tanks were built in sections – in 1961, 1968 and 1972. Each tank has a volume of 6500m^3, giving an overall volume of about 39,000m^3. For diverse technical, safety-related and economic reasons, construction of new tanks was inevitable.

The Stadtentwässerungswerke München (SEW) therefore decided, in 1998, to build four new digestion tanks – each now offering a volumetric capacity of 14,600m^3. The construction of these tanks and the operations building was put out to tender at the end of 2002.

ORIGINAL DESIGN

The original design envisaged a cross-section in the form of a double cone cylinder. In this plan, the occurring vertical forces were transferred mainly via the bottom plate of the passage, as well as the lower cone point of the tank.

The prestressing concept linked to this load-bearing performance envisaged a horizontal annular prestressing with individual unbonded monostrands, each installed around 360°. The planned anchorage recesses of the prestressing tendons were arranged at 90° intervals around →

View of digestion tank 1 – construction stage 5 completed, digestion tank 2 – construction stage 5 completed, inner framework construction stage 9 completed, and part view of digestion tank 3 – construction stage 8 completed.

the top of the tank, in order to achieve the highest possible force distribution.

For the meridian prestressing tendons (vertical prestressing tendons) seven to 22-strand post-tensioned prestressing tendons were planned. The large 22-strand prestressing tendons ran through the lower cone point, intersecting up to three layers. The lower anchorage of all post-tensioned prestressing tendons was realised by means of a so-called "loop" anchorage.

Tensioning of the conic prestressing tendons with VT 1000 prestressing jacks.

IMPROVED PROPOSITION WITH BBR SYSTEM

The detailed proposal was worked out by the civil engineering company Peter Jäger Bauingenieure AG of Basel and exclusively uses BBR VT CONA CMM 0406 150 1770 unbonded tendons, with the proviso that no modification be made to the external geometry of the tanks. The prestressing concept offered a cross-section optimisation, with a better transfer of the vertical forces to the foundation. In contrast to the original design, these forces are almost exclusively transferred, via a foundation ring at the equator, to bored piles into the ground. Compared to the tender design, this results in lower dimensions of the foundation area and in lower construction costs.

With this detailed proposal, the ARGE Neubau Faulbehälter Klärwerk Grosslappen consortium, consisting of Wayss & Freytag Ingenieurbau AG and Bauer Spezialtiefbau GmbH, won the tender based on both technical and commercial criteria and was commissioned to build the four digestion tanks and the operations building in spring 2003. A few months later, VORSPANN-TECHNIK GmbH received the order from Wayss & Freytag to carry out all the prestressing work for the digestion tanks.

"THE PRESTRESSING CONCEPT OFFERED A CROSS-SECTION OPTIMISATION, WITH A BETTER TRANSFER OF THE VERTICAL FORCES TO THE FOUNDATION"

PRESTRESSING IN PRACTICE

For the prestressing, BBR VT CONA CMM unbonded tendons were used exclusively throughout. Depending on their position, three different types of tendon profiles were adopted.

Conic prestressing tendons

The conic prestressing tendons were installed in four assemblies, consisting of 51 tendons each – 220 per tank – in the lower cone. These tendons "hang up" the lower cone on the foundation ring. The stressing of the tendons was carried out in the construction joint between construction stages two and three (equator area), with the tendons being stressed on both sides synchronously for a better force introduction and distribution of the elongation value.

Ring tendons

The ring tendons were arranged over the complete height of the tank, standing upright. In total, 227 tendons per tank were installed. As in the original design, they were installed around 360° and were also stressed in anchorage recesses staggered by 90°. In areas with high load concentration – particularly around the equator – it was necessary to increase the prestressing force from the ring tendons. In view of the limited space available, four tendons were arranged one after another. Ring tendon installation was carried out with a dispenser especially developed by VT for this project.

Meridian tendons (vertical tendons)

The meridian tendons were divided in two length groups. The shorter tendons were anchored and stressed in construction stage 5, the longer tendons in construction stage 8. The 96 meridian tendons were anchored in the lower cone by means of a loop. The loops were arranged in 24 groups, each containing four tendons.

TEAM & TECHNOLOGY

- **BUILDING OWNER**
  Stadtentwässerungswerke München (SEW)
- **CONTRACTOR**
  Wayss & Freytag Ingenieurbau AG
- **DESIGNER**
  Peter Jäger Bauingenieure AG
- **TECHNOLOGY**
  BBR CONA unbonded
- **BBR NETWORK MEMBER**
  VORSPANN-TECHNIK GmbH, Munich

SPECIAL LICENCE

When the construction work started, the prestressing system – with licence number Z-13.1-71 – had been technically approved by the building authorities. But since, for this project, tensioning wires with a slightly higher yield stress were used and the minimum deflection radius of 2.6m for the loop anchorages and pipe by-passes was under-run, an individual approval had to be obtained. To this end, VT carried out the required tests and commissioned a report from an expert. On the basis of this expert's report, the Supreme Building Authority of the Bavarian State Ministry of Internal Affairs granted the approval on an individual basis for the use of a prestressing steel with a steel grade $f_{p0,1k}/f_{pk}$ = 1570/1770, as well as for the reduction of the minimum deflection radii. ●

Loop anchorage of the meridian tendons.

MELBOURNE CEMENT FACILITY

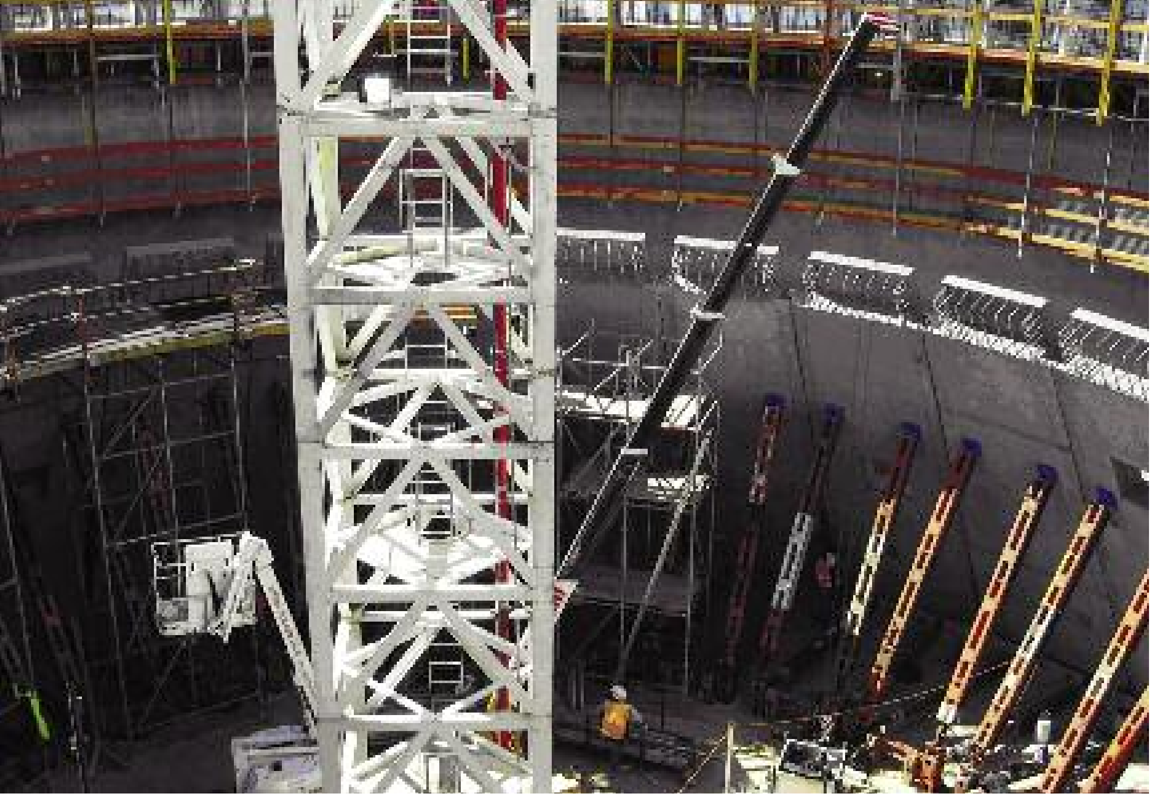
State-of the-art silo

Structural Systems Limited, the BBR Network member in Australia, is currently working on the new Melbourne Cement Facility Silo in Port Melbourne, Victoria. This state-of-the-art cement storage silo has a capacity of 35,000t and is the latest addition to Melbourne's largest cement plant. The facility currently supplies 80% of the cement required by five of the major ready mix companies in Melbourne.

Project facts & figures

- **Capacity – 35,000t**
- **Height – 57m**
- **Diameter – 30m**
- **Wall thickness – 900mm reducing to 450mm**
- **Reinforcement – 535t**
- **Post-tensioning – 130t**
- **Concrete – 2860m³**

This new cement silo will have the ability to load three tanker trucks within its perimeter at one time. This innovation means that separate loading plant is not required – making for a more efficient and quicker turn-around of the ever-busy tankers. Construction of the ring pile cap commenced on 1 April 2006 with the project having a completion date of 22 December 2006. This required the utilisation of a quick and reliable formwork system. BBR Network member Structural Systems Limited successfully bid for the project, based on using its own in-house slipform system. Coupled with the BBR CONA post-tensioning system, this presented the client with a packaged solution for a difficult project with a tight construction programme. →



and safe manner from mast climbers mounted on all four buttresses. The 102m long strand tendons were installed in less than 12 days.

STRESSING & GROUTING

On completion of the strand installation the tendons were stressed in a predetermined sequence to a load of 4,225KN using a 630t jack. This stage was completed in less than ten days. When a project is on a tight schedule, all components must be reliable, user-friendly and readily available – which is why the client chose the BBR CONA post-tensioning system.

The final stage of the post-tensioning was the grouting of the hoop tendons – this activity immediately followed the stressing/cutting of the tendons, once each tendon had been completed.

SLIPFORMING

The slipform pouring cycles were managed in two daily shifts – working 12 hours each. Slipform is a continuously moving formwork, system climbing at a rate of approximately 200mm per hour and occupying a total workforce of 30 men, including concrete placers, on each shift. Structural Systems Limited with its experienced and motivated workforce completed the project on time and within budget.

TEAM & TECHNOLOGY

OWNER
Melbourne Cement Facility Limited

CONTRACTOR
Dynamic Engineering Construction Co. Pty Ltd

DESIGNER
Shedden Uhde

TECHNOLOGY
BBR CONA internal

BBR NETWORK MEMBER
Structural Systems Limited (Australia)

Structural Systems Limited's scope of work on the project was:

- Slipform – supply and operation
- Post-tensioning – supply and installation
- Reinforcement – installation

The on-site set-up of the slipform system took 4.5 weeks from start to the commencement of the first pour. Pouring of the concrete, fixing of the reinforcement and installation of the post-tensioning ducts and castings was undertaken over continuous 24-hour pouring cycles, reducing the need for unsightly construction joints in the external wall.

POURING CONCRETE

The silo was broken into three pouring sections.

The first was to the wall thickness change where the walls stepped on the inside face from 900mm thick to 450mm thick. The wall change formed a shelf on the inside of the silo for the preceding precast concrete panels used to form the cone to sit on. The internal cone structure is the basis of the internal loading feature. The

wall changeover took six days to complete.

The second pouring sequence saw the start of the post-tensioning. The silo has 72 1906 hoop tendons at 1m centres. The hoops are broken into four segments and stressed through four buttresses. The decision to use heavy duty 3mm thick galvanized metal-ribbed duct with a ID of 105mm was taken in order to minimise the risk of damage to the empty duct through the continuous concrete pouring cycle – and also to reduce any problems with strands jamming in the following post-tensioning strand pushing activity.

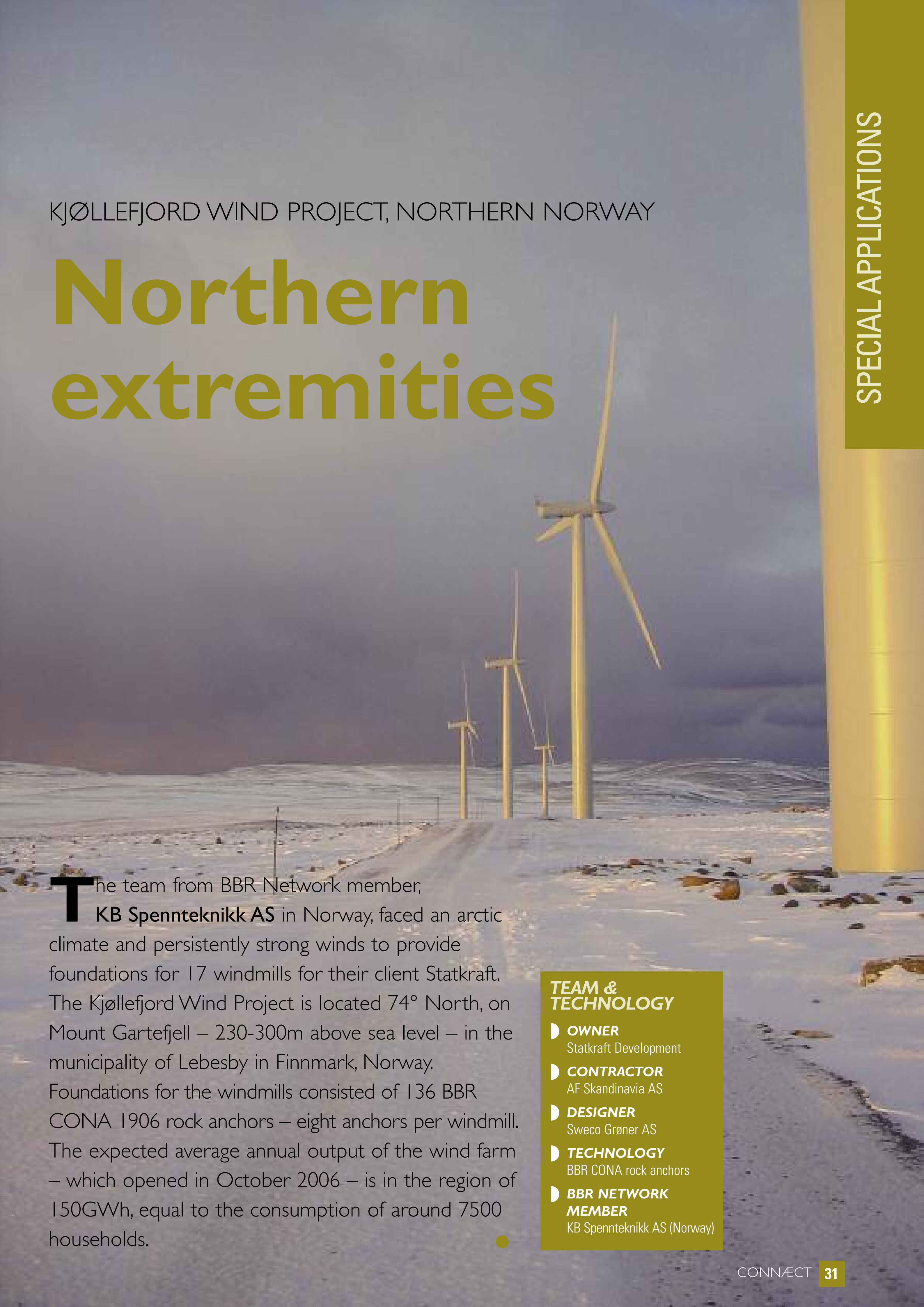
The required stopping height of this second pour was determined by the weight and the cranage capacity for the erection of the precast concrete cone panels. Each panel weighed 26t with a total of 24 in the bottom section and 12 in the top section of the cone, separated with a concrete in-situ ring beam.

When the desired height was reached, a PVC waterstop was installed in the top of the wall to alleviate any moisture penetration migrating through the wall from the construction joint.

The third concrete pour commenced some nine weeks from the completion of the second pour, thus allowing for cone works within the silo structure.

NEW HIGH SPEED PUSHERS

On the completion of the third concrete pour, the 72 1906 tendons were installed using the newly developed, computerised, high-speed strand pushers enabling our post-tensioning installers to work in an efficient



KJØLLEFJORD WIND PROJECT, NORTHERN NORWAY

Northern extremities

The team from BBR Network member, **KB Spennteknikk AS** in Norway, faced an arctic climate and persistently strong winds to provide foundations for 17 windmills for their client Statkraft. The Kjøllefjord Wind Project is located 74° North, on Mount Gartefjell – 230-300m above sea level – in the municipality of Lebesby in Finnmark, Norway. Foundations for the windmills consisted of 136 BBR CONA 1906 rock anchors – eight anchors per windmill. The expected average annual output of the wind farm – which opened in October 2006 – is in the region of 150GWh, equal to the consumption of around 7500 households.

TEAM & TECHNOLOGY

- **OWNER**
  Statkraft Development
- **CONTRACTOR**
  AF Skandinavia AS
- **DESIGNER**
  Sweco Grøner AS
- **TECHNOLOGY**
  BBR CONA rock anchors
- **BBR NETWORK MEMBER**
  KB Spennteknikk AS (Norway)

EXTENSION OF METRO STATION, MADRID, SPAIN

Load handling protects façades

Extension and remodelling of the metro station at Sol, in the centre of Madrid, was needed to accommodate new subway trains which will run along Line 3 of the Madrid Metro. Guillermo Molins Roger from BBR Network member, **BBR PTE,** describes his company's – quite literally – supportive role in the project to extend the length and width of the station.
The first step was to build a reinforced concrete slab over the entire excavation area. As this area was large enough to encroach upon the foundations of the surrounding buildings, it was necessary to install a system to protect the façades of the historic listed structures around the site.

MINING OPERATIONS, AUSTRALIA

Safely meeting production

BBR Network member, **Rock Engineering,** has developed both specialist techniques and purpose-built equipment to keep production on schedule for mining clients in Western Australia.

Pictured here is AngloGold Ashanti Ltd's, Sunrise Dam gold mine, which lies some 220km north east of Kalgoorlie and 55km south of Laverton in Western Australia. The mine comprises a large open-pit operation and underground project with over 12km of development. Gold is located in three broad settings – gently dipping shear zones, steeply dipping shear zones and gold rich breccias.
Rock Engineering has completed many projects for both the open pit and underground. Recently, work has included a successful cablebolting campaign, using thixotropic grout, to stabilise ground conditions so that further production could take place on a footwall. Also, degradation and weathering to the transitional zones of the pit walls has required the application of surface support for ground control in a number of critical production areas. Rolls of up to 80m in length have been installed within time and budget requirements.
Seven portals have now been successfully been established for the underground project. The installation by Rock Engineering of a fence above the western shear zone portal, plus fibrecreting of the batter face, has allowed our client to achieve the full 22.5m vertical bench height.

BBR PTE was asked to design and develop a system which guaranteed that no differential movements could happen during the excavation under the buildings' foundations.
The system that BBR PTE put in place to hold the buildings' façades was based on a set of 32 synchronized loading hydraulic jacks controlled by a specially designed control unit and power pack. Each jack had two sensors – one of them measuring the ram displacement and the other measuring the pressure applied to the jack, the data easily converted to force. Both measurements – displacement and force – were transmitted to the PLC of the power pack which controls the whole system.
Once on line, the system was able to control the jacks automatically, so if a loss of force in one of the jacks were to be detected, the power pack pump would increase the pressure inside the jack until it reached the value of the load transferred by the buildings' foundations. This means that, if the excavation caused the slab to settle, the power pack would activate and reset the jack to its correct load state.

To tare the system, once the jacks were placed and before the excavation started, the jacks were loaded until some movement was detected. At that moment, the load acting on the jack was the one coming from the building and transferred by the pier to the foundation – and this was the load that had to be maintained.

TEAM & TECHNOLOGY

- **OWNER**
  Metro de Madrid
- **CONTRACTOR**
  Línea 3 UTE (Joint venture FCC & CONVENSA)
- **DESIGNER**
  FCC Technical Services
- **TECHNOLOGY**
  BBR hydraulic jacks and synchronized power pack
- **BBR NETWORK MEMBER**
  BBR PTE (Spain)

YELAHANKA UNDERPASS, BANGALORE, INDIA

New underpass for India's silicon valley

The National Highway Authority of India (NHAI), through the SID, Indian Institute of Science, recently entrusted *BBR (India) Pvt Ltd,* with the prestigious and challenging task of providing an underpass beneath a 6-lane National Highway to connect the domestic and technical side of the Air Force Station at Bangalore – without interrupting the traffic on the Highway.

Box-jacking – the most non-intrusive means of tunnelling to construct the underpass – was used. This method enables traffic flows to be maintained throughout the construction period and with only minor restrictions during the brief period of tunnelling. The inconvenience and cost of disruption to infrastructure and traffic flows experienced with traditional construction methods can thus be avoided.

TUNNEL DESIGN

The proposed 36m tunnel consisted of two 3.7m wide shafts for the vehicular traffic. For pedestrians, a 2.7m wide footpath was constructed in the middle of the two shafts. The tunnel was to be built approximately 2m below the existing road surface.

CONSTRUCTION ENGINEERING

The raft portion is critical during construction, as it has to support the reaction from jacks while pushing. So a reaction frame was designed by examining jack reaction forces. A 750 x 1950mm reaction beam was considered for the design and a 300mm thick 14 x 8.5m raft was considered in the pushing region.
Six 6m long segments were cast in a pit on one side of the site and these were then pushed, carefully and gradually, one after the other – while digging out the ground for the tunnel. Four 500 MT capacity jacks were used. An innovative shuttering system was used whereby only partial de-shuttering was required, thus saving time.
The approach ramps on both sides had a slope of 1:10. The excavation was carried out using excavators and the sides of the excavation were soil nailed for stability.

A rainwater harvesting system was installed to allow the water which collects in the gutters to be put to good use – for gardening.

STANDARDS & SAFETY

Rigorous quality control systems were adopted to ensure that the quality of materials received and used conformed to the standards, while our construction methodology was in keeping with standard engineering practices. Test certificates were regularly obtained and maintained.
All efforts were made to ensure the safety of workers on site by following the industry norms for safety. The noise levels were kept as low as possible, so that the air force technical personnel were not disturbed.
Our experience of executing this innovative Rs25m project – within a tight time frame of 125 days – proved that box-jacking is the most suitable approach for the construction of underpasses beneath busy highways. This technology provides a distinct advantage over the cut-and-cover method in such situations, as construction can take place without interrupting the traffic above and the method works well within the constraints of a tight time schedule.

LEGENDARY BBR STAY CABLE TECHNOLOGY

Staying power

Since the early days of post-tensioning, BBR Stay Cable Technology has been recognised as the most advanced and most reliable system on the market. BBR is not only the "godfather" and inventor of high fatigue resistant wire stay cables, but has also pioneered, invented and constructed the world's first project using modern parallel strand stay cables and has invented and successfully applied the world's first carbon stay cables.

Today, BBR Stay Cable Technology can be used for the following applications:

- **Cable Stayed Bridges** have been built in rapidly increasing numbers since 1950 and have been found to be especially economical for medium to long-span bridges from 100 to 1000m, where technical and economic arguments dictate this solution. For smaller bridges, other parameters may be decisive for the choice of a cable stayed solution – such as reduced depth of deck, construction methodology and aesthetics. BBR Stay Cable Technology is the ideal choice for the cables.
- **Suspension Bridges** have been used since ancient times and nowadays suspension bridges with spans close to 2000m have been built. BBR Technology can be used for the main suspension cables as well as for the hangers.
- **Roofs** of grandstands, stadiums, aircraft hangars and other lightweight wide-span structures are an ideal application for BBR Stay Cable Technology.
- **Towers** for communication facilities, chimneys and antennas, as well as wind power stations can be stabilised using BBR Stay Cable Technology.

R&D & QUALITY ASSURANCE

Extensive research, testing and development efforts place BBR at the forefront in the field of post-tensioning and stay cable applications. BBR also

In 1971, the Olympic Stadium in Munich, Germany – with its cable supported membrane roof structure – hosted the Games in 1972. Until 2005, the stadium was home to Bayern Munich FC, one of the world's premier soccer clubs and record title holder in Germany. The 488 stay cables are comprised of parallel strands, with which BBR pioneered the usage of High Amplitude fatigue resistant strand stay cables. Photos: Kevin Lazarz

In 1961, the first bridge to be built using parallel wire cables was the pedestrian Schillersteg Bridge across the Schillerstrasse in Stuttgart, Germany.

offers a variety of solutions to counter cable vibration – such as the BBR Square Damper and cable surface treatments. To assure the highest quality product, all of the system components are subjected to the most stringent testing and Quality Assurance procedures, based on internationally recognised codes and recommendations.

SUPERIOR FATIGUE & STATIC RESISTANCE

For many years, the minimum fatigue test strength for stay cable systems has been 160N/mm^2 (PTI). More recently, a stress range of 200N/mm^2 for 2x106 load cycles – in combination with angular rotations at the anchorages – has been adopted and is now specified by most codes and recommendations. BBR Stay Cable Technology had already fulfilled requirements for such fatigue testing – decades before these provisions were considered to be state-of-the-art!

DECADES AHEAD

Whereas many cable suppliers built their first major cable supported structure in the late 1970s and early 1980s, BBR Stay Cable Technology was used for the first time in the late 1950s and, since those days, BBR Stay Cable Technology has been applied to over 300 major structures around the world – including the breathtaking Tatara Bridge in Japan, which has the longest main span to have been constructed in the 20th Century.

BBR world first applications

1958 – Wire Stay Cable

Standard BBR Wire Cables are composed of 7mm diameter wires of low relaxation grade, with a minimum guaranteed ultimate tensile stress of 1670 or 1770N/mm^2. Typically, the wire bundle is galvanized and covered with a thick-walled UV-resistant HDPE pipe, and the voids in the pipe are filled with a flexible corrosion protection compound.

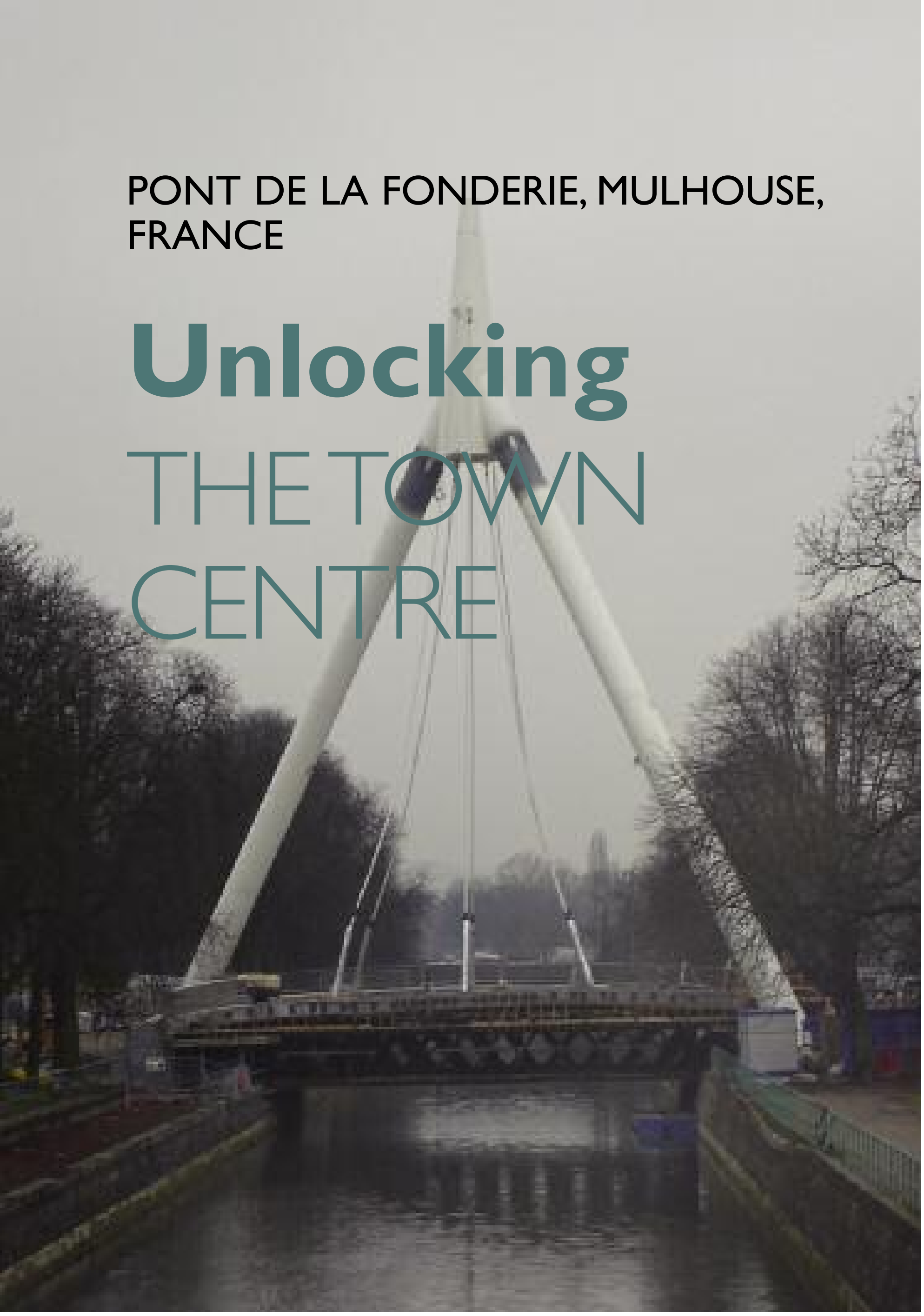
1968 – Strand Stay Cable

Today, standard BBR Strand Cables are composed of galvanized, waxed and PE-coated 0.62" (15.7mm) strands of low relaxation grade, with a minimum guaranteed ultimate tensile stress of 1770N/mm^2 or 1860N/mm^2 inside a UV-Resistant HDPE Stay Pipe.

1994 – Carbon Stay Cable

The BBR Carbon Stay Cables consist of CFRP (Carbon Fibre Reinforced Polymer) wires of 5mm diameter covered with thick-walled UV-resistant HDPE pipe.

The Störchenbrücke in Wintherthur, Switzerland – crossing the major east-west axis of the Swiss Federal Railway Network – was the world's first bridge to be constructed using carbon stay cable technology.



PONT DE LA FONDERIE, MULHOUSE, FRANCE

Unlocking THE TOWN CENTRE

Mulhouse was a pioneering town during the industrial revolution in France and today it is leading the way in providing innovative infrastructure. The new bridge over the Rhine-Rhône Canal is part of the town's "Voie Sud" masterplan to resolve traffic congestion whilst making the town centre more accessible.

BBR Network member **ETIC** was commissioned to carry out the post-tensioning and stay cable works. The 16m wide bridge consists of one 25m long span of post-tensioned concrete with BBR CONA internal transversal cables. The thickness of the slab is 0.64m.

The bridge has one central pylon comprising four metallic tubes from which emerge six BBR DINA 55 stay cables. These are encased in HDPE stay pipes and injected with wax.

The total length of cable used was 170m – approximately 24.3m to 31m for each unit. The cables were prepared in the workshop and delivered to site for final installation and tensioning.

TEAM & TECHNOLOGY

- ***OWNER***
  Ville de Mulhouse
- ***CONTRACTOR***
  ARCADIS, Strasbourg
- ***DESIGNER***
  ARCADIS, Strasbourg
- ***TECHNOLOGY***
  BBR CONA internal
  BBR DINA stay
- ***BBR NETWORK MEMBER***
  ETIC

LOAD TESTING, SLOBODA BRIDGE, SERBIA

Synchronised trucking

Before the reconstructed Sloboda Bridge over the River Danube in Novi Sad could be opened to traffic, the authorities required extensive load testing to be carried out. A local brewery was persuaded to help engineers by supplying 20 identical lorries – each with a full load of beer! Dr Minas from main contractor **DSD Brückenbau GmbH,** takes up the story.

The Construction Engineering Department of Belgrade University planned and conducted the testing on our behalf – in accordance with local standards. Their two-day programme included both static and dynamic testing.

Static tests were carried out in seven phases and were designed to show:

- Maximum vertical loading in bridge centre
- Maximum torsion loading in bridge centre & asymmetrical loading
- Maximum loading between the two outer cables (2 & 3)
- Maximum loading between cables 1 & 3
- Maximum load between pylon and middle cable of the back anchorage
- Maximum load of the 60m long approach bridges

For the dynamic test, a lorry drove over a 10cm high wooden step at different speeds and this showed that the effect of dynamic loading on the stay cables/tensioning in cross section was negligible.

Finally, a comprehensive 138-page report from the University stated that the reconstructed bridge

showed an elastic character and that the capacity of the bridge was actually higher than recommended in the original plans. Following receipt of the report, the bridge was opened for traffic.

THE GREEN BRIDGE, BRISBANE, AUSTRALIA

SECOND LONGEST & **Environmentally Friendly** →

Environmental campaigners often claim that new roads and bridges lead to higher traffic volumes – that they effectively generate additional traffic by providing greater road capacity. BBR Network member **Structural Systems Limited** reports that in Brisbane, Australia, the Green Bridge reverses this criticism by banning private vehicles altogether – and being entirely dedicated to public transport, cyclists and pedestrians. The aptly named Green Bridge is Australia's second longest cable stayed bridge and provides bus, pedestrian and bicycle access via its two bus lanes, dedicated cycle way and footway.

The project client, Brisbane City Council, linked the bridge into the pedestrian drop-off areas, footpath, bicycle path, bus and rail network and local area parking zones, as part of an integrated strategy for encouraging public transport for all journeys that include the bridge and throughout Brisbane.

CONSTRUCTION ELEMENTS

The bridge deck is 20m wide, 520m long with a main span of 185m and back spans of 92.5m. The structure has two 70m-high H-shaped towers in the river. The structural portion of the towers is reinforced, cast in situ concrete, topped with an architectural portion of thin precast panels over a steel structure.

STAY CABLES

The 64 stay cables are between 20m and 100m long and use BBR CONA Stay Cable technology. Each stay cable consists of 31 or 37 parallel 15.7mm diameter seven-wire strands enclosed in a UV-resistant HDPE stay pipe – in a selected architectural dark grey colour. The stay pipe incorporates spiral ribs to act against wind and rain induced vibration.

The strands are galvanized, waxed and individually sheathed with a continuous and wear-resistant coating, providing each strand with a triple protection system. In the anchorage zone, the strand bundle passes though a deviator and spreads out towards the high fatigue resistant anchorages, where each strand is individually guided and locked with high fatigue resistant grips. Ring nuts screwed onto the anchor heads transfer the cable loads by contact pressure to the supporting bearing plates.

The individual strands inside the anchorage are protected by a corrosion-inhibiting compound. Finally, the anchor head is covered by a protection cap injected with corrosion-inhibiting compound. With this system, the anchorage is fully en-capsulated with a multi-barrier protection system.

SUPPLY & INSTALLATION

The supply and installation of the stay cable system was undertaken by Structural Systems Limited using the state-of-the-art, strand-by-strand install-ation method. Anchorages were first installed in the tower and the deck. The HDPE stay pipe was then hung between the two anchorages, using two master strands, and used as a guide for subsequent strand installation. The strand was positioned at deck level and pulled up through the stay pipe to the upper anchorage using a stay cable strand puller, positioned behind the upper anchorage.

STRAND TENSIONING

Each strand was tensioned immediately after installation, using the BBR isostress tensioning method, ensuring an equal force distribution among the strands of an individual cable. Compact multi-strand jacks were used for the final adjustment. All stressing was completed from the tower, ensuring a more elegant deck detail. Each individual strand installed in the cable system can be re-stressed at any time during or after the installation – allowing not only for re-stressing, but also for the selective removal, inspection or replacement of individual strands.

STAYS SUPPORT CONSTRUCTION

The composite deck consists of steel grillages with precast reinforced concrete planks and in-situ concrete stitch joints, in-situ concrete barriers to protect the stays against vehicle impact and architectural features on the cycle way and footway.
The bus lanes have a bitumen overlay and the entire bridge is designed to accommodate the possible addition of light rail in the future, including a substantial additional concrete overlay to accommodate the rails.
The bridge was built using the balanced cantilever technique from both river towers simultaneously. At both towers, deck grillages were erected alternately on each side of the tower, with cable stays reeved and stressed progressively to provide the appropriate support to the deck – during construction and permanently.
After each deck steel grillage was bolted in place, the initial stay installation took place and the stay stressed to the minimal load to support the grillage. The next stage was installation of the precast and stitch concrete. After the stitch reached the required strength, the second stage stressing was carried out to support the steel and concrete – and to achieve the required deck levels.

FINAL DECK LEVELLING

After installation of barriers and deck bitumen, the third stage stressing took place to achieve required final deck levels. The entire bridge design, including the stay cable system, includes provision for future stressing to accommodate light rail at a later stage. The bridge and approach works are expected to open in early 2007.

PROFESSIONAL TEAM

Main contractor, John Holland, took on a design, construct and maintain contract for client Brisbane City Council.
Structural Systems Limited was awarded the design, construction engineering, materials supply, equipment hire, labour, supervision and expertise for the fabrication, installation, stressing, finishing and maintenance of the stay cables.

TEAM & TECHNOLOGY

- **OWNER**
  Brisbane City Council
- **CONTRACTOR**
  John Holland
- **DESIGNER**
  GHD, IBT
- **BBR TECHNOLOGY**
  BBR CONA stay
- **BBR NETWORK MEMBER**
  Structural Systems Limited (Australia)

NAVIA RIVER VIADUCT, NORTHERN SPAIN

BBR triumph on bowstring arch bridge

This significant bridge is situated in Asturias, in northern Spain and was inaugurated in June 2006. The main characteristics of the Navia River Viaduct are the two 160m central spans held up by two arches built on the prestressed deck. The arches are each composed of 17 pairs of parallel stay cables, which descend through the bridge deck to the piers at either end of the arches. David Olivares of **BBR PTE** describes how the stay cables were installed and tensioned.

The bridge has 11 spans and is built with precast segments – making a finished length of 905.4m in total. The precast segments were placed using the cantilever method and by means of a self-launching girder.

PRESTRESSED DECK

The deck was prestressed with more than 900t of post-tensioned steel, including external and internal BBR CONA tendons, and was undertaken with an hydraulic auto-propelled robot which placed the stressing jacks inside the deck.

The deck interior prestressing is made up of 356 BBR CONA 1906, 864 BBR CONA 2406 and 52 BBR CONA 3106 anchorages. Over the permanent piles there are 30 BBR CONA 2406 and 132 BBR CONA 705 anchorages. Alongside the two arches, there are 12 BBR CONA 4206 external prestressing tendons totalling 320m in length. Also, in the arches anchorage zone, there are a further 64 BBR CONA 2406 anchorages.

The deck positioning was carried out using four 1700t vertical and eight 160t horizontal synchronized jacks, equipped with force and displacement instrumentation.

ARCH CONSTRUCTION

The arches consist of a metallic box filled with concrete and their anchorage bases to the deck have 84 bars Ø40 type 935/1030. The bars were stressed before the stay cables were hung from the arches. There are 68 BBR DINA hangers which are joined to the arches by means of BBR Pin-Open Sockets made of cast steel. At the other end of the cable, the movable anchorage passes through the deck to the underside, where each pair of stay cables were stressed with two 300t jacks at the same time.

STAY CABLES

Each of the 68 BBR DINA stay cables was identified and marked because they were associated with their own individual cast steel piece. The installation began by hanging the cast pieces in the arches using a raising tool from which the pieces were supported while the pin was partially inserted.

The BBR DINA cables were fixed to the sockets by means of locking bolts. A crane was used to hang the stay cables from the cast pieces and lifted them until the end lower cable could be inserted into the form pipe. Then the cables were lifted so that the upper cable ends could be fixed into the anchorage.

The final position of the stay cable's active anchorage, after stressing, was calculated according to its lengthening. That is because the force applied to the cables changes, depending on its relative position, length and temperature. When the stay cables were in position, in many cases the stressing sleeve overhung from the support plate and the lock nut could be turned. Conversely, the longest stay cables which had lengthened considerably, had the stressing sleeve inside the form pipe before stressing. So the lock nut was turned after the stressing operation.

STRESSING EQUIPMENT

The equipment used to stress the stay cables included a jack extension which rested on the support plate and allowed the lock nut to be threaded during the cable stressing, a jack with a 300t force at 700 bars and a load cell to show the force applied to the stay cables. To stress the cables, a pulling rod was attached to the stressing sleeve.

FINAL STRESSING

Once the 68 stay cables were stressed and the projecting cable extremities were filled with wax, the two central temporary piles under the arches were removed using four 230t heavy lifting jacks. The heavy lifting unit's jacks were synchronized by a computer and the lowering was achieved with great precision.

TEAM & TECHNOLOGY

- ***OWNER***
  Ministerio de Fomento
- ***CONTRACTOR***
  FCC Construcción, S.A.
- ***DESIGNER***
  Technical Services of FCC Construcción, S.A.
- ***TECHNOLOGY***
  BBR CONA external, BBR CONA internal
  BBR DINA stay, PT bars
- ***BBR NETWORK MEMBER***
  BBR PTE (Spain)

Time and tide wait for no man!

Chee-Cheong CHANG from **BBR Construction Systems (M) Sdn Bhd** reports on the complex construction and heavy lifting operation of the arch bridge which forms part of a 2km access bridge from the Kedah coast to Bunting Island. It has an 80m span and 9m depth navigation channel.
The challenge was to design and construct a fixed arch bridge which was aesthetically pleasing, whilst buildable in seawaters – yet still economical!
The arch was made of steel for ease of fabrication and assembly. The assembled arch on a barge was vertically lifted into position using BBR heavy lifting strand jacks.

GEOMETRY & CONFIGURATION

The dimensions of the arch at its base are 80m longitudinally and 20m transversely. The two arch planes are inclined inwards at 17° from the vertical with 13 hangers on each side.
The overall width of the deck, made of composite steel, is 15.1m. The 290mm thick RC slab is supported on steel cross girders at 4.8m spacing. These cross-girders are supported by two longitudinal steel edge girders hung from hangers at 4.8m spacing.
The initial portion of the arch between the pile cap and deck level is formed by post-tensioned reinforced concrete buttresses for better durability in the splash zone. The rest of the arch consists of a steel box of 1m x 1m cross-section, with 30mm thick plates. The steel arch came in sections which were butt-welded, forming a continuous curved arch.

CONSTRUCTION METHOD

The construction method enabled prefabrication of the steel arch components offsite at a steel fabrication yard in Malacca, Malaysia. The steel box sections for the arch were fabricated to a maximum length of 12m for easy delivery by trailers to the assembling site at Lumut Port, Perak.
At the port, a flat top barge was moored to the shore for transporting the arch to the site. A 150t crane was used to lift and assemble the steel deck sections on top of the barge.
Temporary steel towers were erected on top of the barge to support the arch segments. The steel segments were lifted into position starting from bottom to top. After an alignment check, the joints were butt-welded.
Prefabricated BBR DINA hangers were installed using a small crane. The lower anchor was lifted into position before the upper anchor was secured. A stressing jack was used to stress each hanger from the bottom to take up the initial sag of the inclined hanger. The force in the hanger had to be below the force that would lift the edge girder from the temporary supports.
Meanwhile at the bridge site, the concrete buttresses were being constructed on top of the pile caps. Each buttress was inclined in both directions. It was cast in several stages up to the fourth cast. The fifth – and final – cast was to provide adequate clearance for the erection of the prefabricated steel arch. BBR CONA 1906 post-tensioned tendons were used to take care of the bending and deflection of the inclined buttress during construction.

Facts & Figures

Load per lift point = 105t

Capacity of strands = 12 x 26.1 = 313t

Factor of safety = 3.0

For the erection of the arch, temporary steel trestles were erected on top of the completed concrete deck near the arch buttress. The trestles were used for supporting the jacks for heavy lifting of the arch.

The barge, with the prefabricated arch on top, was slowly towed in between the two pile caps. The steel arch bridge was raised vertically to its final level using strand lifting techniques.

Upon securing the arch to the deck, the buttress rebars were coupled and remaining portion (fifth cast) of the concrete arch buttress was cast thereby joining the steel arch to supporting piles. After the concrete had attained sufficient strength, the forces on the strand jacks were released, thereby transferring the bridge load to the arch buttress.

Precast deck segments were installed over the steel cross-beams. A topping concrete was used to make up a total structural thickness of 290mm.

FOUNDATIONS

Basically, it is a steel arch bridge with the ends fixed into the pile cap. However, because of the heavy lifting method of construction, the horizontal thrusts at the foot of the arches could be reduced.

Stage 1 – During construction

Concrete buttress together with circular piers and approach beams was analysed as a frame to support the steel arch. During the construction stage, this frame is an individual frame taking its own weight and load of the steel arch as a point load at the tip of the buttress. All these loads will induce permanent stresses, moments and reactions within the frame structure.

Stage 2 – In service

When the steel arch was lifted in place, it needed to be permanently fixed to the buttress through fixed joints. All those loads applied at a later stage – like concrete deck slab, SDL and LL – will be transferred to the foundations through the fixed arch action. In design, all these resultant stresses and moments need to be added to the residual stresses and moments from the construction stage, that is, before the arch was fixed in position.

HANGERS

The hangers were fabricated using the BBR DINA system. Each hanger is made up of 42 wires of 7mm diameter with tensile strength of 1670N/mm^2, providing a breaking load of 270t. For design, the maximum stress in the wire from all loads in service is restricted to 45% UTS (ultimate tensile strength).

STAY CABLES

Lifting cycle sequence

1. **Wedges were locked in upper chuck.**
2. **Load was raised to a distance equal to the available jack stroke.**
3. **Lower chuck was being closed and the upper one opened.**
4. **Main jack was retracted and the upper chuck moved back to its initial position, ready for next cycle.**

At each end of the wire, a button head was cold-formed using a BBR button-heading machine. It was threaded and anchored by the fully threaded anchor head. This system provides good fatigue resistance. The wires were protected with an external high density polyethylene pipe (HDPE) and wax.

Dead end anchorage was selected to be at the hanger top, as no stressing needed to be done here. Live end anchorage was provided at the hanger bottom to allow stressing. By designing the anchor bearing plates welded on top of the longitudinal edge girders, stressing could be carried out easily on top of the bridge.

Once the steel arch was lifted to its final position, the deck levels were surveyed. The forces in the hangers were fine-tuned to target achievement of the designed deck levels, while checking that the forces in the hangers did not deviate significantly from each other. By using hydraulic jacks and a stressing chair, the deck was raised or lowered by adjusting the locknut to the threaded BBR DINA anchor heads.

"THE FORCES IN THE HANGERS WERE FINE-TUNED TO TARGET ACHIEVEMENT OF THE DESIGNED DECK LEVELS"

HEAVY LIFTING

Lifting point

The steel arch bridge weighed 420t. Four lifting points – one at each corner of the bridge were needed. At each lift point, a 260t strand jack with a 1206 strand bundle was used.

Vertical lifting and then sliding into place was considered. As the deck area was small, it would have required extensive and complex steel trestles partly sitting on the deck and partly on the pile cap. So, a simple direct vertical lift was chosen. This method also loaded the buttresses directly and equally.

The difficulty was in locating the lifting points. If the point were to be directly on the arch, the lifting point on the trestle would be outside the deck in both directions. This was solved by locating the four lifting points on the first cross-beam of the deck. Then the lifting point would be cantilevered in one direction only from the deck. The connection of this first cross-beam to the arch was strengthened to take the temporary load arising during lifting. Lifting directly from the arch had another disadvantage which was that the lifting point elevation would be higher and required a higher and more costly trestle.

Temporary trestle

At each lifting point, a temporary steel trestle was installed on top of the deck, close to the concrete ➔

buttress. It served as a temporary support point for the jack and working platform. As the structure was cantilevering over the deck, tie down bolts were installed to hold down the structure against overturning.

Lifting system

The BBR Strand Lifting system was used to do the lifting. Each lift point had a main jack, a pair of locking chucks (upper and lower), a dead end anchor, a main pump and a chuck pump.

The main jack had a centre hole through which the 1206 strands passed. The jack nose was removed and the jack was placed vertically with its piston (ram) stroke movement at the top. The main pump was used to push the main jack's piston out or retract the piston to its original position.

Chucks were used to grip – or release – the strands. The chuck pump hydraulically locked and unlocked the chucks, using wedges, during the lifting cycle.

Dead end anchor

The anchor was fixed to the soffit of the first cross-beam of steel deck. Upon parking the barge, each strand was locked into the dead end anchor with spring-loaded wedges to ensure strands were locked at all times.

Having towed the barge from Lumut to the sea outside the pile caps, the date and time of the lifting needed to be decided. Ideally, the lifting was to be done when the sea was most gentle and at a time of lowest tidal height difference. But due to time constraints, the lifting took place on the date where the tidal height difference was highest – 1 July 2004. The time to lift was chosen as 1500 hours – when the tide was going out.

Parking the barge

The team had to ensure that, once the barge was parked between the pile caps, the lifting would be carried out promptly. This was because the space between the barge and pile cap was tight. Rough sea might push the barge and arch against the pile caps and they would be damaged.

"IDEALLY, THE LIFTING WAS TO BE DONE WHEN THE SEA WAS MOST GENTLE AND AT A TIME OF LOWEST TIDAL HEIGHT DIFFERENCE."

By using tugboats and winches, the barge was manoeuvred in between the pile caps. Next, the temporary tie-downs on the arch longitudinal edge girders – needed for transporting the arch – were removed to enable lifting from the barge.

Lifting the arch

After the barge was parked, strands were threaded through the first cross-beams and locked into the dead end anchors. All the strands were cut to equal length to ensure they would have same tension upon lifting. By monitoring the pressure gauges at the four lifting points, the forces were increased until the arch was lifted from the barge.

Lifting was carried out in incremental heights of 200mm for all four points simultaneously. This was achieved manually by having a team leader with four operators communicating with walkie-talkies. Each 200mm was further divided into two incremental lifts of 100mm each. After several lift cycles, survey instrumentation set up on Pile Cap 68 would check the difference in levels at the four points. The difference in levels was kept to 50mm maximum.

To equalise the levels at the four points, the amount to jack-up was determined to the required values and then jacked-up at the same time. After this, it went back to normal jacking of 200mm stroke.

Lifting continued from 3pm to 6pm on the first day, achieving a 3m lift height. The rate was 1m/hour.

On the second day, lifting continued until the full height of 7.6m was reached – at which point, the jacks and chucks were locked. Then the arch was secured against lateral movement by connecting the steel deck to the concrete deck.

Load transfer

After securing the arch, the last portion of the concrete buttress (fifth cast) was constructed. When it had gained strength, after 14 days, the jacks were released to transfer the force from the hanging system to the buttress. The operation was completed by lowering the jack ram gradually while keeping the lower chuck open to allow strands to move downwards.

TEAM & TECHNOLOGY

OWNER
Public Works Department

CONTRACTOR
Gamuda Berhad

DESIGNER
BBR Construction Systems (M) Sdn Bhd

TECHNOLOGY
BBR Heavy Lifting System
BBR DINA stay
BBR CONA internal

BBR NETWORK MEMBER
BBR Construction Systems (M) Sdn Bhd

DEVENTER BRIDGE, OVERIJSSEL, THE NETHERLANDS

Strengthening innovation

Deventer is a town in the Dutch province of Overijssel and is largely situated on the east bank of the River Ijssel. The BBR VT CONA CME Band System was used for strengthening work on the nearby twin parallel bridges which carry the A1 motorway over the Ijssel. →

"OVERALL, IT WAS GREAT EXPERIENCE – A GOOD TECHNICAL AND ECONOMICAL SOLUTION, DEVELOPED BY INTERESTING DISCUSSIONS AMONG ENGINEERS, WAS NOT SUPPRESSED BY RIGID INTERPRETATION OF STANDARDS"

Each bridge has a total length of approximately 1100m and is divided into two approach bridges and the central bridge over the river. This project comprises the strengthening of both bridges. The east approach bridge is 280m long and the west bridge is 450m long. Both bridges were built with pre-cast segments and, in cross-section, are of double box girder construction. The central part of the bridge – with a 150m main span – was built according to the free cantilever method. Rijkswaterstaat, the Dutch Ministry of Transport, Public Works and Water Management, decided to strengthen the bridges with external post-tensioning tendons, as well as other rehabilitation measures. The strengthening was necessary due to increased traffic loads and the need to use safety lines for traffic during the daily traffic jams.

DESIGN AT TENDER

Construction contractor Heijmans Infra selected DSI Netherlands as partner for the prestressing works. The original design was based on a 19-strand system, with few further explanations about the corrosion protection system. A rough appraisal showed a prestressing steel quantity of 530t. The tender process would culminate in a technical and commercial assessment of the bids submitted.

DSI CHOOSES BBR VT CONA CME

DSI was responsible for working out a concept for the external prestressing system and chose the BBR VT CONA CME Band System with 16 Dyform strands with a cross-section of 165mm^2 and tensile strength of 1820N/mm^2. Rijkswaterstaat approved the judgment of DSI by designating the quotation as best proposal in the technical competition – their success was completed by also winning the commercial bid.

CONSTRUCTION STAGE

Materials delivery started in late October 2005. At the end of January, stressing of the first approach bridge started. Mostly, it was necessary to stress with four jacks, simultaneously, because of the fragile structure. In individual situations, there was insufficient space available for standard jacks. Then the tendons were stressed, band-by-band, with a smaller jack which revealed an additional advantage of the Dyform strand. The achievement of the expected steel elongation indicates that the friction is similar to stressing the whole tendon at once. The strengthening of the following three approach bridges was carried out subsequently and the job was completed in July 2006.

COMPETITIVE ADVANTAGE

The BBR VT CONA CME Band System proved to be a very competitive alternative – the advantages far outweighed the seemingly higher material costs. The prestressing concept proved to be a solid solution. The Band for the BBR VT CONA CME System is manufactured for the BBR Network under patent by VORSPANN-TECHNIK GmbH & Co. KG.

The BBR VT CONA CME Band System: Key decisive factors

TIGHT SCHEDULE

The construction period was an important factor because of the tight schedule. The factory-provided corrosion protection system reduces the additional work on site to a minimum. Secondly, the BBR VT CONA CME Band System does not limit the tendon length. In addition, with a lower friction value, it was possible to extend the average tendon length by about 40%. Both factors led to a very attractive installation time for the external tendons.

WINTER WORK

The contractor was interested in taking advantage of the fact that the post-tensioning works within the box girder could be carried out during the winter. As the corrosion protection element of the system is a substantially grout-free solution, it is not affected by low temperatures.

DYFORM CHARACTER

The geometry of the cross beams meant that economically it was almost impossible to avoid a minimal radius of curvature of 3m. It was possible to convince the client to use the Dyform strand which showed excellent characteristics during deviation and deflection tests.

TENDON REDUCTION

Even the addition of a further line of tendons, as a result of the restriction to 16 strands in the band system, was not seen as a disadvantage. The critical impact of the anchorage zone was reduced by sharing out the anchorages in several crossbeams. The extension to the average tendon length meant that the total number of tendons was reduced by 20%.

INNOVATIVE SADDLES

Our package was completed with an innovative solution for the saddles – the extraordinary requirement for 1000 pieces permitted a new production method.

PATENT & PROOF

An additional plus was that the patented BBR VT CONA CME Band System had already been successfully applied in Netherlands in 2001.

USHIGASE WATER RESERVOIR

Seismic strengthening WITH BBRV

The Ushigase Water Reservoir was built in 1987 as a governmental water facility located on Kyushu Island, southern Japan. The reservoir required seismic strengthening because of ageing, reports Seiichiro Ogawa of the **Shiraishi Corporation** which was contracted to carry out this work.

Shiraishi uses the new seismic strengthening system for reinforced concrete water storage facilities called ECO-REFRE (Existing Concrete Structures-Refresh). ECO-REFRE was developed and first applied in 2004, as a repair and strengthening system for existing concrete structures, such as water reservoirs and distribution facilities. The system involves the installation of external cables, both horizontally and vertically, outside of the structure – the prestressing force is transferred two-dimensionally. This new technology enables shorter timescales and reduced costs when compared with traditional systems which involve wall and column thickening works. In addition, strengthening work can be performed while the facility is being operated and capacity does not change.

The Ushigase Water Reservoir is a box-shaped facility of 50m x 30m x 6m. The strengthening work was completed using the ECO-REFRE System, applying BBRV system tendons (12 wires 7mm diameter) in four tiers and with anchor stressing. The stressing anchorages and fixed anchorages were placed at 27 points. Special measures were applied to counter the effects of the soil pressure induced by earthquakes which results in deformation of the shorter sides. Protrusions were placed on the tendons installed in the top tier of the shorter sides, in order to provide deflection force.

TEAM & TECHNOLOGY

- **OWNER**
  Kumamoto Prefecture
- **CONTRACTOR**
  Okubo Kensetsu
- **CONSTRUCTION**
  Shiraishi Corporation
- **TECHNOLOGY**
  BBRV System
- **BBR NETWORK MEMBER**
  Japan BBR Bureau (Japan)

ROAD BRIDGE UPGRADING PROJECT, SINGAPORE

Repairs in live traffic

John Mo of **BBR Construction Systems Pte Ltd,** the Singapore-based BBR Network member shares some details of their extensive bridge and flyover upgrading project for the Land Transport Authority – under live traffic conditions – which his company has recently undertaken on and around two of Singapore's major highways.

The Pan Island Expressway (PIE) and the East Coast Parkway (ECP) are vital thoroughfares – both of which serve Singapore's Changi Airport. The PIE is the oldest and longest of Singapore's expressways and extends for around 41km along the length of the island, connecting Tuas in the west, to Changi Airport in the east. Built almost entirely on reclaimed land, the ECP runs for some 20km along the south eastern coast and has an interchange with the PIE at the Changi Flyover.

As the bridges and flyovers had to remain open to traffic at all times, only limited lane closure at night was allowed to carry out the works. In addition, as the works were mostly on expressways, safety was a high priority and truck-mounted attenuators were deployed whenever lane closure was carried out.

To provide access to the bridges and flyovers, boom lifts and working platforms were used. Where suitable, boom lifts were parked on the hard shoulders to provide access. Where platforms were suitable, they were suspended from the bottom of the deck slab and spanned across roads and waterways.

SUPERSTRUCTURE STRENGTHENING

Locations that required strengthening of the superstructure by external prestressing were at

Road bridge upgrade locations

- **Eunos Flyover** – Paya Lebar Way (PIE) across Jalan Eunos
- **Bridge on PIE** – across Bedok Canal
- **Bedok North Flyover** – bridges on Bedok North Road across PIE & slip road
- **Bridge on Upper Changi Road East** – across Bedok Canal
- **Metal culvert** – near lamp post #200 on Tampines South Flyover Exit 4B
- **Paya Lebar Flyover** – Paya Lebar Way (PIE) across Paya Lebar Road
- **Tampines South Flyover** – bridge on Simei Avenue across PIE & bridge on Tampines Avenue 5 across slip road from PIE
- **Changi Flyover** – bridge on PIE across ECP
- **Tanah Merah Flyovers** – bridges on Xilin Avenue across ECP
- **Laguna Flyover** – bridges on Bedok South Avenue (1 across ECP)
- **Marine Parade Flyover** – bridges on Still Road South across ECP including ramp structure

TEAM & TECHNOLOGY

- ***OWNER***
  Land Transport Authority
- ***MAIN CONTRACTOR***
  Singapore Piling & Civil Engineering Pte Ltd
- ***DESIGNER***
  Parsons Brinckerhoff Pte Ltd and Maunsell Consultants (Singapore) Pte Ltd
- ***TECHNOLOGY***
  BBR CONA, MRR range
- ***BBR NETWORK MEMBER***
  BBR Construction Systems Pte Ltd (Singapore)

Bedok North Flyover, Upper Changi Road East across Bedok Canal, Paya Lebar Flyover and Tampines South Flyover. The objective was to increase the load capacity rating of the bridges so as to cater for heavier vehicles in the future.

CFRP STRENGTHENING

Access openings were created at the soffit of box girders. CFRP (carbon fibre reinforced plastic) was installed beside the openings for structural strengthening purposes. In addition, CFRP was also installed on piers for strengthening. The locations where CFPR was used were Paya Lebar Flyover, Eunos Flyover, Changi Flyover, Bedok North Flyover and Tampines South Flyover.

ELASTOMERIC BEARINGS

Elastomeric bearings at Eunos Flyover and the PIE across Bedok Canal were replaced, while those at Bedok North Flyover and Tampines South Flyover were rehabilitated.

EXPANSION JOINT REPLACEMENT

The existing expansion joints were removed and replaced with asphaltic plugged joints at the Pan Island Express across Bedok Canal, Bedok North Flyover, Tampines South Flyover, Changi Flyover, Tanah Merah Flyovers, Laguna Flyover and Marine Parade Flyover.

PROTECTIVE COATINGS

Anti-carbonation protective coatings were applied to all the bridges and flyovers.

JET GROUT PILES

For the metal culvert near lamp post #200 on Tampines South Flyover, Exit 4B, jet grout piles were used to strengthen the ground and a new concrete lining was constructed within the culvert. BBR proposed this alternative design and method to avoid construction of a new bridge deck over the culvert and, thus, extensive traffic diversion, as the culvert is located below a busy expressway. Furthermore, there were numerous water and telecoms services – including fibre optic cables – above the culvert and below the expressway. A successful result was achieved despite having to maintain a cross-sectional area reduction of not more than 12% for the culvert – and working in a confined space where the headroom inside the culvert was only 2m.

ALL ENGLAND LAWN TENNIS & CROQUET CLUB

Raising the roof

Over the next three years, main contractor Galliford Try will be progressively redeveloping the Centre Court at the All England Lawn Tennis Club in Wimbledon. BBR Network member, Structural Systems (UK) Ltd, is carrying out strengthening works to the superstructure.

Construction work has been phased to accommodate the All England Lawn Tennis Club Championships each summer. Last year, the main stand around the Centre Court was demolished to level 1 and a new seating arena is being constructed, ready for the 2007 Championships. This will increase the seating capacity and include new media commentary boxes.

Later this year, the new roof will be erected over the Centre Court in time for the 2008 Championships and, finally, in 2009, the new sliding roof section – which will cover the centre court playing area – will be installed.

During the design stage, it was found that a number of beams would need to be strengthened – firstly, to cope with the weight of demolition equipment being used at the early stage of redevelopment and, secondly, to accommodate the new loads which will be imposed on the structure by the new roof design.

The design of the strengthening has been produced by Capita Symonds, using FRP (fibre reinforced polymer) strengthening systems. The Remedial Division of Structural Systems (UK) Ltd is undertaking the application process.

Due to the complexity of the initial design, changes have been made in instances where the original plans differed from the "as-built" structure. However, the good working relationship between Galliford Try, Capita Symonds and Structural Systems (UK) Ltd will ensure that the work programme will be completed on schedule for the AELTCC to hold the 2007 Championships as planned.

TEAM & TECHNOLOGY

- **OWNER**
  All England Lawn Tennis & Croquet Club
- **CONTRACTOR**
  Galliford Try Construction Ltd
- **DESIGNER**
  Capita Symonds
- **TECHNOLOGY**
  MRR range
- **BBR NETWORK MEMBER**
  Structural Systems (UK) Ltd

Unique challenges

HUNTLY POWER STATION UPGRADE, NEW ZEALAND

A $530 million project by Genesis Energy to upgrade its Huntly Power Station has affected much more than the site itself – it has also affected the heavy haulage route that leads to it. Paul Wymer and Hugo Jackson of **BBR Contech** report that equipment required for the upgraded facility is so heavy that several bridges required strengthening to cope with the load. In the case of one turbine being delivered from Mitsubishi Corporation, this means an all-up truck weight of nearly 500t!

The new 385MW combined cycle gas turbine power plant is located next to the existing Huntly Power Station, adding significant capacity to the station's current output of 1050MW. Commissioning was completed in December 2006 and it aims to contribute to the steady 2% to 3% annual increase in demand for electricity nationwide.

MINIMAL TRAFFIC INTERRUPTION

BBR Contech was involved in strengthening three bridges on the heavy haulage route – the St Stephens overbridge at Great South Road, the Mangatawhiri Stream bridge and the Whangamarino bridge. All are on State Highway 1 – between the Port of Auckland and the power station – and carry significant traffic loads every day, which meant much of the work had to be done at night with one lane closed to ensure minimal interruption to traffic.

WHANGAMARINO RIVER BRIDGE

The strengthening of the Whangamarino River bridge provided some unique tests for the team, including the challenge of accessing the underside of the deck units. BBR Contech solved the issue by designing a suspended scaffold, which was assembled on the banks of the Waikato River before being towed upriver on flotation devices and hoisted into position.

Working at night and section-by-section, the team strengthened 33 deck beams and two pier beams using a combination of BBR CONA multi-strand and bar externally post-tensioned tendons, whose anchorages needed to be installed under the bridge and bolted through the deck. FRP composites were also used to strengthen the precast concrete deck units at the location where the anchorages were bolted through the deck.

Even though the strengthening measures were only required for the short term, all tendons and anchorage components received full permanent corrosion protection so that the upgraded bridge can continue to provide full-strength service for other heavy loads well into the future.

"The project required a well co-ordinated team and BBR Contech offered a pragmatic, solutions-based approach" says Richard Pearce, Genesis Energy's e3p (Energy Efficiency Enhancement Project) Project Manager. "BBR Contech was responsible for implementing Connell Wagner's engineering design and, wherever challenges, arose BBR Contech had proposed solutions ready at hand – they are a great contractor to work with."

TEAM & TECHNOLOGY

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- ***MAIN CONTRACTOR***
  BBR Contech
- ***DESIGNER***
  Connell Wagner Ltd
- ***TECHNOLOGY***
  BBR CONA external, MRR range
- ***BBR NETWORK MEMBER***
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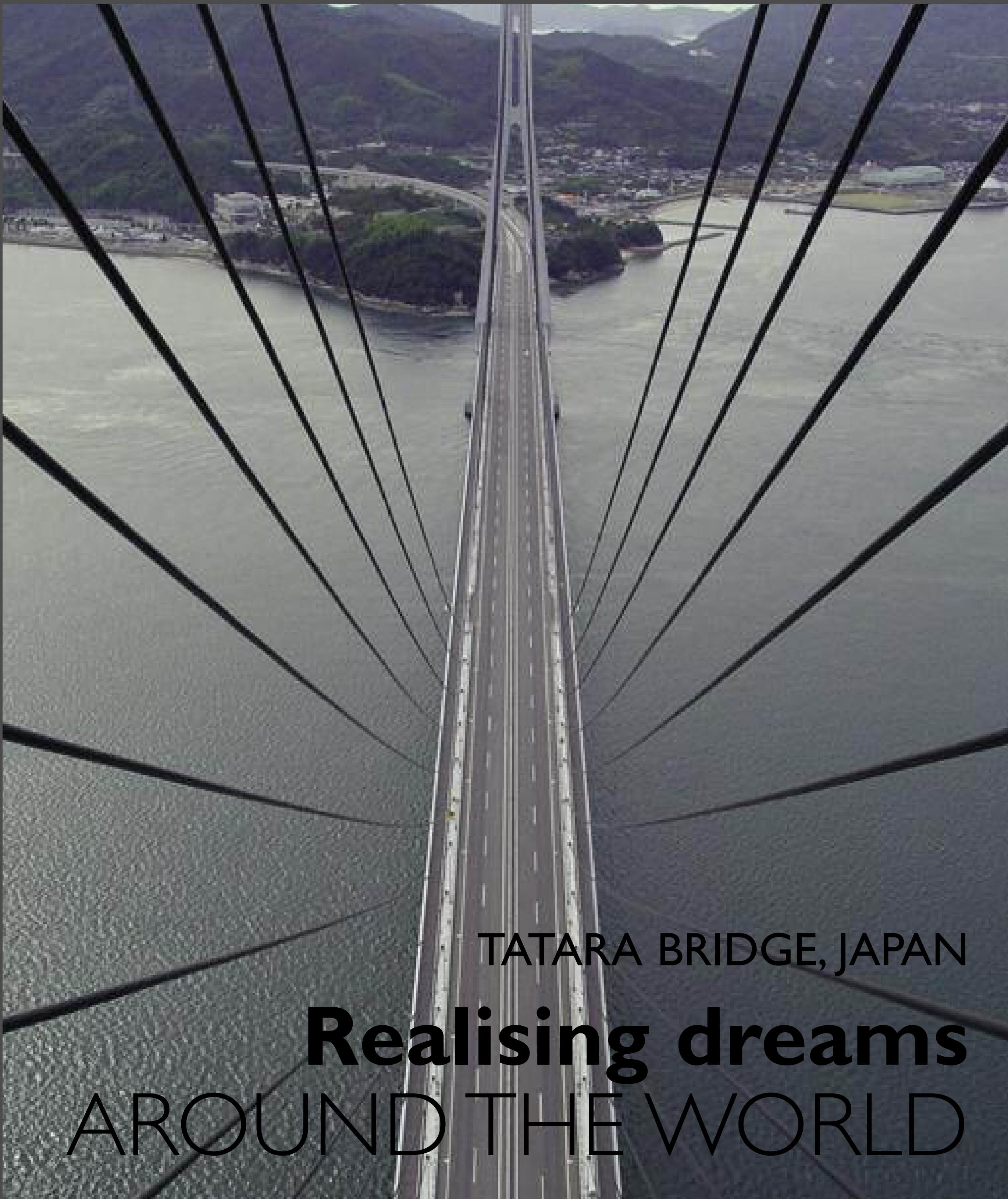


TATARA BRIDGE, JAPAN

Realising dreams AROUND THE WORLD

The Honshu-Shikoku Expressway, consisting of three routes linking two main islands, Honshu and Shikoku, across the Seto Inland Sea, is a massive project aimed to form part of the trunk road and railway network in Japan. The total length of these roads is approximately 164km. Piotr Krawczonek of BBR VT International Ltd tells the story of the construction of a crucial part of this scheme – Tatara Bridge – which has set a technological benchmark for long cable-stayed bridges around the world.

➔

The westernmost route that connects Ikuchijima Island with Omishima Island includes Chodai's design – Tatara Bridge – a steel-concrete hybrid cable stayed bridge, measuring 1480m in total length and has an 890m main span. When opened on 1st May 1999, this bridge had the longest centre span in the world – surpassing its sister bridge, Normandy Bridge in France which has a total length of 2141m, with a 856m centre span.

In 1973, the bridge had originally been planned as a suspension bridge, however due to its location – in the Seto Inland Sea National Park – the plan was modified. In 1989, rethinking of the topographical and environmental constraint area – as well as current technological advances in long-span bridge developments with computer-based structural analysis – resulted in a change of design to a cable stayed bridge with the same main span. Consequently, less excavation in the national park area was required, thus decreasing the environmental impact on the surrounding area – with the added benefits of lower construction costs and a shorter construction period.

"ERECTION OF THE BRIDGE STARTED IN APRIL 1993 AND TOOK A LITTLE MORE THAN SIX YEARS. NO TEMPORARY SUPPORT WAS REQUIRED IN THE WATER WHEN ERECTING THE GIRDERS".

BRIDGE CONSTRUCTION

Erection of the bridge started in April 1993 and took a little more than six years. No temporary support was required in the water when erecting the girders. Girders were lifted up from the sea by a travelling crane, positioned at the forward edge of the girder overhang, and the work relied on balance between the side and main girders at the tower.
Construction was accomplished without any accidents – although a typhoon did come along while the centre span was at its furthest extension, with the installation of the remaining final segment.

ENGINEERING DESIGN

Tatara Bridge is a hybrid cable stayed bridge consisting of concrete girders in the side spans (270 and 320m) and steel girders in a 890m section of a centre span. The design concept of a structural system that supports light-weight steel girders in the centre span – by making the side span heavy and rigid with concrete girders and intermediate piers – delivers several advantages:

- The sectional forces acting on the girders and towers are reduced.
- Vertical displacements of the girders are well-controlled.
- Fluctuations in cable tension are reduced.

The deck is 30.6m wide and carries four lanes of traffic in both directions, as well as additional lanes for bicycles, motorbikes and pedestrians.
The two steel towers are 220m high and shaped like an inverted "Y" with a slit. This shape was chosen after examining the wind resistance, the structural efficiency and aesthetics. A full aero-elastic model of a tower was tested in the wind tunnel to optimise the shape of the column and its rectangular section, with notched corners to reduce vortex shedding.

BBR STAY CABLE SYSTEM

The BBR stay cables were installed in a two-plane multi-fan configuration. Each tendon – produced and assembled in the workshop – consisted of a semi-parallel bundle of galvanized wires, protected by an HDPE jacket filled with an internal corrosion protection compound. The cable jacket is made of black HDPE, which is very durable in exposed conditions. Its outer surface is dimpled so that it repels rainwater and breaks up gusts of wind which would cause the cable to vibrate. The high amplitude fatigue resistant anchor sockets are completely sealed with no internal voids. The longest tendons are 460m with a diameter of 170mm. The length of the cable is heavily relied on to control the shape. The ends of the strands are fixed by sockets which are sufficiently resistant to fatigue from bending vibration, as well as axial force.

TEST & ANALYSIS

Various analyses, tests and experiments were conducted and focused on the characteristics of long-span structure and the aerodynamic stability of the entire bridge.
One of them was large-scale loading test, at a scale of 1/50, which was conducted to verify the accuracy of the analysis and confirm the capacity of the bridge. The results of the model test enabled, the ultimate loading capacity to be evaluated.
Also a large-scale full model wind tunnel test, at a scale of 1/200, was conducted to evaluate the effects of topography. This showed that the maximum gust response displacement at mid-span was within design tolerances.
After the bridge had been structurally completed, the vertical and horizontal vibrations were measured by means of heavy-duty exciters, to confirm the accuracy of the vibration characteristics applied in the design. As a result, the measured logarithmic decrement for the main girder basically satisfied the design value requirement.
Many more technological advances were built into the design, testing and erection works of the bridge – and all of them continue to contribute greatly to the realisation of the dreams of 1000m-class long span cable stayed bridges around the world.

BAHRAIN CAUSEWAY

The world's longest bridge

The provision of post-tensioning work for the Saudi Arabia-Bahrain Causeway, meant that BBR technology was not only applied to one of the world largest bridge projects ever constructed, but was also subjected to impressively stringent conditions in terms of durability. Dr sc techn Pietro Brenni of BBR VT International Ltd reflects on the construction and technology at the heart of this landmark project.

Since the '60s, there had been a proposal to build a causeway – in the form of a dam right across the strait of Bahrain and also between Bahrain and Qatar. Nothing came of this, but the idea of a fixed linkage between the Kingdom of Saudi Arabia and Bahrain was never abandoned. In 1976, a feasibility study was carried out and included hydrographic and topographic surveys, soil investigations, traffic forecasts. This led up to a preliminary design for a 25km long four-lane causeway consisting of bridges and embankments, as well as about 50km of approach roads in Saudi Arabia and Bahrain and a border station.

Traffic across the strait between Bahrain and Saudi Arabia was about 90,000 passengers by air and about 80,000 by sea per year and the freight carried was about 60,000t each year. This freight volume would have increased tenfold by the time the Causeway was built and was expected to reach 2.3 million tonnes in 2000. A much larger increase was foreseen for the passenger traffic – when the Causeway was built the daily traffic was expected to be 15,000, but within a year this was expected to have increased to 110,000 passengers.

MATERIALS DESIGN

For the bridge superstructure which was evaluated in both concrete and steel, a single box girder cross-section was chosen. For the steel bridge, the span length was 85m and for the concrete bridge 70m, both determined by economic considerations. During the detailed design stage in 1977, it was decided that the design should be made only in steel. Finally, after a design review, a panel of experts recommended that a concrete design ought also to be drawn up and put out to tender. So the consultants embarked upon a design in pre-stressed concrete based on a 65m span length bridge with two separate box girders in precast elements of full span length over vertical steel piles of large diameter.

CONTRACT AWARD

The international construction community showed great interest in this project and, after evaluation of 39 responses, a shortlist of 22 consortia was invited to tender by July 1980. The bids were evaluated and reviewed by a joint technical committee in Washington. Ballast Nedam Group NV, in joint venture with Bandar, was called for negotiation and they were awarded the contract awarded in May 1981.

BBR post-tensioning methods were considered to be one of the most critical elements in terms of facilitating an effective construction scheme, whilst at the same time offering the solution for impressively stringent conditions in terms of durability – and thus, BBR technologies found their way into one of the world's largest bridge projects ever constructed.

STRUCTURAL DESIGN

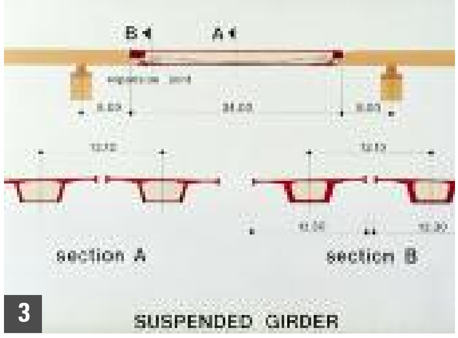
By the time it was possible to state definitively whether the design based on the two main structural elements – box girder and pile – satisfied the requirements, the engineering, production planning, manufacturing and construction had reached a stage at which it would no longer be possible to implement changes without overrun of the overall construction period and the overall costs!

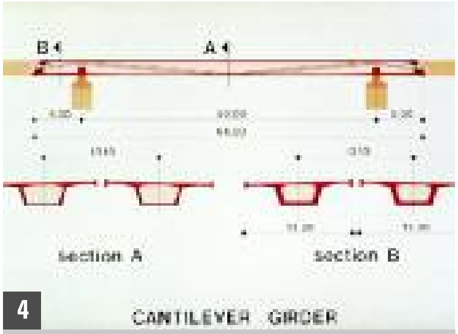
Substructure

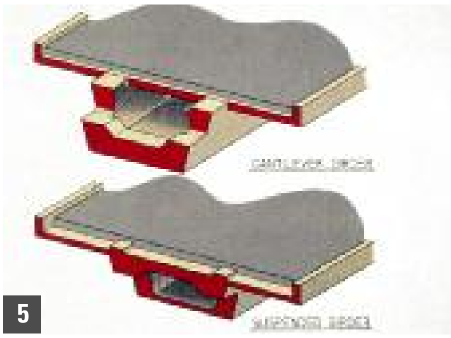
On the substructure, combining pier and pile to make one continuous pier-pile element reduced the degree of freedom available to the designer. Additionally, the single pier chosen forms an extremely slender structure and the one diameter pier-pile allowed for some variation – namely in the choice of the foundation level of the pile tip.

Superstructure

For the superstructure, a system of cantilever and suspended girders, lengths of 66 and 34m respectively, appeared to meet the desired load distribution in the superstructure and eliminated the undesirable eccentricity of the pier load, while a slender design and a smooth bridge deck line in →







1 & 2 Construction of the standard section
3 & 4 Typical standard cross-section and PT layout
5 & 6 Halving joint between cantilever girder

the final phase were achieved. The suspended girder was held by a concrete halving joint between the cantilever girder, which was also provided with a halving joint structure for the purpose. In the overall system assembly, the super-structure was formed by a box girder which was relatively stiff against torsion and was carried by four teeth, while the substructure consisted of a single pier restrained by the (spring) rigidity of the soil.

Shipping channels

Finally, the specification required shipping channels for all but one of the bridges. According to this, the span of 50m could be maintained for three channels, raising the elevation by 13m, but a main shipping channel with 90m free passage was needed, requiring the deck elevation to be raised by more than 24m. At the free passage height of 28m, this part of the track had to deviate completely from the standard system, whilst also considering the design constraints imposed by needing earthquake load and a potential ship crash load of 5600t to be absorbed by the piers

FOUNDATIONS

The foundation style chosen was based on a gravity structure – the piers to support the main and secondary spans were designed with a rectangular cross-section. For the superstructure, the obvious choice was a prefabricated concrete segment solution, built in free cantilever method and glued together for the bridge with a 150m main span.

The piers were restrained at the foundations and were of such dimensions that the freely supported superstructure could be extended easily in both directions without additional provisions to compensate for the imbalance moment arising during connection of elements to cantilevers.

BBR POST-TENSIONING

All box girders were designed and executed with both longitudinal and lateral post-tensioning. The longitudinal post-tensioning consisted of BBR CONA 1906 strand. The number of cables for the cantilever and the suspended girder was six and four per web respectively. Lateral post-tensioning was achieved using BBRV 1907mm diameter wire bundles. The engineering and construction programme of some four years would necessarily lead to the installation of 500 linear metres of single bridge per contract-month, up to a total of 25,000m.

MATERIALS & DURABILITY

The Causeway has to fulfil its function in the severely aggressive surroundings of the Arabian Gulf. The environment is characterised by an elevated salt content in the sea water, daily average air temperature fluctuations of approximately 18°C from 9 to 28°C during the coldest months and from 23 to 41°C during the hottest months, daily average relative humidity varying from 60% during the driest month to 80% during the most humid months – and finally, a combination of a rapid daily temperature changes combined with an extremely drying wind.

These very aggressive factors meant a number of consequences for the design – particularly detailing – and also for construction. Special measures had to be taken, both in design and construction, to keep all crack development – due to shrinkage and temperature stresses – within limits.

Alternative design philosophy

An alternative design, based on the use of large pre-fabricated elements and on the development of special heavy equipment, was partly derived from the experience with the Zeeland Bridge and the Delta Project in the Netherlands and partly as a rather obvious consequence of the very restricting conditions imposed by the environment.

- **Soil conditions – bearing stratum <23m, water depth <12m and deck level with 5m clearance – dictated the choice of a short standard span of 50m, a box girder of approx 2.5m depth and a weight of 1000t.**
- **Aggressive water and atmosphere, the very warm climate, the considerable total length of the bridge of 25km – combined with the high degree of durability needed – favoured the use of pre-fabrication, combined with BBR post-tensioning technology.**
- **Water conditions, wind conditions, the entire location of the bridge in the sea – and a layout spread over 25km – pointed towards large pre-fabricated elements.**
- **Four years for design and construction of the overall 25m called for maximum use of – and large scale – pre-fabrication.**
- **From numerous alternatives for the substructure, it was decided that standard longitudinally prestressed prefabricated 3.5m diameter pile-elements, placed in 3.90m diameter boreholes, was the best solution. Each pile would be 40m long and weigh 400t.**

Source: *Hendrick van Tongeren, Saudi Arabia – Bahrain Causeway: Ballast Nedam Group N.V., Drukkerij Waalwijk b.v., Waalwijk, 1985, 215pp*






7 View of the main span passages in prefabricated concrete segments
8 Detail of the BBR CONA Anchorages
9 Prefabrication yard
10 Jack-up platforms
11 Erection of the standard element with Ibis lifting vessel
12 Free cantilevering part to cross the main free passage

By far the main cause of damage to concrete structures along the Arabian Gulf is corrosion of the reinforcement, nearly always the result of passivation degradation by chloride ions. One of the major factors dictating the lifetime of concrete in warm sea water is the quality of the raw materials, the density and amount of cover of the concrete, and the extent of wet-curing given to it.
The specification for the concrete cover was set to 50mm, following the lines of the *fib* recommendation issued by the Commission on Concrete Sea Structures, where the minimum concrete thickness is set, in general, from 60 to 100mm respectively 1.5 times the maximum particle or rebar size, to be applied for reinforcing steel and/or post-tensioning cables depending whether the exposed zones are completely underwater, exposed to tidal and splash, or in a wet or dry atmosphere.
The amount of concrete cover, combined with the correct use of post-tensioning, was an important factor as regards durability.

PREFABRICATION

The concrete elements for the bridge structure were pre-fabricated at a yard on the north side of Umm Nasan island. The location was selected mainly for nautical reasons – close to a fairway of sufficient depth. The yard was approximately 850m long and 300m wide – and its layout was dictated by the usage of a 1-gantry crane with a lifting capacity of 1400t, span of 80m and a clearance of 20m under the hook.
The batching plant was manufactured with a capacity of 2 x 50m^3 per hour. All cement was delivered by sea, for which purpose an unloading quay with crane was built. All reinforcement was cut and bent in the yard and made into prefabricated cages – a total amount of 35,000t was used.
In view of the short period available, the timely and accurate design and manufacture of the various pieces of equipment needed for the chosen construction method was fundamental to achieving the completion date. In late 1982, the equipment for the substructure and the superstructure had been delivered.

SUBSTRUCTURE CONSTRUCTION

The construction method for the piles consisted of two jack-up platforms used for drilling boreholes for biles in the seabed. Two adjacent positions could be drilled by using two drilling rigs from each platform. A total of 500 holes with a borehole diameter of 3.75m had to be drilled. After installation of the casing by crane from the jack-up platform, the drill was lowered and drilling into the hard layers, on which the casing remained supported, could be carried out.

PILE INSTALLATION

The concrete piles, varying in length between 20 and 35m and with a maximum weight of 300t after assembly, were transported to the yard's port by the large travelling gantry crane. From there, the pile was taken over by a special pile barge.
Once at the site, the pile was lifted up above the casing by a 1000t floating derrick and lowered into the borehole. Finally, the space between the pile and the borehole was filled with grout.
The overall average production amounted to 6.5 piles per week – whilst an average of 4.5 piles per week had been planned.

INSTALLATION OF SUPERSTRUCTURE

The superstructure elements were transported with the Ibis lifting vessel, brought into position and lifted by means of a gantry placed so that the girders were at the vessel's centre of gravity. The entire installation process could be monitored on a television screen set up in the deck house.
The bridge girders were suspended from 4 or 5 rods of high quality material mounted on a spreader bar made of steel pipes, suspended from the double gantry frame of the lifting vessel by 2x2 sheave blocks. The vessel was equipped to correct the position of the element with high accuracy – the elements themselves had centering pins, bearings and softwood spacers to accommodate the positioning and concrete time dependent deformations.

LEVELLING & COMPLETION

After six months, shrinkage and creep had virtually stopped and the piles had settled, so the girders could be aligned with a movable scaffolding set up across the bridge and equipped with jacks allowing jacking-up and levelling of the cantilevered girders. The bridge was made continuous over stretches of 300m, each of these stretches ending with a grid.
The main span superstructure was realised with traditional prefabricated segments installed by the free cantilevering method. The hammerhead piece, measuring 12m, weighed 650t and was installed by floating derrick.
The design and the construction of the Saudi Arabia-Bahrain Causeway Project, handed over at the end of 1985, was only made possible by the application of knowledge and resources from the wide background of experience and leading-edge professionalism offered by all parties involved in the project. BBR is particularly proud to have contributed with its proven post-tensioning technology to the successful realisation of one of the world's largest ever bridge projects.

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