# CONNECT

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Fourth Edition 2010

## Excellence through people

How continuing investment in people drives quality and success within the BBR Network

## Golden Strands

**50th Anniversary feature**
Evolution of stay cable technology and application across 400 projects

## High speed rail projects

Bridge construction for Spain's exciting new high speed train network

## Win-wind situation

Green energy technology and expertise

## In the public arena

Innovative and durable solutions for international stadium and arena projects

## Nuclear inspection

Inspection and maintenance of post-tensioning at Swedish power plants

THE MAGAZINE OF THE GLOBAL BBR NETWORK OF EXPERTS


# A Global Network of Experts

www.bbrnetwork.com

The BBR Network is recognized as the leading group of specialized 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 and technicians, as well as the very latest internationally approved technology.

## 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 knowledge 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 specialized equipment or transfer of technical know-how.

## ACTIVITIES OF THE NETWORK

All BBR Network members are well-respected within their local business communities and have built strong 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, cryogenic LNG tanks, dams, marine structures, nuclear power stations, retaining walls, tanks, silos, towers, tunnels, wastewater treatment plants, water reservoirs and wind farms. The BBR brands and trademarks – CONA, BBRV, HiAm, DINA, SWIF and CONNAECT – are recognized worldwide.
The BBR Network has a track record of excellence and innovative approaches – 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 – with professionalism, innovation and the very latest 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), a subsidiary of the Tectus Group (Switzerland); KB Spennteknikk AS (Norway), BBR Polska Sp. z o.o. (Poland) and VORSPANN-TECHNIK GmbH & Co. KG (Austria / Germany), all members of the KB Group (Norway); BBR Pretensados y Técnicas Especiales, S.L. (Spain), a member of the FCC Group (Spain).


Maybe the first thing you will notice about this edition of CONNAECT is that it has grown even larger. This has happened despite the global financial crisis – because, our international teams have been extremely busy indeed. We have the latest and approved technology, but it is our people – whether in offices or on sites – who make the light of our excellent technology, know-how and the BBR brand shine so brightly.

They are able to do this because they are well-informed and can be confident of their specialist knowledge. As well as taking great care in the selection and continuous education of the right team members, we provide many opportunities for training and encourage a high level of communication within our large global family.

Meanwhile, we continue to develop new technology and systems to support our people in their work. The rolling-out of our e-commerce platform – BBR E-Trace – places us in a unique position in the industry and represents a significant step forward in ensuring we continue to work together to deliver the very highest quality of service to our customers.

Thanks to Frau Irma Birkenmaier, who kindly shared some recollections with us, we can now reflect further and draw inspiration from the sheer dedication and pioneering spirit of her late husband, one of our founders – Max Birkenmaier.

In the past year, we have also celebrated a milestone in the stay cable arena – we have completed our 400th cable-stayed project and, in 2010, we celebrate the 50th anniversary of our first ever stay cable project. Our dedication and commitment to quality down the years means that we now have the greatest and longest experience in this specialist area – and are looking forward to creating more records in the future!

**Bruno Valsangiacomo**
Chairman
BBR VT International Ltd

**Marcel Poser**
CEO
BBR VT International Ltd

# Editorial, sources and references

**EDITORIAL OFFICE**
BBR VT International Ltd
Technical Headquarters and Business Development Centre
Switzerland
www.bbrnetwork.com
info@bbrnetwork.com

**EDITOR** Jane Sandy
**CONTRIBUTING EDITOR** Thomas Richli
**DESIGNER** Caroline Donner
**CONTRIBUTING DESIGNERS** Valentina Milhajlovic, Daniel Senn
**PUBLISHER** BBR VT International Ltd
**NUMBER OF COPIES** 11,000
Printed in Switzerland


**SOURCES AND REFERENCES**
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Flying over the fjord: en.wikipedia.org & www.roadtraffic-technology.com
**Buildings section** Scientific solution: plato.stanford.edu Sustainable future: en.wikipedia.org
**Tanks & Silos section** Nuclear inspection: www.vattenfall.se
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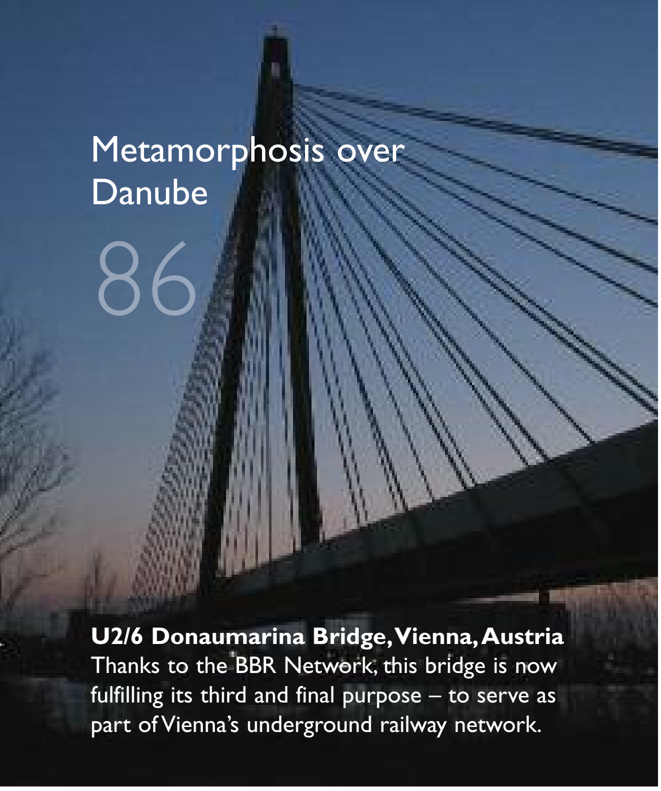

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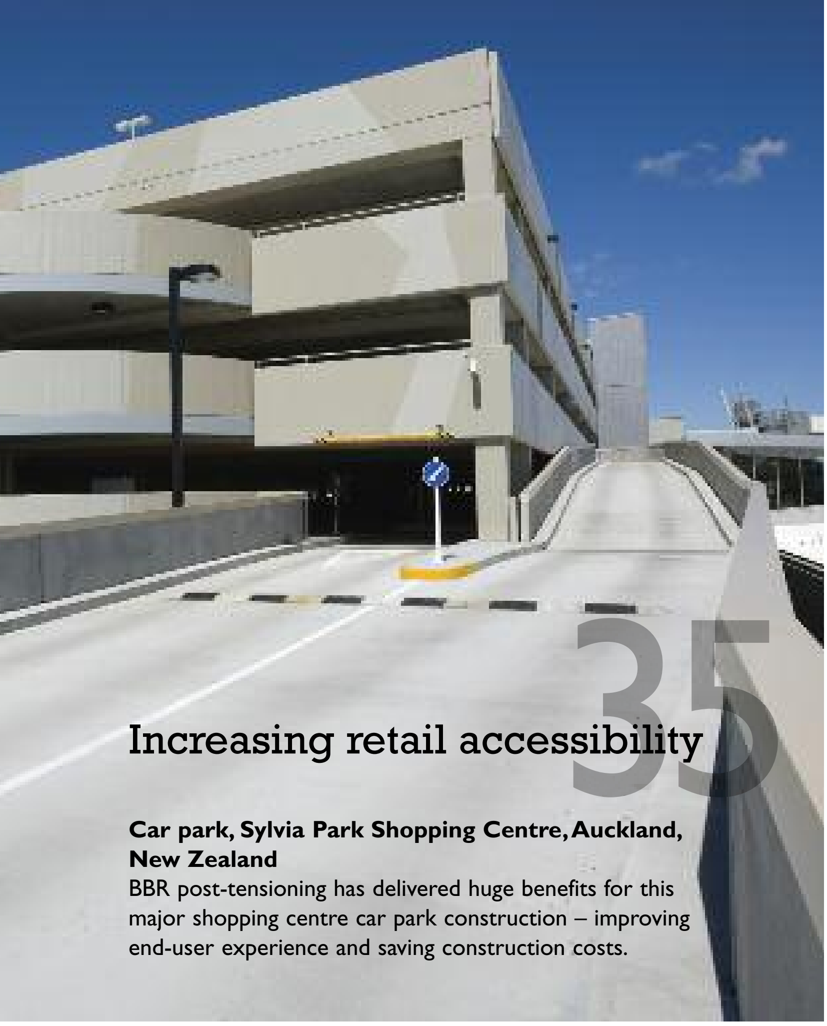

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**With 66 years at the leading edge of construction technology, the BBR Network now extends to over 50 countries and, as the world's leading group for post-tensioning, stay cables and related construction engineering, has completed some of the most challenging projects on the planet. This does not happen by chance – BBR VT International's CEO, Marcel Poser talks about the blend of technology, culture and diversity which drives their success, as well as business performance over the last twelve months.**

### WHY DOES THE BBR NETWORK 'WORK'?

MP: Well, first you have to understand the Swiss culture – there are a lot of similarities between the BBR Network and the way things work here.

In Switzerland, we have the highest foreign population in all of Europe and lived peacefully and successfully together for centuries. We have four national languages, plus English as a business language and administratively, we are organized into 'cantons' – or federal states – which, although governed centrally, have a great deal of autonomy. In Switzerland, we have the world's oldest direct democracy – meaning that it is always the people who have the last word.

The BBR Network functions similarly and our business approach is based on shared understandings first, rather than the enforcement of centralistic rules. OK, yes there are clear boundaries for people to move within, as well as clear and ambitious targets and a common understanding of rules within this family … which rarely have to be enforced. We have all the desire to provide excellence in construction services and above market average quality to our customers. We respect and value each organization's individuality – it is what makes them successful in their own market place. The Network members form alliances, collaborate and share resources as you might discover in many articles in this year's edition of *CONNAECT*.

### WHAT IS THE ROLE OF BBR HEAD-QUARTERS WITHIN THE NETWORK?

MP: Our role is to provide our Network with the means to be the most successful – cutting edge technology, systems, methodology, business and process optimizations. We centralize only what really makes sense without encroaching unnecessarily on the local businesses – truly the Swiss approach. Items which are centrally organized obviously include R&D, procurement of key products, quality assurance, education, training, performance assessment, as well as technical and engineering consulting for challenging, unique and special projects. We are the 'think-tank' of the network – identifying and absorbing the knowledge available within the family. We are also the main interface for new clients and international business relations.

### HOW DO YOU ENSURE GOALS ARE ACHIEVED?

MP: Mainly, we listen. We believe in and operate a collective approach to product and strategy development – something that would probably drive an old-fashioned R&D traditionalist crazy. But it's just no good imposing new products or methodology when you don't know exactly what people all around the world actually want – as a business model, that just doesn't work for us. Over the years, we've built our business and technology on shared visions. This comes about by talking to people and understanding their challenges and needs. We try to react


and provide things before they're actually needed – so we're always looking ahead. Of course, at the heart of this are customer requirements – it's logical that if we satisfy our customers, we will have a successful business. We also take an active and leading role in industry dialogues and committees and our participation is aimed at introducing new and improved technology and techniques. We are always engaged in initiatives for improving quality, performance, longevity and reduce lifetime maintenance costs for the structures involved.

### HOW DO YOU MANAGE CONFLICTING NEEDS?

MP: The latest developments mean our technology is now so very flexible that any differences in market requirements can be met by good construction design. Within a competitive environment, you simply cannot afford to develop a product to fit one market alone – and resource sharing only works if the same systems are used by all. Our universal BBR VT CONA CMX post-tensioning systems – which we started developing way before the European CE-marking regulations were applicable – are now so easily adaptable to suit local conditions that most special needs can be fulfilled without reengineering – and most importantly, without costly and time consuming project-specific testing. Take the Catagunya Dam – featured in this edition of *CONNAECT* – where the base technology is our high capacity CMI system for nuclear applications which, because of the extensive testing beyond requirements already completed on the CMI system, also easily fulfills the needs for these largest–in-the-world ground anchors.

In short, sustainable development, having solutions for market trends before these trends are fashion, combined with our Network members who are locally well-connected and have strong local roots and share the common goal of delivering the highest quality for our customers is our secret for success.

### HOW DO YOU MANAGE QUALITY WITHIN THE NETWORK?

MP: As far as quality assurance is concerned, this is a massive area for us – our reputation depends upon it. That's why, in 2009, we launched the BBR E-Trace system which integrates delivery with quality control and unites it with shared knowledge. So, if there's a problem somewhere, everyone can share the solution and the international pool of knowledge increases.

Finding the right system was important for us – it had to be something which was easy to use and didn't bend BBR Network members out of shape. So, we opted for in-house development of a completely new, never seen before web-based solution, rather than imposing off-the-shelf business management software on everyone.

The BBR Network members, as PT Specialists, have the most vital role in delivering quality … the best technology is meaningless if it is installed poorly. Professional execution is ensured by our certified PT Specialists, for whom we provide training, assessment and support so they remain at a high level. We have also contracted an independent auditor who not only audits us, but also all our manufacturing facilities as well as our Network members.

### GIVEN BBR E-TRACE, DO YOU ONLY RELY ON ELECTRONIC COMMUNICATION?

MP: Even in this digital age, there's nothing quite like personal contact to ensure that understanding is achieved and maintained. Last year alone, we had many opportunities to bring BBR Network members together. As well as the Annual Conference, we've organized training seminars. We've also always supported members locally – for instance, at meetings with contractors and customers. E-tools are great and extremely helpful, but personal contact remains a vital ingredient – at the end of the day, the construction business is still a people business and E-Trace, our products and consulting work are only gears in the perfectly synchronized, precise BBR chronograph … well, a Swiss-made BBR chronograph to be absolutely precise!

### WHAT'S BUSINESS BEEN LIKE OVER THE LAST YEAR?

MP: Actually, it's been rather good – despite the global financial crisis. In 2009, the total annual BBR group turnover reached over CHF 300 million in post-tensioning, stay cable and related construction engineering – this revenue would be even more than doubled if all group activities were to be included. While in some regions it's been a tougher year than usual, generally BBR Network members have been enjoying a good, steady flow of interesting work – as you'll see from the pages which follow. More-and-more diverse projects are appearing in our magazine which reflect the wide diversity of the BBR Network and its customers.

Looking ahead, there are again some exciting projects in view including the Sava Bridge in Belgrade, Serbia which – with its 376 m long main span – will be the second longest cable-stayed bridge in Europe, the Basarab Bridge in Romania, Vidin Calavat in Bulgaria, more record dams in Australia, nuclear works in Scandinavia and many more projects which are at too early a stage for me to be able to reveal too much right now.

In terms of products, we are diversifying our portfolio beyond post-tensioning and stay cables, such as the measurement equipment already introduced and the newly–launched, brand new CE-marked BBR VT pot bearings we will continue to push for new frontiers and more innovation. ●

# Excellence through people

The BBR Network pursues the ambitious goal of providing not only the finest approved Swiss technology, but also the best service and installation capabilities to their customers around the globe. This goal is being met through the use of quality assurance tools – such FPC and BBR E-Trace – combined with a considerable investment in people to ensure the highest level of customer service. Thomas Richli, Business Development Manager at BBR Headquarters provides this report.

A significant portion of the turnover of the BBR group goes into service, where a carefully considered supply chain process and well-trained, experienced staff are of vital importance in delivering the highest installation standards for our clients.

## HIGHEST CUSTOMER SERVICE STANDARDS

Our PT Specialists are qualified and certified to assemble and install European approved and CE marked BBR VT CONA CMX PT kits. They are responsible for compliance with all regulations set out in the relevant European Technical Approvals (ETAs) for our PT kits, for complying with the respective standards and regulations in force at the place of use, for ensuring a professional execution of PT works and for endorsing all safety-at-work and health protection regulations.

BBR Network members have a long history in design and installation of PT, as well as related construction fields. They are under the continuous supervision of BBR VT International – the ETA Holder – and are experts in all post-tensioning tasks, such as:

- Logistics and supply of a complete PT kit to the construction site
- Full assembly and installation service on site
- Quality assurance.

Although each of our PT Specialists have different organizational structures suited to best serving their local markets, they all maintain the following key departments:

- Technical
- Logistics
- Site operation

Together, this team takes professional responsibility for the project from design to completion, dealing with and reporting on technical, logistical, safety and best practice issues along the way.

## BBR PT SPECIALISTS – CAREFULLY SELECTED AND ASSESSED

All our BBR PT Specialists go through a series of application, qualification and certification procedures before they are finally certified by the ETA Holder. After a complete and successful certification process – conducted by experts from BBR Headquarters, or from an external certification body – we issue an official BBR PT Specialist certificate which can be viewed and downloaded from our BBR Network website www.bbrnetwork.com.

Our certification process has four active phases:

- Application from a potential BBR Network member to be certified for BBR PT works in a particular territory
- Preliminary evaluation and assessment
- Issue of a certificate
- Continuous re-evaluation and renewal of the certification.

During the process, we verify all references and carry out 'reality checks' locally to satisfy ourselves that the organisation and its staff meet the BBR criteria for experience, capability and best practice.

All our PT Specialists are audited and re-evaluated every 12 months after the first issue of a certificate. Re-evaluation includes all elements of the preliminary evaluation as well as further assessments.

## CONTINUOUS TRAINING PROGRAMMED

We continuously educate our PT Specialists in post-tensioning and stay cable products – in respect of systems, quality assurance procedures and installation of systems. In order to keep our members up to date, we organize regular practical and theoretical training courses in various regions of the world for technical, logistics and site staff. All our training sessions are concluded with an exam and fully documented. Sometimes, training sessions are also witnessed by independent institutions and/or authorities. After the training courses, attendees are responsible for cascading the knowledge to their company personnel by arranging local internal training sessions. In addition to training required by us as an ETA Holder, we make local training visits to the PT Specialist's location – such as for introductions to CMX systems or logistics procedures.

In 2009, five international training sessions were held. We organized two logistics courses where BBR PT Specialists were successfully trained on our new trading and quality assurance platform BBR E-Trace. Two stay cable seminars were also held in Zurich and Singapore where we also introduced our newly developed strand stay cable system, BBR HiAm CONA. In Paris, at our annual Global BBR Conference, commercial and technical presentations were given including project reports from around the world.

A culture of continuous education within the BBR Network ensures a high quality execution of post-tensioning work for our customers. ●


BBR FACTORY PRODUCTION CONTROL

# Highest quality standards and full traceability

**Four years ago, we implemented the BBR Factory Production Control (FPC) system which provides highest product quality standards – and full component traceability, the most direct way of ensuring quality.**

Traceability is the process of recording information relating to the changes made at every point in the life of a component – starting from the raw material through production, storage, supply to the PT Specialist, storage in stock, supply, storage and installation on site. Our goal is the 'cradle-to-grave' collection of component data.

Data is exchanged between parties involved by way of contractual documents such as orders, drawings, operating and processing forms and procedural documents. Most recently, our FPC process has been incorporated into our new trading platform – BBR E-Trace.

Compliance with the complete Factory Production Control system is audited by an independent approved or 'notified' body – MPA NRW – and any non-conformity must be rectified prior to the CE marking. In addition to our continuous audits and testing of the production – the approved body continues to exert full control during the validity period of our ETA.

These provisions guarantee proper quality and compliance of the kit components delivered to site.

## Independently Assured Quality

**Stefan Lipkowski of independent testing, monitoring and certification body, the Materialprüfungsamt Nordrhein-Westfalen (MPA NRW), describes his organization's work with the BBR Network.**

As a 'notified body' for matters concerning European Construction Products Directive 89/106/EEC (CPD), we have been working together with BBR VT International on the basis of a certification and monitoring contract since 2006.

We are responsible for the initial type-testing of the European-approved BBR VT CONA CMX post-tensioning systems, the initial inspection of factories and Factory Production Control (FPC), the certification of the product, the continuous surveillance, assessment and approval of Factory Production Control and the audit testing of samples.

Our certification procedure determines whether consistent development of the internal quality management system and exemplary implementation of the Factory Production Control by BBR VT International – a multiple ETA holder – fulfills the given requirements.

This process-driven approach ensures that BBR VT International can draw on many excellent references over a comparatively short period. To maintain effective and efficient operation of processes, BBR has implemented a stringent qualifying procedure for manufacturers and users. Supported by the adoption of an internet-based tool (BBR E-Trace), the interaction between all parties concerned and the traceability of required documents have been crucially improved. An additional advantage of this innovative procedure is the continuous monitoring of the internal quality management system by BBR VT International and by MPA NRW for inspection at any time.

Our objective is to develop the relationship and co-operation with BBR VT International, as part of an international network with the common goal of permanent improvement of performance to ensure a high level of quality for approved post-tensioning systems.

MPA NRW
Materialprüfungsamt Nordrhein-Westfalen
certified and surveyed
No. 11 9181

BBR e-Trace

BBR E-TRACE

## Trading & QA Platform

**BBR E-Trace – our in-house developed internet-based software – links all members of the Global BBR Network including BBR PT Specialists, BBR Component Manufacturers (CMs) and ETA Holder, BBR VT International. This comprehensive e-commerce platform leads users through the quality process, ensuring that each step is documented and recorded.**

The platform facilitates the everyday work of all BBR Network members and also supports effective supply chain management.

### ENGINEERING DATABASE
The platform includes a powerful and continuously updated engineering database of all our systems including CMX, where all system and part details, drawings, specifications, quality checks are available for all CM and PT Specialist users.

### PROCUREMENT AND ORDER FULFILLMENT
PT Specialist users can procure BBR components (parts) from our selected CMs. The users can check and compare supply scenarios and corresponding delivery times and then they can either directly place an order or make an inquiry online with one of our CMs.

### STOCK MANAGEMENT
In BBR E-Trace, we are able to view the stock, at any time, including all individual Quality Certificates of all our CMs, after they have produced the BBR parts to our specifications and stored them.
Once an order is confirmed, the CM allocates the respective parts before the PT Specialist receives, checks and stores the components. The results of the incoming inspection are documented.

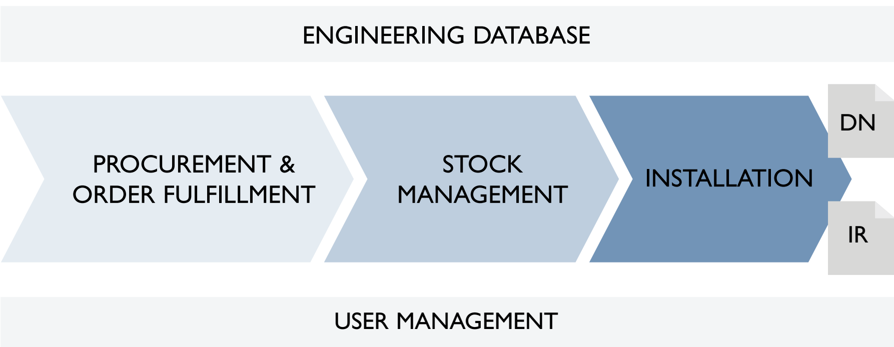
### INSTALLATION
The installation process starts with opening a construction site in BBR E-Trace before parts can be delivered to a site with a Delivery Note (DN). Once all components are installed on site, an Installation Report (IR) respective Definite CE marking is issued and can be handed to the client upon request. The construction site database enables the generation of individual project reference sheets or lists.

### USER MANAGEMENT
The following trained users within PT Specialists and CM organisations are involved:
- Procurement and order fulfillment manager
- Quality manager
- Logistics and stock manager
- Technical manager
- Site and construction manager

### COMMUNICATION
BBR E-Trace provides a complete online database of all PT Specialists and CMs and their users including contact details, plus a series of shared tools to facilitate efficient communication and swift decision-making. Latest changes and enhancements are communicated through the front page news facility.

### QUALITY MANAGEMENT AND DOCUMENT CONTROL
The platform leads the user through the quality process required. Each step is documented and recorded in the platform and can be tracked and viewed whenever needed. The platform enables uploading, storing, tracking, viewing and downloading documents online.

### TRACEABILITY
Traceability is one of BBR E-Trace's primary strengths. The built-in tracking system provides the facility to track, identify and instantly trace all parts, no matter what their current status – every single part can be detected at any time.




**BBR E-TRACE MODULES**

# Sharing global knowledge
## AND EXPERIENCE

Once a year, the Global BBR Conference is held with delegates coming from all over the world. We share knowledge and experiences while learning more about the BBR Network's latest progress and plans. In addition, several social events, such as the BBR Gala Dinner and the BBR Charity Golf Tournament take place.

### PARIS '09

In 2009, again, the Global BBR Conference proved to be a huge success with over 50 delegates converging on Paris.
The conference was launched with an evening cruise along the River Seine during which the assembled delegates joined to congratulate the winners of the BBR Project of the Year 2009 and the newly launched 2009 CONNAECT Awards – the perfect start to the Global BBR Conference!

### PROGRESS, PRODUCTS AND QUALITY

The main conference program began with an introduction by Marcel Poser who gave details of past, current and upcoming activities of the international BBR Network as well as the completely newly developed BBR VT CONA CMX family.
The next presentation was run by Piotr Krawczonek who emphasized the vital role played by quality management within the BBR Network. After Thomas Richli's session on steel price fluctuations, he was joined by Piotr for the first real-time demonstration of the new BBR E-Trace system which went live during summer 2009.

### STAY CABLE STRUCTURES – UNIQUE BBR EXPERIENCE

Marcel Poser opened the comprehensive stay cable seminar and was followed by Antonio Caballero who presented a detailed technical evaluation.
To be certain that delegates clearly understood this complex topic, a 30-question 'exam' was held at the end of the session. Congratulations go to delegates for their ability to absorb such information so brilliantly!

Kampong Pandan Flyover, Kuala Lumpur

### BBR PROJECT OF THE YEAR 2009

The prestigious BBR Project of the Year Award 2009 was presented to BBR Construction Systems (Malaysia) in recognition of their work on the Kampong Pandan Flyover in Kuala Lumpur. The highly complex 12-span, 568 m long highway flyover scheme was designed based on balanced cantilever construction using form travelers. BBR CONA tendons were installed for the spans and cantilever to build the structure in an efficient and timely manner without any interruptions to busy traffic flows.

*BBR Polska site engineer, Bartosz Lukijaniuk, and his wife enjoy a 3-day trip to Switzerland – the prize for producing the* **Best Engineering Report 2009,** *a comprehensive technical report on construction aspects of the striking new sports arena in Lodz.*

### PEOPLE, PLACES AND PROJECTS

BBR Network members formally shared details of their recent work and led discussions about particular technical aspects of their projects. Presentations included:

- Sports Arena Łódz – Bartosz Łukijaniuk, BBR Polska (Poland)
- Seismic strengthening of Kawarua River Bridge – Paul Wymer, BBR Contech (New Zealand)
- Ormiston Road Bridge – Paul Wymer, BBR Contech (New Zealand)
- South Hook LNG Terminal, South Wales – Bob Freedman, Structural Systems (UK) Limited

### INTERNATIONAL INSPIRATION

The meeting was closed with an inspiring workshop where several international groups dealt with specific commercial and technical topics affecting the BBR Network.

### BON APPETIT – ET AU REVOIR!

Le First Restaurant, opposite the Jardins des Tuileries, was the venue chosen for staging the BBR Gala Dinner. Finally, the event had reached its end ... and a new clock started to run the countdown to Washington 2010.

### WASHINGTON 2010

We are holding our conference this year to coincide with the International fib Congress and Exhibition – which is held only once every four years. The fib's theme is particularly appropriate to BBR – "Think globally … build locally" – it's what we've been doing for years! ●

# Remembering our roots

**Frau Irma Birkenmaier, now aged 92 years, was married to BBR-founder Max Birkenmaier for some sixty years and has agreed to share some reflections and fond memories about the early days of the company. Even today, she continues to take great pride in the pioneering achievements of those early days and to enjoy relationships created during business trips all over the world.**

BBR was first formed, in 1944, when three technically brilliant young engineers – all graduates of ETH, the Swiss Federal Institute of Technology in Zurich – started a partnership known by their initials – BBR – Max Birkenmaier, Antonio Brandestini and Mirko Ros.

Both Max Birkenmaier and Antonio Brandestini had been working with a specialist geotechnical firm, Swissboring, while Mirko Ros was at EMPA, the Swiss Federal Laboratory for Materials Testing and Research. As WW2 drew to a close, it was clear that ingenious construction technology solutions would be required to offset the materials shortages, particularly cement and steel.

Frau Birkenmaier describes Max as very much an engineer and technically brilliant – although he was a rather academic, conservative type, while Antonio was more of an outgoing entrepreneurial character, a businessman. Meanwhile, Mirko Ros' family had academic roots, his father being a professor at ETH. Basically, they formed a very good team.

In the early days, Frau Birkenmaier supported the young entrepreneurs as a clerk in their offices on Zurich's Limmatquai and Max used to take his son, Max junior, on construction site visits. A certain family atmosphere developed within the business, as both Max and Antonio used to maintain contact with their employees. Clearly, this was encouraged by Antonio who invited business partners, professors and BBR Network members to his home.

She recollects that in 1958, Max's expertise was applied to a more personal project – securing the family home that they were building, on sloping ground, with post-tensioned anchors. Apparently, Max had many ideas which went beyond pure post-tensioning – for example, he investigated how PT could be used to store energy ... stress – store – and finally relieve. During his career, he was heavily involved in norm committees and received a honorary doctorate from ETH for his achievements.

The dedication and work of our pioneering founders acts as inspiration and a guiding light as we continue, today, to develop construction technology to meet the demands of the future. ●

# Timely launch for rail viaduct

## Barbantiño Viaduct, Galicia, Spain

A land of stunning natural beauty, Galicia, in the northwest of the Iberian Peninsula, is also famous for its gastronomy and as the home of the legendary ‘Camino de Santiago’. Each year, tens of thousands of Christian pilgrims and other travelers flock to Santiago de Compostela – on foot, bicycle or horseback.

Nearby, is the Barbantiño Viaduct that will carry the AVE high speed railway from Madrid to Santiago. Gustavo Delgado Martín, from **BBR PTE** in Spain, describes the innovative solution for constructing concrete viaducts using the incremental launching method on a downward gradient. →

The final design for the Barbantiño Viaduct was a single box concrete girder. The incrementally launched construction method was chosen because of the rough terrain and great height of the piers.

The viaduct is 1,176 m long, with 18 spans (52 m + 16 x 67 m + 52 m). The plan layout is a curve with a 7,250 m radius and the elevation starts at 2.21% and ends with a 1.09% descending slope.

## DOWNHILL LAUNCHING

Launching was executed downhill from the top abutment – the total weight to be launched downwards in the last phase was 43,000 t. The maximum height of the viaduct above the valley floor is 98 m. The superstructure was built based on a weekly cycle and the standard section length was 33.5 m.

On the top of each pier, a guiding system was installed which consisted of two steel structures positioned on both sides of the deck which helped to guide the structure during the launching.

The viaduct was launched with three pulling jacks and three retaining jacks. The pulling and retaining jacks each have a capacity of 5,000 kN, with 42 compacted steel strands and the stroke of each jack is 400 mm. With this capacity of stroke, we reached launching speeds of six meters per hour.

All jacks were synchronized. A retaining force was set and, once the pulling force was bigger than the retaining one, the viaduct started to move. The movement of the pulling jacks was synchronized in displacement, using the total pulling and retaining force as the control parameter.

## CLAMPING

For the execution of each segment, we used a clamping system composed of 12 jacks, each with a braking capacity of 250 t, providing a total braking force of 3,000 t – which ensured the viaduct did not move between two consecutive launchings.

In addition, this clamping system was activated each time that an alarm became active during the launching process. This meant that the launching was stopped and the viaduct was clamped by the 12 transversal jacks.

### TEAM & TECHNOLOGY

**OWNER**
Administrador de Infraestructuras Ferroviarias (ADIF), Spain

**MAIN CONTRACTOR** Ave Maside UTE (FCC + COMSA), Spain

**DESIGNER** FCC Construcción Technical Services & EIPSA, Spain

**TECHNOLOGY**
BBR VT CONA CMI internal
Launching
Bar

**BBR NETWORK MEMBER**
BBR Pretensados y Técnicas Especiales, S. L. (Spain)

"LAUNCHING WAS EXECUTED DOWNHILL FROM THE TOP ABUTMENT – THE TOTAL WEIGHT TO BE LAUNCHED DOWNWARDS IN THE LAST PHASE WAS 43,000 T."

### EQUIPMENT

All the equipment involved in the launching was instrumented and controlled by a PLC – pressure transducers for measuring the pulling, retaining and braking forces, anemometer for measuring the wind speed, clinometers at the pierhead, encoder and laser for measuring the launching speed and stroke sensors. Meanwhile, all measuring instruments in the piers communicated with the main control unit via a wireless connection.

### POST-TENSIONING SYSTEM

The viaduct has 907 t of post-tensioning – comprising 497 t of launching post-tensioning and 410 t of service post-tensioning completed after the final launching. The system used was BBR VT CONA CMI 1906 and 2406 anchorages and couplers.

This method of construction ensured the project was realized on time – the main bridge structure was completed within nine months.

## Local insight:

### Spain's high speed trains

Alta Velocidad Española (AVE) is a high speed railway service, with trains operating at speeds of up to 300 km/h on dedicated track in Spain. The name translates literally into English as **'Spanish High Speed'** – but the acronym is also a play on the Spanish word 'ave', meaning 'bird'. All AVE trains are currently operated by RENFE, the Spanish state railway company. The Spanish government has an ambitious long-term plan to make 7,000 km of high-speed railway operational by 2010 – with all provincial capitals being, at most, only four hours from Madrid, and six-and-a-half hours from Barcelona.

According to the Strategic Plan for Infrastructure and Transport (PEIT) developed by the Spanish **Ministerio de Fomento** (Ministry of Public Works), a second expansion program is planned to start in 2010-11, when the last lines of the first program currently under construction begin operation. This plan has a ten-year scope and its aim is to extend the 300 km/h network to 10,000 km by the end of 2020. This would be the most extensive network in Europe, with several operational links with France and Portugal – and is by far the most ambitious high speed rail plan currently underway within the European Union.

VIADUCTS IN VILLENA-SAX, SPAIN

# Span-by-span concrete decks

The success of Spain's new high speed railway infrastructure is ensured, says José Luis Plaza Bacete of **BBR PTE** as it will provide a real alternative to traveling by car – thus reducing congestion at the eastern exit of Madrid, the A3 motorway, where there are always traffic jams.

Part of this enormous project is the construction of two new viaducts on the approach, from Madrid, to Comunidad Valenciana – Viaducto de la Acequia del Rey and Viaducto de Cordel de Sax. BBR PTE is involved in the construction of these two viaducts. Our work consists of the supply, installation, stressing and grouting of all the longitudinal tendons.

**TEAM & TECHNOLOGY**

**OWNER** Administrador de Infraestruturas Ferroviarias (ADIF)

**MAIN CONTRACTOR**
FCC Construcción, S.A.

**DESIGNER**
FCC Construcción Technical Services

**TECHNOLOGY**
BBR VT CONA CMI internal
Advanced shoring

**BBR NETWORK MEMBER**
BBR Pretensados y Técnicas Especiales, S. L. (Spain)

## DESIGN HIGHLIGHTS

The design has been developed by the technical services department of FCC Construcción. The BBR VT CONA CMI multistrand system is being used for the post-tensioning, in accordance with the European Technical Approval ETA-06/0147. The cross-section is the same for both viaducts and consists of a section of lightened concrete slab with five webs. The slab is 14 m wide, including the lateral cornices, and is 2.10 m high along the whole deck. The technology used is BBR VT CONA CMI 2106 and 2406 for both viaducts. The work is being executed concurrently by two separate project teams.

## VIADUCTO ACEQUIA DEL REY

This concrete lightened slab viaduct has an overall length of 1,394 m between abutments and has 44

spans, 25 m + (42 x 32 m) + 25 m. The viaduct is being constructed using conventional formwork. The first span completed was in the middle of the viaduct. Once this span was concreted, stressed and grouted, two sets of formwork were installed either side of the centre span. The same operation is being repeated span-by-span until the deck arrives at both abutments. One work team executes all the works, changing from one span to the opposite, achieving complete cycles of one span per week.

Acequia del Rey has approximately 360 t of post-tensioning steel. All the longitudinal tendons consist of 15.7 mm diameter strand and the multistrand system chosen is the BBR VT CONA CMI 2106 and 2406 fixed type K couplers, used at the end of each phase in the construction joint. A 750 t hydraulic jack is being used to stress the tendons.

### VIADUCTO CORDEL DE SAX

This viaduct consists of a concrete lightened slab deck, similar to Acequia del Rey. It has an overall length of 1,458 m between abutments, with 46 spans, 25 m + (44 x 32 m) + 25 m. However, the construction method is different – a moveable scaffolding system for full span cast-in-situ is being used. It is moved forward over piers, span-by-span, until it arrives at the opposite abutment. The casting cycle has been optimized into a stable week-by-week rhythm. Cordel de Sax has approximately 385 t of PT steel. All the longitudinal tendons consist of 15.7 mm diameter strand and the multistrand system chosen is the BBR VT CONA CMI 2106 and 2406 fixed type K couplers.

### KEY BENEFITS & ADVANTAGES

One of the infrastructure owner's main requirements was rapid construction. Use of the BBR system enabled the post-tensioning to be carried out at a low concrete strength – achieving significant time savings.

In addition, the repetition of identical tasks in each span favors rapid construction and helps to reduce direct and indirect costs.

The program envisages that all post-tensioning work for both viaducts will be finished in less than 12 months. The new AVE route to Valencia – Murcia is expected open for passenger service during 2012 and we will be proud to have contributed BBR know-how and technology to this exciting project.

GAUTENG FREEWAYS IMPROVEMENT PROJECT – PACKAGE E, JOHANNESBURG, SOUTH AFRICA

# Launching in Africa

**Paul Heymans from BBR Network member Structural Systems (Africa) talks about their contract for three incrementally launched bridges which form part of a major freeway upgrade project in-and-around Johannesburg, South Africa. This is the first major contract secured by the Structural Systems Group – and first use of BBR VT CONA CMI multi-strand technology – on the African Continent.**

A major drive was initiated by the South African National Roads Agency Ltd (SANRAL) in 2006 to upgrade the highway network in the Gauteng Province of South Africa, with the majority of upgrades in the Johannesburg and Pretoria areas.

This major upgrade project was tendered in different packages. Package E was won by the Siyavaya Highway JV – a joint venture between Group 5 Civil Engineering, one of the top three civil engineering contractors in South Africa, and various smaller civil engineering contractors.

Package E contains three incrementally launched bridges on the N12/N17 highway intersection and at the N3/N12 Elands interchange in Johannesburg, South Africa and Structural Systems (Africa) has been contracted for:

- Design of cast beds and temporary piers, design and supply of temporary bearings, design of modifications to abutments to suit launching equipment, design and supply of launch girders including connection to bridge deck.
- Supply and site operation of incremental launching equipment and braking system.
- Supply of BBR VT CONA CMI anchors, strand, galvanized ducting for post-tensioning.
- Site installation, stressing and grouting of all post-tensioning.

Two of the bridges are straight and constructed on either side of an existing bridge. They are 150 m long and on an average downhill slope of 4%. We devised a brake system to restrain the bridge during launching using two 400 t brake jacks connected to the bridge deck with 40 mm stress bars, as well as a series of brake pins for parking the bridge between launches. The third bridge is a horizontally and vertically curved bridge with a total length of approximately 400 m.

The introduction of BBR Technology by Structural Systems into South Africa has been widely welcomed by designers and contractors throughout the region. We look forward to many more challenging projects here in the future!

**TEAM & TECHNOLOGY**

**OWNER** South African National Roads Agency Ltd (SANRAL)

**MAIN CONTRACTOR**
Siyavaya Highway Joint Venture

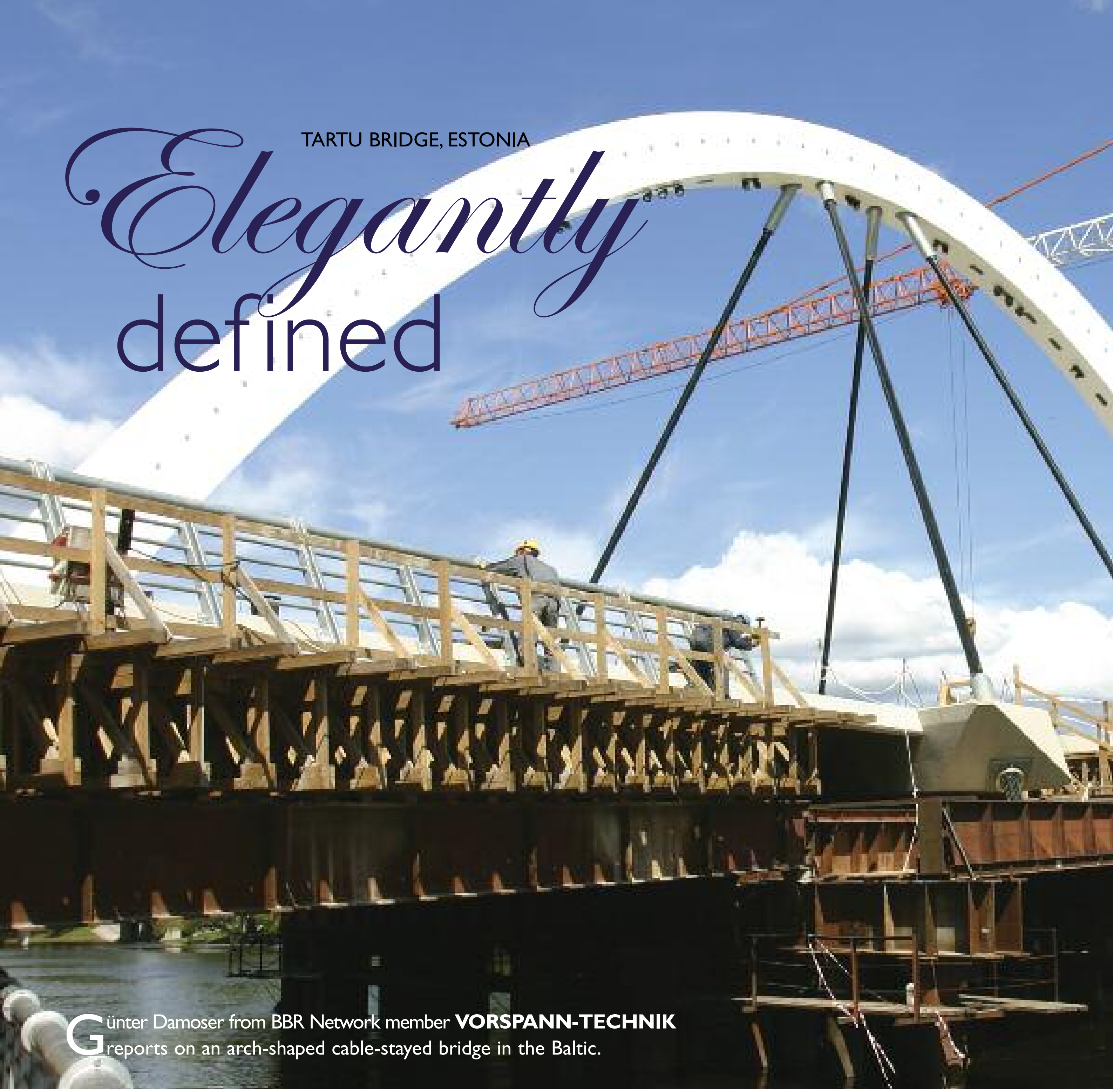
**DESIGNER**
UWP / Nyeleti Consulting Joint Venture

**TECHNOLOGY**
BBR VT CONA CMI internal
Launching

**BBR NETWORK MEMBER**
Structural Systems (Africa)

TARTU BRIDGE, ESTONIA

# Elegantly defined



**Günter Damoser from BBR Network member VORSPANN-TECHNIK reports on an arch-shaped cable-stayed bridge in the Baltic.**

This bridge is a very good example of how the use of stay cables can add much to the architectural appearance of a structure and make it just perfect. Although the bridge is not huge – with a span length of only some 70 m – it attracts the viewer, inviting closer inspection and discovery of every detail, as well as enjoyment of how well the design fits the environment.

## BRIDGE DECK

The bridge deck is of concrete, post-tensioned longitudinally, with post-tensioned transversal beams which carry the deck with the help of stay cables. The ends of the beams exceed the deck in a transversal direction, thus accommodating the stay cable anchorages. In doing so, they allow the visitor to observe the flow of forces from one load bearing element to the other.

## STAY CABLES

With an upwards glance, the viewer discovers where the cables penetrate the arch, as they are anchored on the inside. The pipes and joints are all neatly crafted. Floodlights are installed on the underside of the arch, illuminating the bridge which has become a city centre architectural attraction. Each of the four cables is made up of 73 0.6" diameter prestressing strands which are galvanized, waxed and PE-sheathed. We used VT stays which were designed to be installed into the particularly small recess pipes of the steel arch. As usual for the system – and in line with the demand for easy and quick erection – the cables were entirely preassembled on the bridge deck.

## STRESSING

Stressing was completed with four multistrand jacks – one at each of the deckside anchorages. In this way, the cable forces required by the design could be introduced very precisely and without variances from one cable to another. The whole cable installation – from set up of the special equipment, production and erection of the cables, through to completion of stressing – took only four weeks.
The opening of the new bridge was officially

celebrated with a big party shortly after its completion in summer 2009. Since then, of course, the bridge serves to guide vehicles and pedestrians over the River Emajögi and, at the same time, takes its place as a new landmark in the city of Tartu – with every right to do so!

**TEAM & TECHNOLOGY**
**OWNER** City of Tartu, Estonia
**MAIN CONTRACTOR** Tilts, Estonia
**DESIGNER** Transmost
**TECHNOLOGY** VT stay cable
**BBR NETWORK MEMBER**
VORSPANN-TECHNIK GmbH & Co. KG (Austria)



TOARC 1 & 2, A75-A9 HIGHWAY, FRANCE

# THE FRENCH CONNECTION

This new highway, in the south of France, has been constructed to make the connection between the southern part of the A75 and the A9. It is an important route, explains Claude Néant from BBR Network member **ETIC,** because it forms part of the Pan-European E15 highway.
All of the bridges for this new highway are comprised of thin concrete slabs which we post-tensioned with BBR VT CONA CMI after concreting. There are six bridges on this section, all were post-tensioned – we used a total of 120 t of steel in the six slabs.
Three of the bridges were incrementally launched using a centric BBR VT CONA CMI tendon, BBR jack and a nose beam. We also supplied and installed elastomeric bearings and expansion joints.
The three identical bridges to be launched were each 48 m long, with two 24 m spans and had 1.06 m thick slabs – each bridge weighed 1600 t. They were built and post-tensioned from one abutment and pushed, during the night, over the existing highway. The pushing operation was carried out by installing the nose beam and, below the slab, one centric BBR VT CONA CMI tendon – one end connected to a steel pulley, fixed on the abutment at the front of the slab and the other, to a special steel plate, fixed to the back of the slab.
Two special BBR 19T15 jacks were assembled and connected directly to one special pump. Using this method allowed us to increase the capacity of movement and reduce the total duration of the launch.

**TEAM & TECHNOLOGY**
**OWNER**
ASF (Autoroutes du Sud de la France)
**MAIN CONTRACTOR** JV RAZEL – BEC
**CONSULTANT**
SETEC International / Scetauroute / EGIS
**DESIGNER** RAZEL T&M – Saclay (91)
**TECHNOLOGY** BBR VT CONA CMI internal
Launching
Heavy lifting
Bearing
Expansion joint
**BBR NETWORK MEMBER** ETIC S.A. (France)

# Flying over …

HARDANGER BRIDGE, NORWAY

Hardanger Bridge – which is set to be the world's most breath-taking bridge project – is now under construction amid the dramatic scenery of the Norwegian fjords. It is a 1,375 m long suspension bridge – 30 m longer than San Francisco's Golden Gate Bridge – with a main span of 1,310 m. When completed, explains Stig Solbjør of **Spennteknikk,** the BBR Network Member in Norway, the bridge will replace the ferry connection – across the world-famous Hardangerfjord.

A ferry-free connection will improve long distance travel, as well as local journeys in the inner Hardanger area and getting to-and-from Odda and Voss – between Bergen and Hardanger – and travel towards the upper part of Hallingdal will also be made easier.

## FUNDING & APPROVAL

The €270 million Hardanger Bridge construction project will be partly financed by toll charges, local and regional contributions and savings on current government subsidies for funding ferry services. Approval for the bridge was given at the end of February 2006 by the Norwegian Government. While construction of the approach road began in March 2007, bridge construction started in May 2009.

## BRIDGE OUTLINE

The bridge will carry two lanes of traffic and have a separate pedestrian and cycle-way. The towers are approximately 200 m high and the side spans are 20 m and 45 m on the north and south side of the bridge respectively.

The relatively small difference between the bridge's length and span is because the towers must stand near the shore – the steep mountain walls either side of the fjord mean that the fjord itself quickly becomes very deep. The maximum water depth near the bridge is about 500 m and the mountains surrounding the fjord are about 1200 m high. Beneath the bridge, the clearance for maritime traffic will be 300 m wide and 55 m high.

The main span is designed as a closed steel box beam and the bridge will be connected to each end with a rock anchor system, developed by Spennteknikk.

## INFRASTRUCTURE CONNECTIONS

The project also comprises a 2.4 km tunnel and 0.8 km of road between the tunnel and the bridge. In addition, a 0.9 km footpath and a cycle path will be built towards the bridge. At the northern end, the approach road will start at a roundabout inside the existing Vallavik tunnel. This roundabout will divide the traffic between Granvin, Ulvik and the new Hardanger Bridge.

The southern side of the bridge will connect to a 1,200 m-long tunnel that ends in a three-way roundabout. The approach road will be 7.5 m wide and the speed limit will be set at 80 km/h. The toll collection plaza will be at the southern end of the bridge.

The bridge is scheduled to open in 2013, at which point it has been estimated that the daily traffic volume will be 2,000 cars.

## TECHNICAL DESCRIPTION

The suspension cables will be anchored by 76 BBR VT CONA CMI 2506 tendons installed on each side. The cables will be placed in individually drilled holes from the upper anchor zone down to a tunnel and anchored with anchors.

The pylons will be anchored to the rock by a total of of 32 BBR CONA 1206 rock anchors – with an average length of 21 m and with a anchoring length of approximately six meters.

The two pylons on each side will be connected by three prestressed box girders, the latter featuring 78 BBR VT CONA CMI 1506 tendons. The access viaduct will be constructed as a traditional prestressed triple box girder with a length of 45 m and, here, the BBR VT CONA CMI 1906 post-tensioning system will be used. ●

**TEAM & TECHNOLOGY**

**OWNER** Statens Vegvesen

**MAIN CONTRACTOR** Veidekke Entreprenør AS

**CONSULTANT** Statens Vegvesen, Norconsult AS and Rambøll AS

**TECHNOLOGY** BBR VT CONA CMI internal

BBR CONA rock anchor

BBR VT TOBE pot bearing

**BBR NETWORK MEMBER**

KB Spennteknikk AS (Norway)

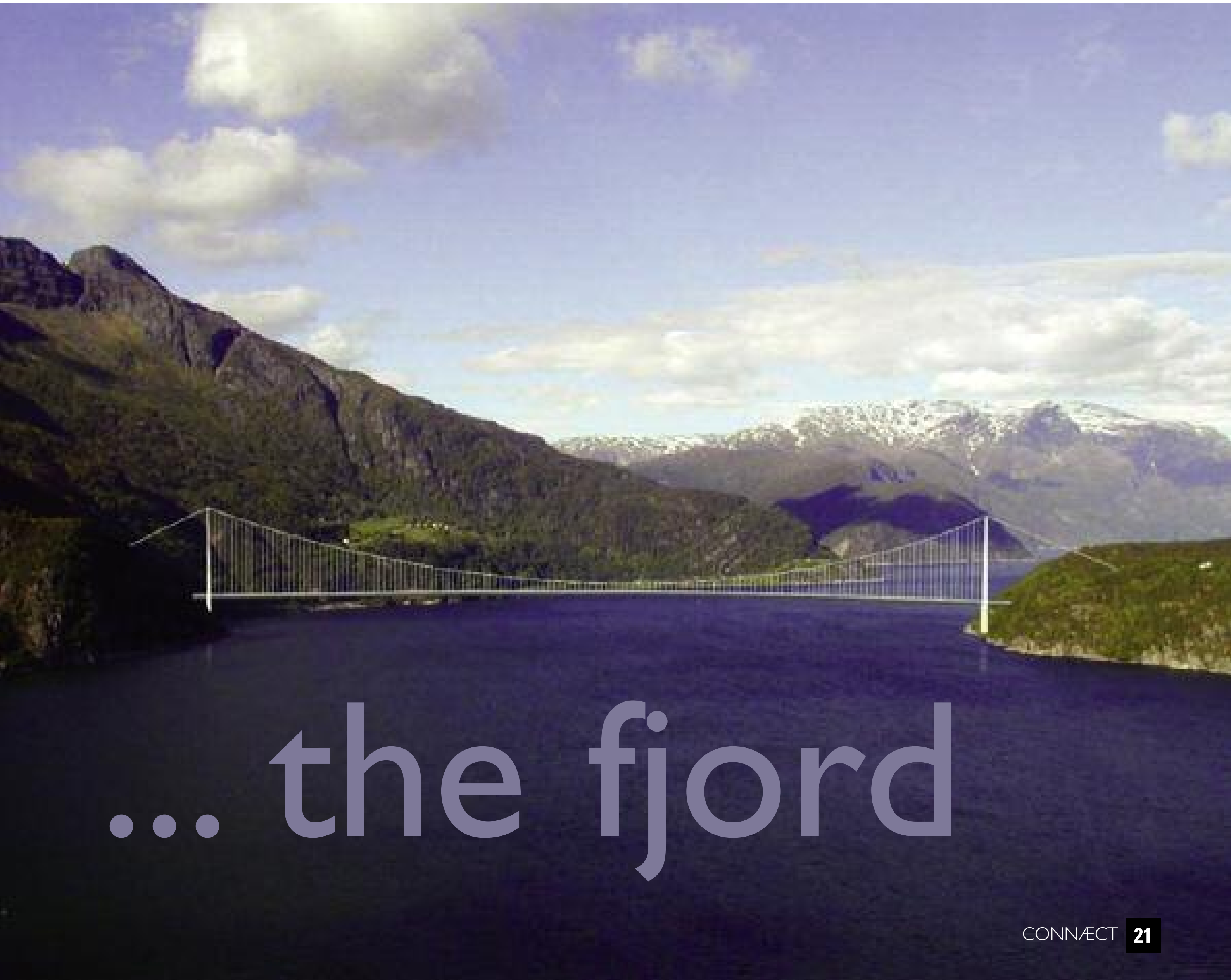
## Local insight:
## Hardangerfjord

With a length of 179 km, the Hardangerfjord is the third longest fjord in the world and the second longest in Norway. The creation of the fjord began about 10,000 years ago when the Scandinavian land mass started to rise up as glacial ice started to melt. The lower parts of the valleys became flooded and so created the Hardangerfjord. The valley was originally not only made through glacial erosion, but also by the high pressure of melt water pushing its way beneath the ice.

Human history of the fjord reaches back, far beyond Viking history, to the time of hunters on the surrounding mountains and, later, farming along this fertile area now considered to be the fruit orchard of Norway. The fjord has good conditions for fish farming. In 2002, fish farms were producing more than 40,000 t of salmon and rainbow trout annually – making the Hardangerfjord one of four major fish farming regions of the world.

The fjord's history as a tourist destination began in 1875 when travel entrepreneur Thomas Cook started weekly cruise departures from London to Hardangerfjord. Today, the fjord is divided among 13 municipalities covering some 8,471 km² of land – but inhabitants only number a little more than 70,000.





# WATER UNDER THE BRIDGE

Climate change has meant that an ever-increasing amount of water is flowing through the River Rhine and needs to be moved towards the sea without delay. That is why, as part of a flood prevention scheme in Wageningen, a dam connecting with the Lexkesveer ferry has now been replaced by a bridge. Ben Grundlehner from Netherlands-based BBR Network member **Spanstaal,** takes up the story.

The ferry of Lexkesveer, near the old city of Wageningen, is firmly established – there are historical accounts of the ferry dating back to the 15th century. It was one of several ferries which crossed the Rhine, giving access between the North and South of the Netherlands. For more than 500 years, there has been a dam between the southern winter dike and the ferrystop, at the summer dike.

To improve transportation and provide extra storage of water, the dam – which was in a good shape – had to be replaced by a bridge as the winterbed was deepened. At the same time new natural habitats – wetlands – have been developed.

## LEGO CONSTRUCTION

It was appropriate that water should also have played a major role in the design and construction methodology for this new bridge. As the building site only had a very short period without water ingress, a construction method was chosen which allowed the bridge to be completed within four weeks. This involved a system of 'Lego bricks' stressed together by post-tensioning tendons.

## PLACING AND STRESSING

The bridge piers were prefabricated in two 60 t sections. After placing them in the pierfoot, the components were stressed using two BBR CONA 1206 tendons. In total, nine piers were placed – at a rate of one pier per day.

In the following two-week period, ten deck spans were constructed using pretensioned prefabricated 20 m hollow core beams. After placing the beams on the piers, they were stressed together in a transverse direction using post-tensioning tendons. In total, 200 BBR CONA 0706 tendons were used. A concrete overlay was not necessary.

## TRAVELLING IN COMFORT

The individual spans were made continuous by so-called bending joints, to give extra comfort to those travelling by car across the new bridge. All movements were concentrated at the abutments where expansion joints were built in.

This solution made it possible to build a 200 m bridge within four weeks and without any problems being caused by water. And so the new bridge was opened for traffic on 4 August 2009, giving way to cars above – and free-flowing water under the bridge.

### TEAM & TECHNOLOGY

**OWNER** Rijkswaterstaat
**MAIN CONTRACTOR** Ballast Nedam Infra Midden
**DESIGNER** Grontmij
**TECHNOLOGY** BBR CONA internal
**BBR NETWORK MEMBER**
Spanstaal B.V. (Netherlands)

JAMARAT BRIDGE, SAUDI ARABIA

# Improved safety and space

**Jamarat Bridge in Saudi Arabia is not only a place of great religious significance, but it also has a functional value as transportation infrastructure. It is a pedestrian bridge that is located very close to Mecca and Mina – and plays a very important role during the Hajj pilgrimage. The pilgrims line themselves up on the bridge in order to throw stones at the three Jamarat Pillars during the 'stoning of the devil' – a ceremony that is an integral part of the Hajj.**

The old Jamarat Bridge in Saudi Arabia was built in 1963, primarily for the convenience of the pilgrims and, ever since, has not only been of great use during the religious festival, but has also become one of the many important tourist attractions in Saudi Arabia. The old Jamarat Bridge was refurbished in 2006 to accommodate even more people on the bridge and avoid accidents.

## INCREASING CAPACITY

About 4.2 billion Saudi riyals (US$1.2 billion) were allocated by the Saudi government to carry out the expansion of the Jamarat bridge and construction of new levels. This project has already helped prevent any injuries or death from occurring among pilgrims, as had been the case in previous years.

The bridge is now multi-storied to provide more space. The Jamarat Pillars have also been expanded so that more people can perform the ritual without having to fight for a space at the front. An emergency evacuation space has also been built in, so that the pilgrims can be speedily removed from the bridge. The present capacity of the bridge is more than 500,000 pilgrims per hour, but this will be reduced to 300,000 pilgrims per hour to control the movement of pilgrims towards the holy mosque while performing the Tawaf rituals.

## MAIN BRIDGE CONSTRUCTION

The new main bridge consists of four levels, excluding the ground level, and is about 100 m wide. It was constructed by the segment-by-segment method, with columns only at the sides and two underpasses.

To serve these levels there are 11 escalators – four at the entrance to the main bridges and seven at the exit.

Also there are 11 ramps at the entrance and 12 at the exit, serving all directions – giving access to-and-from Mecca, Mina and Muzdalifa.

Marwan Al Kurdi & Partners Co. was the subcontractor for the erection of some 2,000 precast prestressed girders for all the ramps. ●

**TEAM & TECHNOLOGY**

**OWNER**
Ministry of Municipal and Rural Affairs

**MAIN CONTRACTOR** Saudi Binladin Group

**DESIGNER**
Dar Al-Handasah (Shair and Partners)

**TECHNOLOGY** BBR CONA internal

**BBR NETWORK MEMBERS**
Huta-Hegerfeld Saudia Ltd (Saudi Arabia)
Marwan Alkurdi & Partners Co. Ltd (Jordan)

# Viaduct quintet in park

DESPEÑAPERROS VIADUCTS, SPAIN

Five magnificent new viaducts are now taking shape, in an area of Jaen province, southern Spain, which has been declared a Natural Park by the Government of Andalucía. David Olivares Latorre of **BBR PTE** provides an outline of this fascinating project.

We are responsible for two different activities during the viaduct construction – stressing of the 39 and 45 m spans and deck positioning between piles. The precast deck segments are being placed using a launching girder. The 900 t of prestressing steel applied to the project consists solely of external BBR VT CONA CME technology – the only construction system used on the Despeñaperros viaducts.

## CONSTRUCTION SEQUENCE

As construction of the first span commences, four 500 t vertical and horizontal positioning jacks are positioned over the piers at the beginning and end of the span. Next, the precast segments are joined and correctly positioned, suspended from the launching girder.

External polyethylene pipes are inserted inside the deck and are dragged and welded. Once every tendon pipe is fixed in the 2406 and 3106 anchorages, the steel strands are fed into them and stressing of the span begins. When enough force is achieved along the deck, span positioning is carried out using the four jacks.

## CORROSION PROTECTION

Corrosion protection for the cables is provided by the grouting of the 39 and 45 m tendons. We used a special grout, which was in accordance with ETAG 013. It is a very satisfactory construction process because all the span activities can be finished in less than a week. ●

### TEAM & TECHNOLOGY

**OWNER** Ministerio de Fomento

**MAIN CONTRACTOR**
FCC Construcción, S.A.

**DESIGNER**
FCC Construcción Technical Services

**TECHNOLOGY**
BBR VT CONA CME external
Advanced shoring

**BBR NETWORK MEMBER** BBR Pretensados y Técnicas Especiales, S. L. (Spain)

**The M6 Duna Motorway is a Public Private Partnership infrastructure project in Hungary and runs in a North-South direction from Budapest to Pecs. One section has already been completed and Jürgen Diatel from BBR Network member VORSPANN-TECHNIK advises that the section between Dunaujvaros and Pecs will be completed by 2011. The two bridges, known as No. 993, are a major element of this stretch of the new motorway.**

The project includes the construction of two similar bridges, each one with a total length of 629 m. Both superstructures are being built using the incremental launching method and consist of 13 spans with a maximum length of 50 m. The single prestressed concrete box girder is 3.5 m high. In total, there are 46 standard 25 m long sections and eight smaller 11 m long side sections.

## UNIQUELY APPROPRIATE

The construction concept uses two different types of post-tensioning. For the centric tendons, BBR VT CONA CMI internal with 0.6" diameter is being used. Over successive planning phases, the concrete cross-sections were progressively reduced, thus four different types of CMI tendon are being applied. The carriageway slab will have 16 tendons with 19, 12 and six strands and eight tendons with 19 strands are being installed in the bottom slab.

All tendons run over two sections. Half of the tendons are stressed at the construction joints and elongated by fixed couplers. In the first three sections, different tendon types are used. In the carriageway slab, there are eight tendons each of BBR VT CONA CMI 1206 to 1906 and from BBR VT CONA CMI 0606 to 1206. In the bottom slab, the tendons are all BBR VT CONA CMI 1906 and are continued with BBR VT CONA CMI 1506.

It is only possible to meet the high requirements of the design work because of the uniquely small centre spacing and edge distance requirements of the BBR VT CONA CMI system, compared to other products on the market.

BRIDGES 993, M6 MOTORWAY, DUNAUJVAROS, HUNGARY

# IMPRESSIVE **SPEED**

### ECCENTRIC PT

For the eccentric post-tensioning, the BBR VT CONA CMB 4x0406 band system for external tendons is being used. Each unbonded tendon consists of 1606 strands placed in four double-extruded BBR VT CONA CMB bands. The length of the tendons extends from 141 m to 293 m. The deviation points are constructed as PE-saddles at the support cross beams with a maximum length of 3.34 m. After launching is complete, tendons are installed through the openings created in the carriageway slab for the two steel beams used as a launching device. The tendons are stressed – in one direction at both ends simultaneously – to 2,940 kN.

As a consequence of the tough construction schedule, the standard erection time of one week was reduced to between three and five days per section and working time was extended to 24-hours-a-day, seven days-a-week. Both superstructures are being built simultaneously – and the maximum weight of bonded tendons installed, stressed and grouted per week is 35 t.

Thanks to the excellent engineering work of FÖMTERV and Pont-TERV and the advanced technology of our BBR VT CONA CMX system, we are able to build highly economical bridge structures in an impressively short time. Although boundaries can always be pushed further, safety and quality should never be forgotten while focusing on construction time and costs.

**TEAM & TECHNOLOGY**

**OWNER** M6 Tolna Autoplaya Koncesszions Zrt

**MAIN CONTRACTOR**
M6 Dunaujvaros – Szekszard Epitesi

**DESIGNER**
FÖMTERV and Pont-TERV, Budapest, Hungary

**TECHNOLOGY** BBR VT CONA CMI internal
BBR VT CONA CMB band

**BBR NETWORK MEMBER**
VORSPANN-TECHNIK GmbH & Co. KG (Austria)

DUBAI BYPASS PHASE III-AL QUDRA BRIDGES, DUBAI

# PT relieves TRAFFIC TENSION

With their significant track record of completing over 50 bridges in the Middle East region, BBR Network member **NASA Structural Systems LLC** was appointed by main contractor Wade Adams to perform the specialist post-tensioning works on the flyovers for the US$18 million Dubai Bypass Phase III-Al Qudra project.

Warwick Ironmonger, General Manager for Structural Systems' operations in the Middle East, and Mahesh Nayak, Contracts Manager for NASA Structural Systems LLC, provide an overview of the project which will connect the Bab Al Shams Resort road to the Arabian Ranches roundabout – thus relieving the busy Dubai Bypass road.

## EAST & WEST BRIDGES

The flyovers included two identical parallel (East and West) bridges – each one 418 m long with eight spans. A uniform cross-sectional depth of 2.3 m was made possible for both the 44 m end spans and the considerable 55 m intermediate spans by adopting a post-tensioned solution wherein each bridge deck consisted of five prestressed webs forming a cast-in-situ four-cell box structure.

Each web featured eight BBR VT CONA CMI 1906 tendons which ran through six construction stages. Half of the tendons were coupled and stressed at each of the five successive construction joints to provide an even distribution of the prestressing forces. After successful single-end stressing, each of the tendons – up to 165 m long – were grouted in less than 30 minutes using high performance colloidal mixers, in compliance with the project specification.

Structural Systems' remit, delivered under the vigilance of the RTA, included the supply of BBR post-tensioning kits, shop drawings related to the post-tensioning works, designing the anti-burst and splitting reinforcement, plus installation, stressing and grouting works.

## COMPLEMENTARY EXPERIENCE

The Al Qudra Bridge project, which consumed a substantial 800 t of PT strand, is the largest bridge project completed to date by Structural Systems in the Middle East region. With Structural Systems currently undertaking the post-tensioning works on the significant Nad Al Sheba Bridge project, also for the Dubai RTA, it is clear that infrastructure demand and BBR presence are both growing in the Gulf. ●

### TEAM & TECHNOLOGY

**OWNER**
Roads & Transport Authority (RTA), Dubai

**MAIN CONTRACTOR**
Wade Adams Contracting LLC

**CONSULTANT**
Wilbur Smith Associates & Alturath Engineering Consultants

**TECHNOLOGY**
BBR VT CONA CMI internal

**BBR NETWORK MEMBER** NASA Structural Systems LLC (United Arab Emirates)

BRIDGES IN RIGA, LATVIA

# Latvian continuation

**Günter Damoser from BBR Network member VORSPANN-TECHNIK provides an overview of two major bridge construction schemes in the Baltic.**

The Riga South II Project consists of various bridges and overpasses on a junction formed by the new transversal road from the central districts of Riga to the South West. This continues on in a direct line from the newly constructed bridge over the River Daugava (Riga South I Project).

The bridges are all being built as prestressed concrete bridges on conventional shoring, post-tensioned with BBR VT CONA CMI 1906 tendons. Tendon layout is being performed in the usual way – with a construction joint between two regular construction sections, about half of the tendons ('A' tendons) are coupled with fixed couplers whereas the other half of the tendons ('B' tendons) are continued without couplings into the next construction section. In the next construction joint, the 'B' tendons are coupled. In a few cases, movable couplers are used to guide tendons into the next construction section. The transversal beams are also post-tensioned.

Meanwhile, the Vairoga Bridge Project is a typical multi-lane railway overpass, consisting of two adjacent 506 m long bridge structures. They are being built concurrently on conventional shoring and post-tensioned longitudinally with BBR VT CONA CMI 1906 tendons. Lengthwise, four spans each form a continuous deck system, separated from the next by a road joint.

Several years ago, VT began to promote and implement post-tensioning systems in Latvian projects and, with these bridges, we were able to successfully continue that relationship. ●

### TEAM & TECHNOLOGY
**(Riga South II Project/Vairoga Bridge)**

**OWNER OF BOTH PROJECTS**
Construction Department, City of Riga

**MAIN CONTRACTORS**
Latvijas Tilti / Latvijas Tilti and Tilts

**DESIGNERS** Celuprojects with Vektors-T and Giprostroymost / Tiltprojects

**TECHNOLOGY** BBR VT CONA CMI internal

**BBR NETWORK MEMBER**
VORSPANN-TECHNIK GmbH & Co. KG (Austria)

This bridge project is located on the Shatt Al-Arab river at the town of Al-Dair, some 40 km north of Basrah city. When completed, the bridge will connect the communities on either side of the river and provide a direct link to the Iranian border. Safwan Ani of BBR Network member **SPC** describes the early stages of construction work.

AL-DAIR BRIDGE, BASRAH GOVERNATE, IRAQ

# Community connection

The bridge is made up of 13 spans – each span 36 m long, with five girders to be installed on each span and the total bridge width is 15 m.
SPC is constructing the girders and our responsibilities include submitting the prestressing design calculation, bending and assembling the reinforcement cage on the casting bed, installing the prestressing ducts and anchorages, fixing the side forms, casting the girder, prestressing the tendons to the required force in two stages and grouting the ducts.
Each girder will have five BBR CONA 1006 tendons and the anchor heads will be BBR CONA 1206. All design and expected elongation calculations were carried out by BBR Headquarters in Switzerland.

**TEAM & TECHNOLOGY**
**OWNER** State Corporation for Roads and Bridges
**MAIN CONTRACTORS** Abdullah A. Al-Jiburi Contracting Company
**PRESTRESSING & GIRDER FABRICATION** Specialized Prestressing Company
**TECHNOLOGY** BBR CONA internal
**BBR NETWORK MEMBER** Specialized Prestressing Co (Iraq)

# NETWORKING IN NORWAY

One of three important new crossings associated with the E6 highway widening project is at Kolomoen – between Oslo and the 1994 Olympic resort of Lillehammer. The new bridge here will take traffic over the E6 at this intersection between the E6 and the R3, approximately 150 km north of Oslo. The crossing is well-known from traffic news reports on the radio – because there are often long queues!

MOTORWAY INTERSECTION BRIDGE, KOLOMOEN, NORWAY

The Norwegian Roads Department decided that the three new crossings – under construction as part of the project to widen the E6 from two to four lanes – should have a special design. The cable-stayed bridge at Kolomoen features a deck which is carried by 12 front stays, 12 back stays and four cross stays. The bridge deck itself is made of light-weight concrete and is 30 cm thick, except for the edge beam, where the thickness is 50 cm.

### PYLON INSTALLATION

The pylons are 30 m high and shaped like an equilateral triangle. They lean outwards from the bridge and there is no inter-connection between the pylons.

Purpose-made fixed BBR VT TOBE pot bearings were used as flexible supports under each pylon. The pot bearings were designed with a pin-and-bucket guiding device on top of the bearing to simplify the positioning of the pylons during installation.

Temporary support was provided by BBR VT CONA CMI single prestressing cables which were used to keep the pylons in position during installation and stressing of the stay cables. Spennteknikk performed all of the PT work, delivery and installation of the stay cables and delivery of the other purpose-made steel components – which were produced in our factory.

# Technical insight:
## BBR VT TOBE pot bearings

Bearings are provided to allow structures – such as bridges, offshore installations and large buildings – to expand and contract, as well as transfer the loads from the superstructure to the substructure. There are two types of bearings commonly used – neoprene (elastomeric) bearings with or without sliding pad, and pot bearings such as BBR VT TOBE pot bearings.
Neoprene bearings are more desirable for their simplicity of installation and maintenance-free performance. However, both load bearing and movement capacity limit the application of neoprene bearings to short spans and distances between expansion joints.

### POT BEARINGS

Pot bearings are available for large loads and movements and are therefore the type of bearing most frequently used. Pot bearings consist of a base plate containing a rubber cushion inside a low cylinder or ring which allows a small rotation in the base plate. The top plate rests on a piston which, in turn, rests on the rubber cushion inside the cylinder. Since this rubber disc is under high pressure, a seal is required to prevent the rubber from squeezing out of the 'pot'. The top plate can have one of three arrangements either allowing or preventing movement – fixed, free (multidirectional) or guided (unidirectional). Bearings must be installed by qualified personnel, such as the members of the BBR Network.

### BBR VT TOBE POT BEARINGS

The BBR VT TOBE pot bearing family consists of three types – Type F, fixed, type A, multidirectional and type E, unidirectional. Standard bearings cover vertical loads ranging from 520 to 33,400 kN and horizontal forces from 0 to 3,260 kN. They are designed to a rotation/tilt angle of ±20 per mille and movement capacities of ±50 mm and ±100 mm respectively. In addition, guided bearings can accomplish lateral movements of ±20 mm. All models undergo a high quality surface treatment including sandblasting, zinc/aluminum spraying and epoxy sealing as well as painting. Naturally, BBR VT TOBE pot bearings can be customized for considerably larger loads and movement capacities, as well as different surface treatments upon request. All models are designed to European Norm EN-1337-5 specifications and carry the CE-mark. BBR VT TOBE pot bearings stand out for their high capacity, low friction coefficient, low structural height, simple and safe assembly and short delivery time.

BRIDGES

### NETWORK SUPPORT

During installation, we were assisted by the other companies in the Spennteknikk International group. Meanwhile, other BBR Network members provided support for our project – VORSPANN-TECHNIK assisted with jacks, while BBR Polska assisted with experienced staff and self-designed stressing equipment for installation of the stays.

**BBR VT CONA CMI – 3106-140-1860**
17 t, 15 cables in counter weight foundation

**BBR VT CONA CMI – 1906-140-1860**
10 t, 8 cables in the lateral axis on bridge deck

**BBR VT TOBE pot bearings**
- 2 x BBR VT TOBE, type 110 F special, for pylon supports
- 4 x BBR VT TOBE, type 30 F, for pendulum supports
- 2 x BBR VT TOBE, type A and E

**TEAM & TECHNOLOGY**

**OWNER** Statens Vegvesen
**MAIN CONTRACTOR** Hæhre Entreprenør AS
**CONSULTANT** Johs. Holt AS
**TECHNOLOGY** BBR VT CONA CMI internal
BBR VT TOBE pot bearing
Stay cable
**BBR NETWORK MEMBER**
KB Spennteknikk AS (Norway)

# Major bridge CONSTRUCTION

## in mining subsidence area

**TEAM & TECHNOLOGY**

**CLIENT**
Federal Republic of Germany, represented by DEGES Deutsche Einheit Fernstraßenplanungs- und –bau GmbH, Berlin

**MAIN CONTRACTOR**
Gerdum u. Breuer Bauunternehmen GmbH, Fuldabrück, Germany

**CONSTRUCTION PLANNER**
Gerdum u. Breuer Bauunternehmen GmbH, Fuldabrück, Germany

**INSPECTING ENGINEER**
KHP, König & Heunisch Planungsgesellschaft, Leipzig, Germany

**TECHNOLOGY**
BBR VT CONA CMI internal
BBR VT CONA CMB band

**BBR NETWORK MEMBER**
VORSPANN-TECHNIK GmbH (Germany)

1

2

3

4

5

**The Friedetal Bridge crosses through a former potash mining area and thus represents an engineering challenge, reports Dipl.-Ing. Thomas Weber of VORSPANN-TECHNIK who delivered a complete prestressing system for this exceptional project.**

The Friedetal Bridge is one of two major bridges in the still missing section of the A38 Südharzautobahn between Halle and Göttingen, Germany. The A38 is part of 'Verkehrsprojekt Deutsche Einheit Nr.13' – *see, page 57, CONNAECT 2009 for more about these projects*). It begins at the motorway triangle Drammetal, south of Göttingen, is routed through the Halle / Leipzig area, where it intersects with the A9 motorway and terminates in the A14 near Parthenaue. The A38 is intended to relieve the traffic burden on the A2 which lies a bit further to the north and – together with the A7 between Drammetal and Kassel, as well as the A44 south of Kassel – to provide an additional connection between the Halle / Leipzig area and the Ruhr region. With span lengths of 45 m, 65 m, 90 m, 85 m and 35 m in the end spans and 165 m in the main span, the Friedetal Bridge attains a total length of 485 m. The height above ground is about 30 m. The A38 crosses the Friedetal valley on two separate superstructures, each of which is built from single-cell reinforced concrete hollow caissons. The hollow caisson cross-section attains its greatest height, 8.50 m, at axes 40 and 50. Between these two axes, as well as in the end spans, the superstructure height is reduced to 3.5 m.

The bridge is being built with both cantilever construction, as well as with conventional support structure techniques. The cantilever construction begins at axes 40 and 50 and each consists of 15 construction segments per axis. A total of four cantilever form travelers have been employed to reduce construction time. This makes it possible to work on both axes simultaneously. The fabrication of falsework sections is accomplished in parallel with work on the cantilever. BBR VT CONA CMI 1906 prestressing elements are being used for internal prestressing. The longest prestressing elements in the course of cantilever construction have a length of 154 m. Overall, the construction will consume 530 t of prestressing steel and 740 anchors. It was decided to use reinforced jacket tubes exclusively, because almost all prestressing elements will be enclosed in concrete.

Once the gap is closed, the external prestressing elements can be installed. This application employs BBR VT CONA CMB 4x04 band prestressing elements. The differing cross-section heights, as well as varying span lengths, made selecting prestressing element guidance a special challenge – which on the one hand is able to meet the static demands and, on the other hand, does not produce geometric collision points. There are 20 prestressing elements in each superstructure – the largest of these are 220 m long. The total tonnage of external prestressing amounts to 140 t.

**PHOTO CAPTIONS**

Main Picture: View from axis 60 in the direction of axis 10, south superstructure finished, north superstructure under construction.
Inset (main picture): Progress of cantilever construction outward from axis 40, cantilever forming traveler in construction segment 13.
Picture 1: View of 'hammer head' at axis 40.
Picture 2: External prestressing elements at axis 50, already tensioned.
Picture 3: External prestressing elements, axis 50 in the background, in the foreground, anchoring pilaster for prestressing elements traversing the main span between axis 40 and 50.
Picture 4: View of the bridge in the direction of axis 10.
Picture 5: View from the crane at axis 50 in the direction of axis 10.

Pictures 1, 4 & 5, courtesy of Gerdum u. Breuer

SEREDENG RIVER BRIDGE, SARAWAK, MALAYSIA

TALBRÜCKE ESELBRUCH, GERMANY

## Enhancing trade and tourism

**The new B480n Talbrücke Eselbruch is currently the largest road construction project being undertaken by the regional roads authority in Hochsauerland – a popular tourist destination – in the German province of Nordrhein-Westfalen. The project is a 3.75 km local avoidance scheme featuring a total of six bridges and a tunnel, near Olsberg, and will be completed – with the help of BBR Network member Spankern – in summer 2010.**

This new route for national traffic will enhance internal development in the Hochsauerland region, as well as its accessibility for tourism and leisure. The Talbrücke Eselbruch bridge has spans of 27.50, 39.00, 39.00 and 27.05 m and a total length of 133 m. The bridge was cast in situ as a double-webbed T-beam in two sections. The construction height is 1.72 m. Originally, after initial calculations, 15 post-tensioning tendons were envisaged, however, so much post-tensioning could not be accommodated in such a small cross-section. So, two longitudinal beams were designed and eight BBR VT CONA CMI 2206 tendons were installed in every span.

**TEAM & TECHNOLOGY**

**OWNER** StraßenNRW

**MAIN CONTRACTOR** Alpine Bau Deutschland AG

**DESIGNER** GMG Ingenieurgesellschaft, Dresden

**TECHNOLOGY** BBR VT CONA CMI internal

**BBR NETWORK MEMBER** Spankern GmbH (Germany)

# TEMPORARY FIXITY

**BBR Construction Systems (Malaysia) Sdn Bhd was awarded a con-tract to construct a prestressed concrete box girder bridge over the Seredeng River, near Sibu. The bridge, which will give road access between Tanjung Manis Port and internal areas, consists of a 165 m main span and two 95 m side spans.**

The cast in-situ balanced cantilever segmental method has been adopted, whereby one segment is cast at a time on form travelers to the left and right of the pier, inducing unbalanced moments to the pier. Due to the short piers, they are relatively stiff, therefore the bridge is not monolithically fixed to the piers – but has instead been designed to sit on pot bearings to release any restrained axial forces generated by creep, shrinkage and temperature.

The deck must not be allowed to transfer moments to the pier during or after construction. As the deck is not connected to the pier during construction, the two cantilevering deck segments from each pier need to be stabilized. Our temporary fixity system involves temporary installation of post-tensioning to attach the deck to the pier. When the cantilever sections from the two piers have been stitched at the midspan closure pour, the bridge becomes continuous and the fixity system is then removed.

A strut-and-tie system is being used to stabilize the bridge during the balanced cantilever construction stages. Steel struts are placed 10 m apart on pilecaps and propped against the deck at the web locations to provide an effective lever arm for the systems to resist unbalanced moments during construction. Vertical tie-downs – utilizing BBR CONA 1906 tendons – prevent the bridge from being raised off the steel struts under all load combinations. Each tie-down has 19 15.24 mm diameter strands – with the dead end anchored in the pilecap, while the other end goes through the web and protrudes on top of the deck. Each tendon is stressed to 70% UTS using a 480 t multijack to hold the deck on the pilecap. Two permanent pot bearings are installed on top of each pier. Ten 600 t capacity temporary sand jacks – designed, manufactured and tested by the BBR team – are installed on top of the pier to protect the bridge pot bearings from overloading and excessive rotation during construction.

Upon completion of the balanced cantilever construction, the sand is released gradually from the jacks, transferring the weight of the bridge onto the mechanical pot bearings. The combination of prestress tie-down tendons and steel struts, serves the vital function of stabilizing the bridge during construction. ●

**TEAM & TECHNOLOGY**
**OWNER** Public Works Department, Sarawak
**MAIN CONTRACTOR** Inai Kiara Sdn Bhd
**TEMPORARY FIXITY DESIGNER** BBR Construction Systems (M) Sdn Bhd
**TECHNOLOGY** BBR CONA internal Balanced cantilever
**BBR NETWORK MEMBER** BBR Construction Systems (M) Sdn Bhd (Malaysia)

## Technical insight:
## Bridge construction methods

Cost-savings on concrete bridges are achieved partly through the construction method chosen which can reach up to 20% of total construction costs and partly through the structural system selected. Thus, the bridge construction method plays a significant role and should be considered during the preliminary design period, with the help of the BBR Network.
The construction method depends mainly on topography and influences bridge cross-section design as well as span. Basically, five major techniques are employed. In addition, a wide range of different or adapted methods are used.

### CONVENTIONAL FALSEWORK
Bridges of this type have a superstructure cross-section of solid or cellular construction. They are built on-site using formwork supported by temporary falsework. Formwork creates the shape of the concrete section and any internal voids or diaphragms.

### BALANCED CANTILEVER
With the cantilevering method, the superstructure of bridges is usually built from one or more piers. Normally, the structure advances from a short stub on top of a pier, symmetrically in segments to the mid-span or to an abutment – the load balancing method. The use of the cantilevering construction method, for medium and long span concrete bridges, is recommended – especially where it is difficult or impossible to erect scaffolding.

### ADVANCED SHORING
The advanced shoring method – or movable scaffold system – has been developed for multi-span bridges over difficult terrain or water where scaffolding would be expensive or not feasible at all. A launching girder moves forward on the bridge piers span-by-span. The method is highly adaptable for a wide range of spans and types of superstructure, and it can handle cast in-situ concrete, as well as prefabricated elements.

### LAUNCHING
The incremental launching method is particularly suited to the construction of continuous post-tensioned multi-span bridges. It involves casting 15 m to 30 m long sections of the bridge superstructure in a stationary formwork behind an abutment and pushing a completed section forward with jacks along the bridge axis. The sections are cast contiguously and then stressed together. The superstructure is launched over temporary sliding bearings on the piers. In order to keep the bending moment low in the superstructure during construction, a launching nose is attached to the front of the bridge deck.

### HEAVY LIFTING
Heavy lifting is a hydraulic lifting technique especially developed for extremely heavy loads and usually applied for the lifting of precast segmental superstructure members. Span-by-span bridges provide a very high speed of construction and are most often constructed using an erection truss under the segments or an overhead erection gantry.

The BBR Network has a proven record – in all construction techniques – for all construction stages from preliminary design through to final execution. BBR Network members all over the world maintain a specialized bridge construction equipment fleet for any type of bridge design.

FREIMANN VIADUCT, A9 MOTORWAY, BAVARIA, GERMANY

# Rebirth of the Tatzelwurm

The Tatzelwurm served its purpose at the northern end of Munich for almost 50 years and now a complex dismantling and construction process is underway. Dipl.-Ing. Thomas Weber reports that his company, **VORSPANN-TECHNIK**, was awarded the contract for carrying out all prestressing work on the new support structure – and the new Tatzelwurm relies on BBR VT CONA CMI tendons.

The Freimann Viaduct is a part of the A9 Nuremberg-Munich federal motorway, located just north of the Bavarian capital, Munich – between the Allianz arena and the Highlight Towers. This viaduct is about 580 m long and, with a total of 20 sections, crosses over a number of transport routes – thus making it one of Munich's most important transport nodes. A bird's eye perspective, looking also at the eastern approach ramp east and western exit ramp, reveals why this bridge structure has been dubbed 'Tatzelwurm' – a snake-like mythical creature originally attributed to the Alpine foothills.

The Freimann Viaduct was originally built in the late 1950s. The peculiarity of this bridge was its single-piece superstructure formed from multi-cell, prestressed concrete, hollow caissons with prestressed longitudinal and traverse beams. Severe corrosion damage to prestressing and reinforcing steel meant that

replacement of the entire structure became unavoidable. In contrast to the original support structure, the new design is comprised of two separate bridge superstructures. In standard areas, these consist of two-rib prestressed concrete plate beams. In approach and exit ramp areas, the superstructure diverges into three and four rib plate beams.

The overhead launching girder technique was chosen by the project's general contractor, DYWIDAG Bau GmbH, because of the restricted construction space and the myriad of transport routes which cross the area. This type of construction utilizes a launching girder positioned above the bridge's superstructure. The complete formwork hangs on threaded rods from these main girders, this means that a crane cannot be used for the delivery of materials from above, as is typical for the underslung launching technique. Thus, special solutions had to be found for many construction stages.

The new structure uses BBR VT CONA CMI 1306, 1506 and 1906 prestressing elements. Prestressing element guidance differs in the various construction segments due to the different spacing of piers. About one third of the prestressing elements have to be run through each construction segment joint in order to comply with standards. All jacket tubes for prestressing elements were installed on site by VT and the prestressing steel strands were sealed. One peculiarity here was that the prestressing elements to be routed further were initially looped back into the current segment then, with the help of a lift mechanism, suspended beneath the overhead launching girder and subsequently pulled out to the front for installation in the next segment. ●

### PHOTO CAPTIONS

Top: Overhead launching girder. View from the east. Superstructure construction for Nuremberg-bound traffic lanes – Frankfurter Ring overpass.
Inset: View of the launching girder from the front. In the background – Highlight Towers, Munich.
Below: View of the completely reinforced superstructure segment just prior to pouring concrete – laterally looped-back prestressing elements.

### TEAM & TECHNOLOGY

**CLIENT** Federal Republic of Germany, represented by Autobahndirektion Südbayern

**MAIN CONTRACTOR**
DYWIDAG Bau GmbH, Nuremberg

**CONSTRUCTION PLANNER**
SRP Schneider & Partner Ingenieur-Consult GmbH, Kronach

**INSPECTING ENGINEER**
Prof. Dr. Konrad Zilch

**TECHNOLOGY** BBR VT CONA CMI internal

**BBR NETWORK MEMBER**
VORSPANN-TECHNIK GmbH (Germany)

# INCREASING retail accessibility

CAR PARK, SYLVIA PARK SHOPPING CENTRE, AUCKLAND, NEW ZEALAND

**BBR Contech** Northern Regional Manager, Keith Snow, reports on how this challenging project was configured and delivered, demonstrating the benefits of the owner, contractor and designer collaborating to produce an optimal solution that meets the requirements of all stakeholders. It also reinforces the international partnering between BBR Network Members in New Zealand and Australia to deliver high performance solutions and create local competitive advantages. ➔

> “Typically car park buildings do not consider quality, user experience or way finding as critical design issues. Kiwi Income Property Trust pays particular attention to every detail and considers car parks as important as the retail experience. The use of concrete, and in particular post-tensioned concrete slabs, allowed for clean clutter-free soffits that significantly improved user experience, quality and sightlines to exit points.
> It was realised during the design phase that post-tensioning would allow each level to be reduced by 200 mm having huge benefits for ramp gradients, resource consent and construction cost.”

**Euan MacKellar,** Sylvia Park Project Director, Jasmax / NH Architecture

The Sylvia Park Shopping Centre is located at the demographic and geographic heart of Auckland and boasts the broadest retail mix of any New Zealand shopping centre. The 24-hectare Sylvia Park is Kiwi Income Property Trust's flagship retail asset and the largest shopping centre in New Zealand. Its prominence, exceptional location and public transport links ensure easy access for shoppers.

The Centre was completed in 2007 and its immediate popularity soon led to a demand for extra car parking for the growing number of visitors.

## RECOGNIZING PT BENEFITS

The new Sylvia Park North Eastern Multi Storey Car Park comprises four levels constructed on top of an existing two-level car park with a total area of 20,000 m$^2$. It was built by Brookfield Multiplex who had extensive involvement in the overall development and construction of the original shopping centre. Brookfield Multiplex, through previous experience with post-tensioning, could see significant construction and delivery benefits to the owner – and enlisted the expertise of BBR Contech to propose an alternative post-tensioned solution.

## LOGISTICAL CHALLENGE

The car park building is bounded by the north retail mall, operational car parks and the main circulation ring road and Southern Rail Line. The owner required minimal disruption to customers during all phases of the construction. However the logistics of delivering and installing the originally specified 1,060 17 m long precast floor units was identified as a huge delivery risk for the construction timeframe specified. Furthermore, the original design also required large amounts of craneage and would have created significant construction traffic movements on Sylvia Park roads which are shared with the public. A different approach was therefore needed.

## COLLABORATIVE DESIGN

Although commonly used internationally, elevated post-tensioned floors have only recently come into use in New Zealand with typical construction usually taking the form of precast prestressed floor units. To ensure the best possible result, BBR Contech worked with Australian BBR Network partner Structural Systems and project design consultant Buller George Turkington to develop the alternative that met New Zealand seismic protection standards. The result is a post-tensioned elevated structure with band beams, created in 20 separate 1,000 m$^2$ pours.


## Technical Insight:
### Advantages of the post-tensioned solution

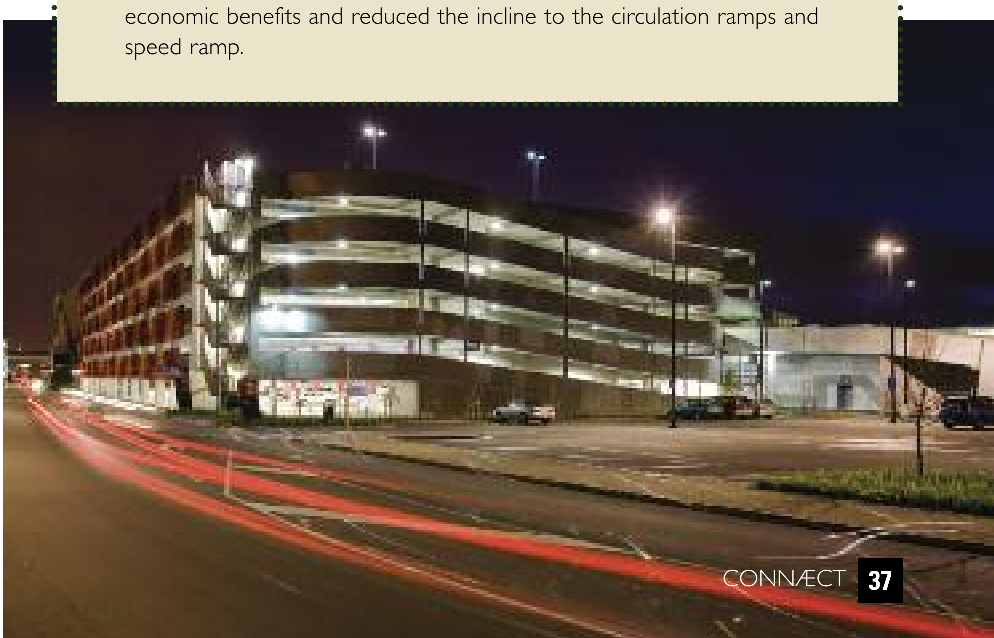
- No hogging or pre-camber from precast units with tolerances easier to achieve.
- Creation of a clean junction at the column / band beam connection giving a tidy and consistent 'off-the-form' finish.
- Elimination of seating issues associated with precast floor units.
- Large floor pours achievable (1,000 $m^2$ floor pours starting 2.00am – and finishing 7.00am before the shopping centre opens) allowing the program to be shortened.
- Integral soffit and band beam finish.
- Higher degree of slab integrity to minimize water ingress and lime leaching onto vehicles through minimizing slab cracking or hollow core units filling with water.
- Combines the crack minimization characteristics of post-tensioning with the application of a sealing additive into the mix design to provide water proofing to the top slab exposed to the elements.
- Elimination of eight columns per floor, compared to the original precast design – highlighting the flexibility of post-tensioning and insitu construction.
- An overall reduction in building height of 880 mm utilizing a post-tensioned solution, against the originally specified precast floor units. This had both economic benefits and reduced the incline to the circulation ramps and speed ramp.

**PT CONFIGURATION**

The post-tensioning configuration comprised BBR CONA flat 0405 and 0505 system with typical slab thickness of 150 mm between band beams. The overall floor depth was kept to a minimum by using band beams with an overall depth of only 580 mm. With clear spans approaching 17 m, this configuration has produced a clean, structurally effective and attractive building which has been integrated seamlessly into the existing shopping centre environment. The implementation of post-tensioning has seen a reduction in materials and resources whilst delivering an architectural look sympathetic to the surroundings. This all took place whilst ensuring minimal disruption to the ongoing retail operation and customers using Sylvia Park.

**TEAM & TECHNOLOGY**

**OWNER** Kiwi Income Property Trust
**MAIN CONTRACTOR** Brookfield Multiplex
**ARCHITECT**
Jasmax / NH Architecture
**STRUCTURAL ENGINEER**
Buller George Turkington
**STRUCTURAL PEER REVIEWER**
Holmes Consulting Group
**TECHNOLOGY** BBR CONA flat
**BBR NETWORK MEMBER**
BBR Contech (New Zealand) (construction)
Structural Systems Limited (Australia) (PT design)



# Record-breaking PT project

TOP RYDE SHOPPING CENTRE, SYDNEY, AUSTRALIA

**Chris Harris, from the BBR Network member in Australia, Structural Systems Limited, reports on the largest post-tensioning building project ever undertaken in Australia which was awarded to SSL by Bovis Lend Lease as part of an ongoing Strategic Procurement Alliance.**

Top Ryde Shopping Centre Redevelopment will be a 130,000 $m^2$ mixed use development, spread over nine floors. Stage 1 of the redevelopment is valued at over A$440 million and will consist of a 78,000 $m^2$ shopping centre and entertainment precinct. In Australia, post-tensioned concrete is used by all the major developers and owners for virtually all suspended shopping centre floors. Cast in-situ post-tensioned concrete provides unrivalled flexibility and economy for these floors.

Top Ryde includes about 1,600 t of post-tensioning for all the suspended floors. At the peak of the structure works, we installed, stressed and grouted over 170 t of post-tensioning in one month.

Most floors are one-way slabs supported by one-way slab band beams, supported by cast-in-situ structural concrete columns, lift and stair cores.

Structural Systems was awarded and is completing the entire post-tensioning subcontract – even though Bovis Lend Lease split most other structure trades and awarded them to multiple subcontractors.

Challenges included procuring materials, supervision and labour to handle a project of this size. Materials were sourced in advance and supervision and labour were drawn from within our own workforce. With experience of delivering post-tensioning for many shopping centres, Structural Systems is a reliable partner for delivering critical structure works to a tight program.

**TEAM & TECHNOLOGY**

**OWNER** Beville Group
**MAIN CONTRACTOR** Bovis Lend Lease
**DESIGNER** Arup
**TECHNOLOGY** BBR VT CONA CMI internal
BBR CONA flat
BBR CONA internal
**BBR NETWORK MEMBER**
Structural Systems Limited (Australia)

ROYAL CHILDREN'S HOSPITAL, MELBOURNE, AUSTRALIA

# MILESTONE IN HEALTHCARE

As one of the largest projects currently under construction in Australia and the State of Victoria's largest ever hospital redevelopment project, the new Royal Children's Hospital is a massive undertaking and a milestone project. Charles Edgar, Project Administrator for **Structural Systems Limited** outlines the scheme.

The new Royal Children's Hospital is being delivered as a Public Private Partnership (PPP) under the State Government's *Partnerships Victoria* model, with a private sector consortium, called Children's Health Partnership (CHP), responsible for building and maintaining it for 25 years while the Government owns and operates it. The CHP consortium comprises International Public Projects as equity holders, Bovis Lend Lease as builder, Spotless Group as facilities manager and architects Billard Leece, Bates Smart HKS (US) – who also utilize consulting engineers Irwinconsult. This building not only aims to provide state-of-the-art facilities but also aims to be Australia's greenest hospital whilst offering a child-focused healing environment set amongst engaging parklands with natural views.

Located next to the existing hospital in Parkville, Melbourne, the building consists of a seven level, 165,000 $m^2$ hospital and a three level 75,000 $m^2$ car park – with the value of this contract coming close to A$1 billion. The project is scheduled to be completed in two stages – completion of the first stage is due in late 2011 and the second in 2014.

Structural Systems began construction on site in August 2008 and, by completion, will have installed some 260 t of post-tensioned beams throughout the building, including several multi-strand transfer beams.

The BBR VT CONA CMI system was used for all multi-strand installations. Six 3106 anchorages were installed into two beams on the lower ground level. These beams were two meters deep and were required to span 25 meters. An additional ten 2206 anchorages were installed into five precast transfer beams on Level 2 which were precast in order to reduce the beam width and to eliminate the need for double-height formwork below.

We are looking forward to the upcoming challenges presented by this significant and exciting project.

**TEAM & TECHNOLOGY**

**OWNER**
Department of Human Services, Victoria
**MAIN CONTRACTOR** Bovis Lend Lease
**CONSULTANT** Irwinconsult
**TECHNOLOGY**
BBR VT CONA CMI internal
**BBR NETWORK MEMBER**
Structural Systems Limited (Australia)

# PT PROOF FOR PRINTER

PRINTING HOUSE, ZAGREB, CROATIA

**In just three weeks, BBR Adria built 16,000 m$^2$ of high performance vibration-free flooring for a high volume printing house. Damir Pavicic explains that the complete satisfaction of their client was their biggest motivation.**

At our first meeting with our client, we recognized that we were dealing with highly professional people who wanted the perfect conditions for their four printing machines – each weighing over 300 t and each costing much more than the complete warehouse construction project itself! They also needed the flexibility to be able to rearrange the machines and add new – and possibly even heavier – ones in the future. Furthermore, the machines create a significant amount of vibration so one must not interfere with another. Finally, the soil was very weak so the subcontractor improved it with jet grouting columns spaced at 2.5 or 4.0 m, depending on the purpose and loadings in the corresponding warehouse area.

## ORIGINAL PLAN

The original plan was to construct a 35 cm thick reinforced concrete slab on grade, with 120 cm deep separate foundation mats for each machine. The owner recognized that, for any future developments, this would mean cutting the slab to make additional foundations for new machines – inevitably interfering with production.

## OUR ALTERNATIVE SOLUTION

To stay within the budget, but – more importantly – to satisfy all the conditions, BBR Adria proposed a high performance, 40 cm thick post-tensioned slab on grade that rather resembles a foundation mat for 10+ storey building. The slab was designed as a flat slab on columns because of the poor soil conditions, plus jet grouting columns over which special reinforcement cages were installed in the slab. For our client, this solution was groundbreaking – this way, they could do whatever they wanted with the machines in future, without any adjustments to the flooring. The requirement for vibration-free conditions were also satisfied, as post-tensioning enables a much larger area of the slab (equal volume, equal mass) to be mobilized to counteract the vibrations, thus enabling a thinner slab.
Finally, post-tensioning removed all the joints and saved a lot of future maintenance costs.

## PROJECT DELIVERY

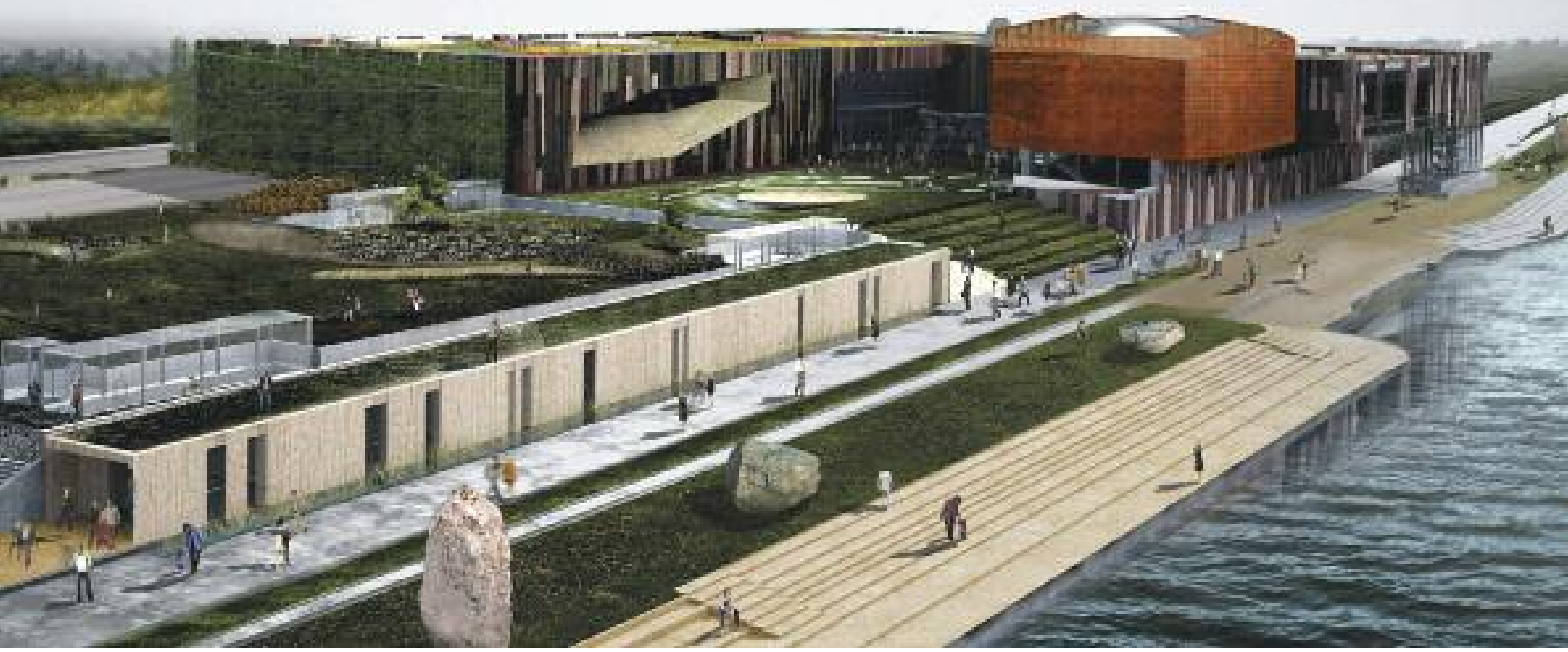
As the warehouse consisted of a production floor and a few storage areas for heavy paper rolls and other equipment, the 40 cm thick slab was designed to cover one third of the total area. Other areas were differently loaded with 50 and 80 kN/m$^2$. For these, 25 and 28 cm thick, respectively, post-tensioned slabs on grade were provided.
For the whole 16,000 m$^2$ of slab, material consumption was 4,900 m$^3$ of concrete, 70 t of prestressing steel strand and 230 t of passive reinforcement steel. In fact, the warehouse consisted of two separate parts that enabled all the works to be done simultaneously.
All 16,000 m$^2$ of the flooring was cast in 16 pours. They were all medium size pours, but executed day-by-day, along with the other works – with perfect organisation from the main contractor. It took us little over three weeks to take the project from finished sub-base to completely finished floor – at temperatures not much above zero degrees Celsius.
At the end of the day, BBR Adria provided around 12% savings in the material of the warehouse floor – and delivered exactly what the client needed. This project demonstrated the ultimate in flexibility, performance, economy and speed – exactly what flat slab post-tensioning is all about!

**TEAM & TECHNOLOGY**

**OWNER** Radin Aktiva (Zagreb, Croatia)
**MAIN CONTRACTOR** Zagorje Tehnobeton (Varazdin, Croatia)
**DESIGNER** AGH Studio (Zagreb, Croatia)
**TECHNOLOGY** BBR VT CONA CMM unbonded
**BBR NETWORK MEMBER** BBR Adria (Croatia)

"FOR OUR CLIENT, THIS SOLUTION WAS GROUNDBREAKING – THIS WAY, THEY COULD DO WHATEVER THEY WANTED WITH THE MACHINES IN FUTURE, WITHOUT ANY ADJUSTMENTS TO THE FLOORING."

# COPERNICUS SCIENCE CENTRE, WARSAW, POLAND



**Bartosz Lukijaniuk, M.Sc. and project manager for BBR Polska reports that the company recently took part in the construction of one of the most prestigious buildings in Warsaw – the Copernicus Science Centre. Along with the National Football Stadium, which is still under construction, the Centre is an extremely important investment in Warsaw – both for the people and government.**

The Copernicus Science Centre is named after the well-known Polish astronomer Mikolaj Kopernik (or in Latin *Nicolaus Copernicus*), who lived at the turn of 15th and 16th centuries and was the first to postulate heliocentric cosmology – which displaced the Earth from the centre of the universe. In his highly significant book, *On the Revolutions of the Celestial Spheres (De revolutionibus orbium coelestium)*, he proved that the Earth – no longer the centre of the universe – revolves around the Sun and today, it is still accepted that the Sun is the centre of the universe.

The Copernicus Science Centre will be soon open on the left bank of the Vistula River in the centre of Warsaw, 10 minutes' walk from the Old Town. It will be one of the first institutions of its type in Poland. It includes interactive exhibits where everyone can carry out experiments or demonstrations and learn about science (for more information please refer to www.kopernik.org.pl).

## PROJECT & SCOPE

The Centre will be a two storey building, with an area of 15,000 $m^2$ which will contain exhibition halls, laboratories, conference halls, a café and offices. Parking places, studios and workshops will be located underground. The planetarium, in a shape of a meteor, will form the multimedia part of the Centre. The whole building will be surrounded with the 'Explorers' Park', where visitors will have an opportunity to discover science in the open air.

BBR Polska's scope of work included comprehensive execution of post-tensioning, covering the installation of 68 BBR VT CONA CMI 1906 tendons – or, put another way, 72 t of stressing steel in 18 post-tensioned beams.

## WEIGHTY ISSUES

The designers sited the main part of the building over the existing road tunnel which contains one of Warsaw's major highways and runs parallel to the river. The tunnel leads under the access road to Swietokrzyski bridge – where BBR stay cables are installed – and facilitates easy access to the bridge. The tunnel was not designed to sustain the loads generated by such a large building, so the designers needed to come up with a way of protecting the tunnel. Their solution was to transfer the loads from the new building to a concrete wall constructed outside of the tunnel structure. This was achieved with a set of post-tensioned beams – the minimum distance between the tunnel and the beams is only around 5 cm.

## CREATIVE PT SOLUTION

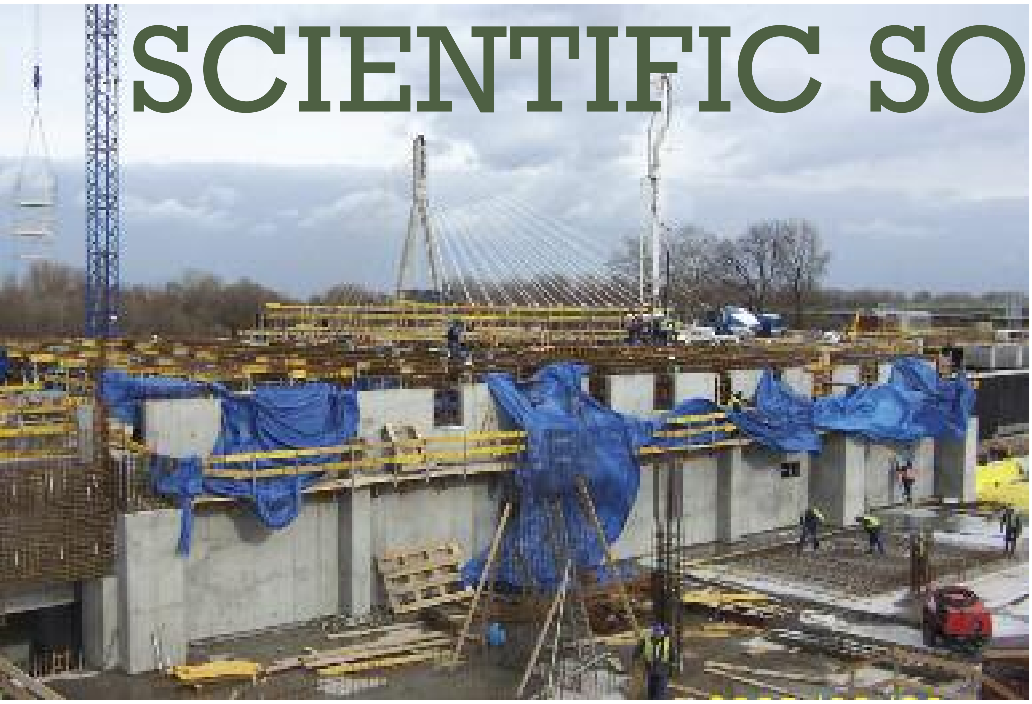
As a result of the designers' idea, the PT platform was created – a set of 16 post-tensioned beams (height 1.6 m, width 0.7 m, spaced every 3.5 m, length approximately 47.5 m) joined by concrete beams and slab. Each beam was stressed with four BBR VT CONA CMI 1906 tendons. Each tendon was equipped with one live end and one fixed end inaccessible anchorage.

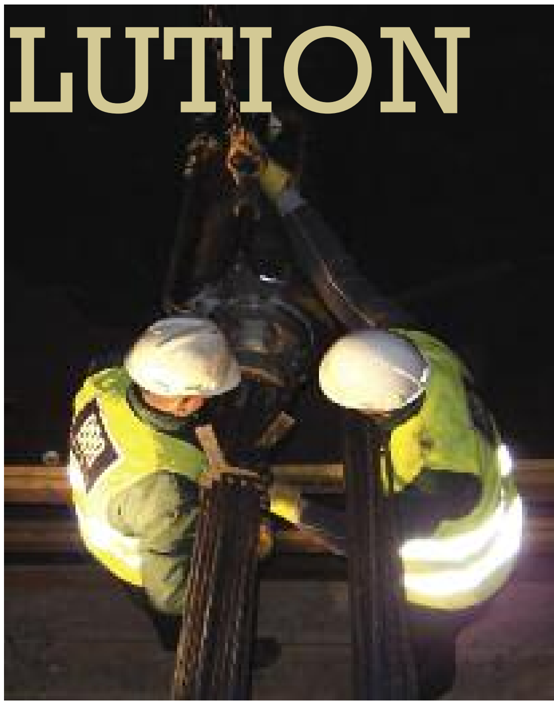
Additionally, two PT beams (height 1.3 m, width 0.7 m, length approximately 32 m) were designed to transfer the load from the building to the columns of the underground car park. Each beam was stressed and equipped as described above.

## PT INSTALLATION

The main contractor was Warbud S.A., one of the largest construction contractors in Poland. Good co-operation with the contractor resulted in a problem-free delivery of the post-tensioning works.

# SCIENTIFIC SOLUTION





Because the designer decided to use inaccessible anchorages, all strands were installed before the beams were concreted. The PT platform was divided into four sections with four post-tensioned beams in each. The slab was concreted after the beams. Each beam is supported on four walls – two at the ends and two located about five meters from the ends. Tendon layout was therefore designed as a parabolic curve and three vents were installed at the two highest points and at the lowest point, between anchorages – in addition to the two vents actually at the anchorages. The two additional beams were concreted later, as they were in a different location.

## STRESSING & GROUTING

The stressing sequence for the PT platform assumed that the tendons were stressed in two stages. During the first stage, one half of the tendons were stressed to total design force and in the second stage, the remainder were stressed likewise. The two additional PT beams above the car park were stressed in one stage.

Grouting was carried out just after stressing operations had finished – we performed three grouting operations after the three stressing sessions.

Thanks to BBR's outstanding PT technology and professional team, the Copernicus Science Centre building can stand above the tunnel. Even Copernicus himself would have approved of the innovative thinking and practice applied to this iconic building which bears his name.

### TEAM & TECHNOLOGY

**OWNER** Warsaw City Council

**MAIN CONTRACTOR** Warbud S.A.

**ARCHITECT**
RAr-2 Laboratorium Archiketrury Gilner + Kubec

**STRUCTURAL DESIGNER**
Buro Happold Polska Sp. z o.o.

**TECHNOLOGY**
BBR VT CONA CMI internal

**BBR NETWORK MEMBER**
BBR Polska Sp. z o.o. (Poland)

ST DAVID'S CENTRE CAR PARK, CARDIFF, UK

# Greener parking

**Richard Gaskill of Structural Systems – the BBR Network member in the UK – explains that significantly more additional parking was required to service the St David's 2 development in Cardiff which led to the construction of a five level, multi storey car park, totaling in excess of 50,000 m². This gives the new centre a total of 3,000 parking spaces and the drama of the development is heightened by the particularly striking elliptical ramp access to the car park.**

As part of the regeneration of Cardiff city centre, the new St David's 2 scheme represents a £675 million investment, totaling 89,891 m² of retail-led mixed-use development, with over 100 stores and 300 luxury roof top apartments, built as seven towers above the shopping centre.

The size of the floor plate meant that each level was typically constructed as seven pours. The frame contractor elected to utilize a slab and beam configuration. Structural Systems supplied the BBR CONA flat 0305 post-tensioning system for the reinforced deck slabs and a BBR CONA flat 0605 system for the 525 mm x 16 m span beams. The car park sits on a transfer slab at level three and is tied to a stair core in the centre of the building. By introducing post-tensioning techniques, the slab depth for the car park was reduced to typically 150 mm – permissibly the thinnest depth for a car park slab – with some areas at 175 mm and nominally 300 mm thick. The beam tendons were mainly 36 m long, although in some instances 56 m long double end stressed tendons were used.

> "USING POST-TENSIONING HAD MASSIVE ENVIRONMENTAL BENEFITS OVER TRADITIONAL REINFORCED CONCRETE AND STEEL STRUCTURES, WHICH WAS IMPORTANT FOR SUCH A LARGE PROJECT."

The construction phase went smoothly, even though there were areas of complexity demanding a close interface between the post-tensioning designers and the services engineer who required multiple penetrations through the post-tensioned beams. Clear and detailed communication was maintained with the contractor throughout the project, from design to completion on site.

The quick erection of the formwork system, in conjunction with the efficient pour sequence offered by the Structural Systems team, enabled the contractor to complete the frame in 27 weeks.

Using post-tensioning had massive environmental benefits over traditional reinforced concrete and steel structures, which was important for such a large project. The use of post-tensioning reduced slab depths significantly so that, overall, less concrete and substantially less rebar was used – which was extremely beneficial to the client in terms of program and budget.

**TEAM & TECHNOLOGY**

**OWNER** St David's Partnership
**MAIN CONTRACTOR** Skanska Construction
**CONCRETE FRAME CONTRACTOR** P.C. Harrington Contractors Limited
**DESIGNER** Arup / Structural Systems (UK) Ltd
**TECHNOLOGY** BBR CONA flat
**BBR NETWORK MEMBER** Structural Systems (UK) Ltd

**Sean Doherty, Manager for Qatar and Bahrain, for BBR Network member NASA Structural Systems gives an overview of the first project successfully completed since his company established a permanent base in Doha, the capital of Qatar.**

QATAR AIRWAYS 4-STAR HOTEL, DOHA, QATAR

# Checking in ON TIME

Qatar Airways is developing a new 4-star, 400-bedroom hotel, near their base at Doha Airport. The hotel will also offer retail shops, restaurants, meeting rooms, a business centre, health club and swimming pool.

The project covers a total area of approximately 45,000 m², including a basement level, ground floor and level 1 podiums, in addition to two six-storey towers. The main contractor, Gulf Contracting Company (GCC), appointed us to design, supply and install post-tensioning – from the ground floor to roof level.

The ground floor and level 1 podium levels were each broken into ten pours, with each pour separated by a combination of expansion joints and / or delayed pour strips. A post-tensioned band beam and slab solution was adopted for these lower levels due to the magnitude of the loadings specified, the need to transfer the swimming pool loads along with several transfer columns supporting the tower levels above, and the presence of significant spans – often upwards of 14 m – between supports.

The PT slabs were generally 200 to 250 mm deep and band beams ranged between 400 to 800 mm deep, with transfer beams thickened to upwards of 1,800 mm deep.

On level 2, a PT band beam and slab solution was adopted to transfer load from the blade walls supporting the majority of the upper floors to the columns below.

The typical levels for both towers consisted of 250 mm deep PT flat plates, spanning between the blade walls that transferred at level 2.

The main contractor's construction program dictated a six month period for the design and installation of 225 t of post-tensioning and for pouring 23,000 m³ of concrete. Working 24-hours-a-day and using the BBR CONA flat PT system, the post-tensioning works were completed on program – and thus the contractor's key milestone date was achieved.

**TEAM & TECHNOLOGY**

**OWNER** Qatar Airways

**MAIN CONTRACTOR** Gulf Contracting Co. WLL

**CONSULTANT** GHD Global Pty Ltd

**TECHNOLOGY** BBR CONA flat

**BBR NETWORK MEMBER** NASA Structural Systems LLC (United Arab Emirates)

AJMAN ONE
– PHASE 1, UAE

# Towering challenge

**The US$730 million Ajman One mixed-use development project is currently the largest building project BBR Network member Structural Systems has undertaken since setting up operations in the Middle East in 1997. Warwick Ironmonger, General Manager of Structural Systems' Middle East operations and Jeff Flynn, Operations Manager for Buildings for NASA Structural Systems LLC, give an overview of the project and the challenges presented by this important fast-track project.**

Ajman One will be a world class residential, commercial and hospitality complex. When complete, the 12 towers will consist of 3,000 (1, 2 and 3-bedroom) apartments, housing up to 6,000 residents and setting new trends for contemporary design. Ajman One will combine all the needs of a modern business lifestyle – a one-stop destination offering shopping, leisure, residential, business and hotel facilities within a single development.

## ECONOMIC SOLUTION

The top podium level and all the 28 / 34 storey tower floors were proposed, by the Consultant, to be post-tensioned flat plates – to speed up the construction program and serve as an economical solution to the slab spans in excess of 10 m.

Having proven their professionalism and dedication to the main contractor Al Zamalek General Contracting LLC, via successful completion of the post-tensioning works for them on over 20 towers in Ajman, NASA Structural Systems LLC was appointed to take on the challenge of the design, supply, supervision and installation of 2,500 t of post-tensioning for the 500,000 m$^2$ associated with the podium level and 12 towers that make up the first phase of Ajman One.

Bonded BBR CONA flat post-tensioning tendons – both five strand and three strand – were incorporated into the design of the podium and tower levels, where careful detailing was employed to deal with the particular constraints of the various structural elements.

## CONSTRUCTION DETAILING

Structural Systems detailed the typical tower floors supporting brittle masonry partitions within the 270 mm slab depth – nominated by the Consultant in order to control deflections within the 10 m spans. However, for the top podium level, it was decided to construct 300 mm thick flat slabs with drop panels – 450 mm deep x 3,000 mm square – as a means of dealing with the 'punching' shear, at slab / column interfaces, created by the unusually high landscaping loads.

Structural Systems considered it prudent to detail a bottom mesh of conventional reinforcement to deal with shrinkage concerns, given the unusually high degree of restraint to shortening provided by the significant core and shear walls, combined with the large pour lengths which exceeded 50 m. A 28-day delayed reinforced pour strip was employed for the central podium area – effectively breaking this 72 m long zone into two or three zones during construction – to provide suitable stressing access for the slab tendons and minimize slab shortening, as well as resulting moments in the support columns.

## RISING TO THE CHALLENGE

Nearly 225 t of strand was required for the 22 pours to the podium level alone, which covered almost 43,700 m$^2$. This, combined with the need to construct the 12 towers simultaneously, provided Structural Systems with quite a challenge if they were to meet the main contractor's daunting construction program milestones.

Rising to the challenge, installation of the 6.5 t and 10 t in the typical and podium pours was generally achieved within 12 hours and 24 hours, respectively – and between 200 and 240 t of 12.7 mm diameter strand was routinely installed, stressed and grouted each month. Quite an achievement for the Structural Systems team!

The use of post-tensioning on this project not only allowed the set milestones to be achieved, but also gave the main contractor the added advantage of being able to remove the formwork within only four days of casting the slabs.

**TEAM & TECHNOLOGY**

**OWNER** Aqaar Properties LLC
**MAIN CONTRACTOR** Al Zamalek General Contracting LLC
**DESIGNER** National Engineering Bureau (NEB)
**TECHNOLOGY** BBR CONA flat
**BBR NETWORK MEMBER** NASA Structural Systems LLC (UAE)



INTEGRATED HOME, TRANSPORT & RETAIL DEVELOPMENTS, SINGAPORE

# Integrating transport

As a city state, Singapore is the second most densely populated country in the world. Today, roads take up 12 percent of our total land area and the demands on our land transport system are set to increase by 60 percent, from our current 8.9 million daily journeys to 14.3 million by 2020. Making public transport the centre-piece of our land transport system will be crucial to keep congestion in check and help protect the environment, observes Lee Chong Whey of **BBR Construction Systems.**

In order to make public transport more convenient, the Singapore Government decided to do more to integrate the bus interchange and Mass Rapid Train (MRT) stations – and even turn them into lifestyle hubs, together with shopping malls. Currently, three such integrated developments are operational – the Ang Mo Kio, Toa Payoh and the Sengkang Interchange. Two more are being constructed at Boon Lay and Clementi. BBR Construction Systems is currently involved in the Clementi Interchange which is targeted for completion by mid-2010. BBR Construction Systems was also involved in the development of Sengkang Square in 2002 and, in 2007, the rebuilding of the AMK Hub.

By mid-2010, the site at Clementi Town Centre which is occupied by the existing bus interchange will be re-developed into a modern 40-storey complex with an integral new air-conditioned bus terminal, a 25,000 m$^2$ shopping mall and residential tower blocks consisting of 388 units. This project will rejuvenate the Clementi Town Centre into a modern hub and forms part of the overall estate renewal strategy together with the National University of Singapore nearby. Post-tensioned beams and precast slabs were provided at the podium levels to achieve the greater clearance span required to accommodate the turning radius of buses at first storey level. The beam span varies from 25 m to 30 m clear and supports various types of loading depending on their usage. In order to maximize the capacity / self-weight ratio, all beams are designed individually, based on their length and also the applied load – as well as the sizes of the BBR CONA castings and anchorages to be used.

The post-tensioned beams are designed to Class 1 structure (BS8110, 1997) specification in order to provide flexibility – allowing the owner to convert the usage of the floor area when necessary. Due to the limitations imposed by beam size and the high applied forces of a Class 1 structure, 'stage stressing' is required for all beams.

### PHOTO CAPTIONS

*Top Left: AMK Hub – integrating bus terminal and retail mall under one roof, directly opposite is an underground pass connecting it to the Ang Mo Kio MRT station.*
*Top Right: Clementi Town Centre – Singapore's latest integrated transport and lifestyle hub is under construction with the help of BBR Construction Systems.*
*Bottom Left: Sengkang Square – Singapore's first integrated transport and lifestyle hub, integrating bus terminal, MRT station, LRT station, shopping mall and a condominium.*

### TEAM & TECHNOLOGY

**OWNER** Land Transport Authority (LTA) / Housing And Development Board (HDB)
**MAIN CONTRACTOR** China Construction (South Pacific) Development Co. Pte. Ltd
**C&S CONSULTANT** Surbana International Consultants Pte. Ltd
**TECHNOLOGY** BBR CONA internal
**BBR NETWORK MEMBER** BBR Construction Systems Pte. Ltd. (Singapore)

MAGIC BOX ATHLETIC COMPLEX, MADRID, SPAIN

## Tricks of the trade

The Magic Box is situated in Madrid, the capital of Spain. **BBR PTE's** David Olivares Latorre reports that it is an enormous box made of concrete and steel with three mobile roof covers that can be opened or closed, depending on the event taking place inside – and the weather conditions!

The Magic Box is an 82,520 $m^2$ complex containing three tennis courts – the Main court has seating for 12,000 people, the Opera court accommodates 3,200 and Circo court 2,700 people.

All the courts are provided with bascule roof covers. The largest is 103 m long and 73 m wide. The construction incorporates the indoor tennis building with 11 indoor tracks, the tennis garden with 16 tracks, restaurants and administrative offices.

The post-tensioning we used for this project was the BBR CONA flat slab bonded post-tensioning system using 0.6" diameter strand, with four strands per anchor – and we used in excess of 200,000 kg of prestressing steel.

**TEAM & TECHNOLOGY**

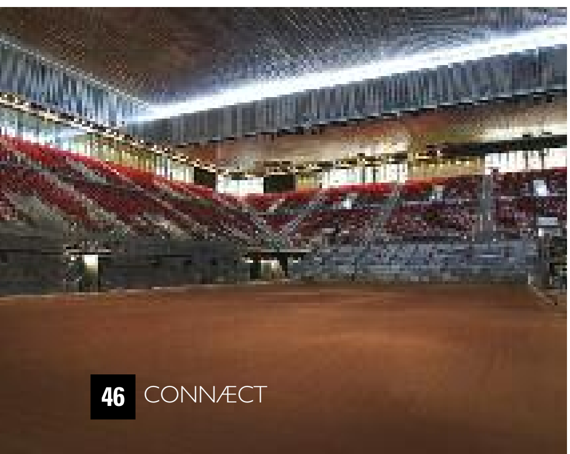
**OWNER** Ayuntaminento de Madrid

**MAIN CONTRACTOR** FCC Construcción, S.A.

**DESIGNER** Technical Services of FCC Construcción & Fhecor

**TECHNOLOGY** BBR CONA flat

**BBR NETWORK MEMBER** BBR PTE (Spain)



TDIC HQ, ABU DHABI, UNITED ARAB EMIRATES

## Alternative design delivers benefits

**Abu Dhabi is a city like no other at present and its master plan in relation to building works is breathtaking. Jim Karabatsos, from BBR Network member, NASA Structural Systems LLC, reports on their post-tensioning design and construct package for the TDIC Headquarters building on the waterfront in the area of Al Maqtaa, just off the main island of Abu Dhabi.**

Leading building firm, Leighton Contracting (Abu Dhabi) LLC, turned to the experience of Structural Systems to provide the alternative design for the post-tensioned slabs associated with the two basement level car parks and the architecturally impressive ground floor level. An economical solution was presented and, in turn, adopted for the project to the benefit of the contractor and client alike. The strength of the alternative design was the elimination of drop panels at the basement levels and introduction of a flat plate, providing a simplified formwork solution, saving time and money.

Working within the constraints of perimeter retaining walls and the overall length of the structure being in excess of 200 m, the Structural Systems' design team detailed an effective and easy to build temporary expansion joint along the perimeter and incorporated pour strips at locations which caused minimal concern to the builder. With typical column grids of 9.3 m x 9.3 m, the slab depths were a consistent 250 mm thick flat plate for the two basement levels with the ground floor incorporating some thicker sections and drop panels to cater for increased design loads, which reached up to 40 kPa in zones.

Over 300 t of 12.7 mm diameter prestressing strands were installed utilizing the BBR CONA flat, fully bonded system. Average pour sizes throughout the works were approximately 1,500 $m^2$.

The design of conventional reinforcement, including significant punching shear reinforcement, required sound detailing to ensure effective coordination with post-tensioning tendons.

Another successful project for NASA Structural Systems LLC. The benefits associated with early striking and re-use of formwork had the flow-on effect of less materials handling and which can allow the following trades to commence site works earlier. Post-tensioning is now the preferred construction solution for further floors of the building.

**TEAM & TECHNOLOGY**

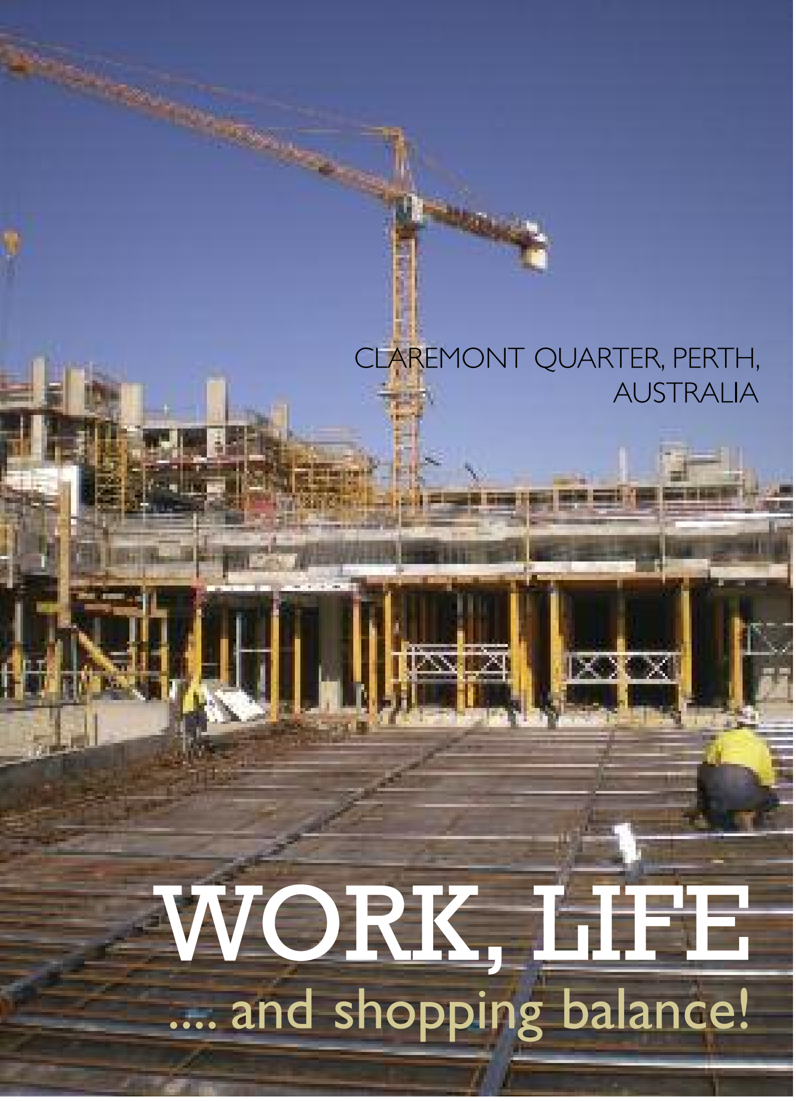
**OWNER** Tourism Development & Investment Company of Abu Dhabi (TDIC)

**MAIN CONTRACTOR** Leighton Contracting (Abu Dhabi) LLC

**CONSULTANT** Surbana International Consultants Pte. Ltd

**TECHNOLOGY** BBR CONA flat

**BBR NETWORK MEMBER** NASA Structural Systems LLC (United Arab Emirates)



CLAREMONT QUARTER, PERTH, AUSTRALIA

# WORK, LIFE

## .... and shopping balance!

**The Claremont Quarter Project is a mixed-use development, in the already thriving Claremont Town Centre. Sean Kelly of Structural Systems Limited – the BBR Network member in Australia – explains how the redevelopment of the existing Claremont Arcade will incorporate work, shopping and living within the one 'urban village'.**

The Claremont Quarter offers 30,000 m$^2$ of retail space contained over two levels, 77 residential apartments, 600 m$^2$ of commercial offices and 1,500 car spaces. Due for completion in 2011, the integrated commercial development is a joint venture between Brookfield Multiplex Limited and Hawaiian. The popular precinct located between city and surf is set to provide residents a combination of entertainment, shopping, work and luxury apartment living.

Structural Systems was awarded the design and construct contract for the post-tensioned banded slab construction for Levels 1 to 5. An alternative price was considered for a flat slab construction – however, the east-west banded slab maximized the benefits for all stakeholders on the project. The design is being spearheaded by Structural Systems' Melbourne office, whilst project management and site labor has all been sourced locally through our Perth office.

Loading in the retail levels (1 and 2) has created some design challenges – with live loads of up to 12.5 kN/m$^2$ and construction loads up to 15.0 kN/m$^2$. As a result, some north-south beams were introduced to improve the serviceability and strength of the banded slab. Coles implemented a turntable to assist with deliveries – which required the design of beams up to 1,300 mm deep for the 11 kN/m$^2$ (superimposed dead) and 12.5 kN/m$^2$ (live) loads. The strength of concrete used in the design is 40 MPa.

The BBR CONA flat system has been implemented for the construction, with a total of 507 t of 12.7 mm strand being used throughout Stages 1 and 2. The general layout of the east–west banded slab incorporates 2,200 / 2,800 mm wide splayed band beams with four 0505 tendons in each beam. Typically, there are two 0405 tendons running east–west in the slab between bands (generally 160 – 185 mm thick) at roughly 2,000 mm centers. These cables are for compression only. The north–south tendons comprise mainly 0405 tendons at 1400 mm centers, their profile is relatively uniform thanks to universal column spacings in the car park levels and typical band beam widths.

The post-tensioned slabs have been split up into 113 pours, with 70 pours in Stage 1 and 43 in Stage 2. The large number of pours has allowed multiple levels to be constructed at the same time giving the main contractor a tighter construction program and greater flexibility. With the BBR CONA flat system in place, a significant saving in reinforced concrete has been achieved, promoting the use of post-tensioning and proving it a viable option for similar projects in the future.

**TEAM & TECHNOLOGY**

**OWNER** Hawaiian and Brookfield Multiplex Developments
**MAIN CONTRACTOR** Brookfield Multiplex Constructions
**DESIGNER** Janine Ralev – Structural Systems Limited
**TECHNOLOGY** BBR CONA flat
**BBR NETWORK MEMBER** Structural Systems Limited (Australia)


PADDINGTON CENTRAL, LONDON, UK

# Sustainable future

**With its striking design by Kohn Pedersen Fox Architects and structural design input from Arup, Paddington Central has been developed to the highest levels of sustainability and is expected to receive the top BREEM rating of 'Excellent'. Structural Systems (UK) Ltd was brought in by the frame contractor, P.C. Harrington Contractors Limited, to advise on a suitable system for the post-tensioned floors – Richard Gaskill takes up the story.**

Paddington Central, part of the Paddington Waterside Development, is located on Paddington's former railway goods yard, along the northern side of Kingdom Street and south of the A40 Westway in Paddington, West London. Comprising three basement levels with ten storeys above – totaling nearly 209,000 m² of which all, except the lower basement, were post-tensioned – the structure makes an impressive addition to the Paddington Basin Development in West London.

Developed by Development Securities PLC and built by Skanska, the building is part of a major regeneration project around the new grassy amphitheatre of Sheldon Square.

## PT CHALLENGE

We proposed the BBR CONA flat 0505 bonded post-tensioning system with three to four strands per anchor.

There were numerous buildability issues to overcome at the design stage. The basement levels and podium had numerous steps between the slab surfaces which ranged from 500-800 mm in depth. This made the installation of the post-tensioning more difficult and required a great deal of co-ordination between all parties involved in the design and installation. The design also demanded three to four different slab depths, on the sub-podium levels, ranging from 275 mm to 325 mm to cater for varying spans and loading conditions.

## COMPLEX SHAPE

The building was a complex shape – with a range of internal penetrations of 18.65 m x 2.1 m. To further complicate issues, there was also a 3.2 m long cantilever to cater for. Typically, the structural layout required spans of 9.65 m x 9 m – but in some cases this was increased locally to 11 m.

To the rear of the building at Level 0, a 9.65 m long x 450 mm deep x 1200 mm wide post-tensioned beam was required to transfer a point load of 250 kN dead load (DL) and 60 kN live load (LL). Internal pans were used on Level 0 due to the limited access to the edge of the slab and, again, a range of slab depths from 275-400 mm was required.

The loading for Levels 2-8 were 0.9 kN/m² (DL) and 3.5+1 kN/m² (LL) with a cladding load of 2.75 kN/m.

Levels 1-9 used a typical combination of

> “THERE WERE NUMEROUS BUILDABILITY ISSUES TO OVERCOME AT THE DESIGN STAGE.”

## **In Focus:** London Paddington

Paddington, historically in the county of Middlesex, was one of the many villages which became part of London. In the 1830s, the temporary Paddington Station – the London terminus of the Great Western Railway – stood on very the spot that Paddington Central is being constructed today.

The railway's development was inspired by Bristol-based merchants who, by providing good transportation links with the nation's capital, hoped to ensure their city remained the second most important port in England.

After Isambard Kingdom Brunel's new – and permanent – Paddington Station was opened in 1854, the temporary station was converted into a railway goods depot. Other claims to fame for the area include the Grand Union Canal – the Paddington arm opened in 1801 and provided an important trading route to the Midlands. And it was at Paddington's St Mary's Hospital, in 1928, that Sir Alexander Fleming discovered penicillin. Paddington Bear arrived on the scene much later, in 1958 – since when, he has ensured that children the world over know the name of one of London's famous stations!

270 mm and 310 mm thick post-tensioned slabs which were constructed as three pours per level.

Level 8, however, also required a post-tensioned transfer beam which was 10.9 m long x 700 mm deep x 900 mm wide and had to accommodate two slots to allow for services to pass through the beam.

There were also minor changes to the slab depths at Level 9 due to a difference in the loadings – 0.9 kN/m² (DL) and 3.5+1 kN/m² (LL) with a cladding load of 4.0 kN/m – and the addition of 750 mm deep x 900 mm wide post-tensioned transfer beams to transfer point loads – of 235 kN (DL) and 365 kN (LL) – from the roof structure.

Level 10 had increased loadings of 2.75 kN/m² (DL) and 7.5 kN/m² (LL), plus a cladding load of between 2.75 and 7.0 kN/m, requiring a 325 mm thick slab overall.

### FUTURE PROOFING

To facilitate potential changes of use of the building or parts of the building over time, we were required to allow for subsequent penetrations through the slab. Accordingly, we built in a certain amount of redundancy into the design to allow for these penetrations to be undertaken without affecting the structural integrity of the slabs. The locations of these additional penetration points were marked on the 'as built' drawings we provided. ●

### TEAM & TECHNOLOGY

**OWNER** Development Securities PLC
**MAIN CONTRACTOR** Skanska Construction
**CONCRETE FRAME CONTRACTOR** P.C. Harrington Contractors Ltd
**DESIGNER** Arup / Structural Systems (UK) Ltd
**TECHNOLOGY** BBR CONA flat
**BBR NETWORK MEMBER** Structural Systems (UK) Ltd

# Water industry *innovation*

AERATION TANKS, EASTERN WATER TREATMENT PLANT, AUSTRALIA

**Structural Systems Limited was selected to design and construct four large aeration tanks, at the Eastern Treatment Plant at Balgholme, south east of Melbourne, Australia.**

Janine Ralev reports that the key selection factors were our alternative design featuring the use of post-tensioning in the tank slabs and the main walls of the structure, as well as the alternative construction method proposed for building the walls using a specially designed in-house moving formwork system.

Structural Systems' scope of works included structure design, concrete, reinforcement, post-tensioning and formwork, documentation, supply and installation of concrete, reinforcement and post-tensioning and site supervision.

## PROJECT PURPOSE

The purpose of the project was to increase the South Eastern sewage capacity to serve the growing population in this area. The current six existing aerating tanks had reached their capacity and four new aeration tanks, with a provision for two future tanks on the same site, were now required.

Our structure package included the design and construction of four additional concrete tanks and associated concrete settled channels, mixed liquor channel, return activated sludge channel (RAS), construction of switch room and related pump station, access walkways, precast baffle walls, suspended concrete slabs and precast concrete tie beams.

## ALTERNATIVE DESIGN

Each concrete tank cell is approximately 92.5 m long by 50 m wide and has 6 m high walls and an operating volume capacity of

## Facts & figures

| | |
|---|---|
| Project footprint | 220 m x 120 m |
| Concrete poured | 16,000 $m^3$ |
| Slab area | 24,000 $m^2$ |
| Post-tensioned walls | 2,200 lm |
| Slab infills | 2,000 m |
| Wall infills | 700 $m^2$ |
| Post-tensioning | 350 t |
| Reinforcement | 2,500 t |

27 ML. Our alternative design solution was a post-tensioned insitu tank construction. The design was carried out in accordance with AS 3735 – the Australian Standard for concrete structures for retaining liquids – with additional requirements on durability of the structure to deliver a design life of 100 years. Each tank cell and related channels were modeled and designed using commercial Finite Element Software 'Strand7' to determine the internal stresses at various stages of the life of the structure. Internal software was developed to incorporate all the possible load combinations – in some instances, up to 40 load cases were considered – and determine the envelope of actions for final design.

**INSTALLATION**

The floor slab was cast in eight individual pours – approximately 50 m by 60 m each. The slab post-tensioning was applied to prevent forming of initial shrinkage cracks ➔

“INTERNAL SOFTWARE WAS DEVELOPED TO INCORPORATE ALL THE POSSIBLE LOAD COMBINATIONS – IN SOME INSTANCES, UP TO 40 LOAD CASES WERE CONSIDERED ...”

and to allow the construction of the walls to commence.

The walls were cast without any horizontal joints in 20-22 m long pours using an innovative moving formwork gantry system developed in-house. Four separate gantries were manufactured to speed the construction and to allow the tank and three channel walls to be built simultaneously.

The main wall reinforcement was fully prefabricated on site and then lifted into place – except for the corners of the walls – because of congestion and the need for special co-ordination with the post-tensioned ducts. Horizontal post-tensioning was installed between each infill pour strip and stressed, together with the additional multistrand tendons in the footing slab.

Precast baffle walls were constructed on the post-tensioned slab in eight separate casting beds per tank cell. After the baffle walls were erected, the precast tie beams were installed and finally, all the pour strips were closed in and the sealing of the tank commenced.

Our alternative post-tensioned design of the slabs and walls provided significant project savings – less concrete and traditional steel reinforcement, reduced labor requirement and fewer overall construction joints, resulting in lowered leakage risk and long-term maintenance issues.

## Alternative design solution

- Post-tensioned concrete slabs cast in situ – with total area of 24,000 m$^2$. The post-tensioned slab was typically 200 mm thick throughout and 500 mm thick underneath the tank walls.
  - BBR CONA flat system – five strands, 15.2 mm diameter, stressed to 85% UTS
  - BBR VT CONA CMI 1206 system – 12 strands, 15.2 mm diameter, stressed to 80% UTS
- Post-tensioned concrete walls cast in situ – approximately 2,200 linear meters of wall, with thicknesses ranging from 450 mm to 550 mm, 6 m high.
  - BBR VT CONA CMI 0706 system – seven strands, 15.2 mm diameter, stressed to 80% UTS
- Concrete cells – each has four passes, divided with precast baffle walls, 74 in total, 180 mm thick, reinforced concrete.
- Grillage of walkways – achieved with 49 precast reinforced concrete tie beams and insitu wall header beams as part of the main post-tensioned wall design.
- Post-tensioned slab infills and reinforced slab & wall infills – strategically located every 50 m to control short and long term creep and shrinkage movements, in order to minimize the risk of sewage / water leakage using standard waterproofing sealants in the joints.

**TEAM & TECHNOLOGY**

**OWNER** Melbourne Water Corporation

**MAIN CONTRACTOR** Tenix Alliance, Australia

**DESIGNER**
Janine Ralev / Structural Systems Limited, Australia

**TECHNOLOGY**
BBR VT CONA CMI internal
BBR CONA flat

**BBR NETWORK MEMBER**
Structural Systems Limited (Australia)

# High quality for energy

SEVENTH & EIGHTH LNG TANKS, BARCELONA, SPAIN

**David Olivares Latorre, from Spanish BBR Network member BBR PTE, reports that to meet the growing demand for natural gas currently being experienced in the metropolitan area of Barcelona, Enagas decided to build a further two LNG storage tanks in the port of Barcelona.**

The LNG is stored at -161 °C in special tanks suitable for such low temperatures. Security and resistance are the primary design considerations for the construction of this type of tank which must be designed to withstand earthquakes and strong winds.
A very high quality control process must be applied during construction – using only the very best construction materials and technologies – because storage of a highly inflammable product is involved.

## NEW TANKS

The seventh and eighth LNG tanks in Barcelona are cylindrical concrete vessels made specifically for Liquefied Natural Gas (LNG) and are 80 m in external diameter and 41 m high. Construction of the two tanks is being carried out simultaneously – thus the project is a great construction challenge!
In total, there are more than 600,000 kg of post-tensioning steel in each one – split between vertical and horizontal tendons. We used the BBR VT CONA CMI 1506, 1906 and 2406 systems for the prestressing on this project.

## INTERIOR POST-TENSIONING

The interior prestressing consists of:

- For the four foundation slab rings – 24 x BBR VT CONA CMI 2406 anchorages in 140 m tendons
- For the horizontal wall – 280 x BBR VT CONA CMI 1506 anchorages in 130 m tendons
- For the vertical wall – 140 x loops with over 90 m in each and 280 x BBR VT CONA CMI 1906 anchorages.

Both the foundation slab rings and horizontal tendons are fitted with galvanized duct and the inferior curves of the vertical loops are made of galvanized duct too, but eight meters of 104 mm diameter stiff duct is connected to the remainder of the vertical straight design. This connection is achieved by way of the expanded end of the tube which permits rigid joints to be formed between sections.

## STRAND PUSHING

The horizontal cables were pushed with the help of a strand pushing machine hung from a crane, while the operators were located on a hydraulic platform. The pushing machine was secured by tying it to the tank to avoid any jerky movements caused by the strand pushing process. Meanwhile, the vertical cable loops were pushed by means of a flexible duct situated between the 1906 anchorage and the pushing machine.

## STRESSING & GROUTING

The foundation slab rings were stressed before the tank construction began and stressing of the other tendons was carried out during construction because of the forces applied to the structure.
The agreed sequence began with the stressing of some horizontal tendons, followed by the first half of the vertical loops. Next, half of the horizontal tendons were stressed before the second half of the vertical tendons. Finally, the lowest horizontal cables, beside the access doors, were stressed.
Having carried out a battery of inclined tube tests using our chosen cement grout, it was applied by the wringing method which results in the complete elimination of any possible water exudation at the top of the tendons.

### TEAM & TECHNOLOGY

**OWNER** ENAGAS
**MAIN CONTRACTOR** FCC Construcción, S.A. + F.I.
**DESIGNER** FCC Construcción, S.A. + F.I.
**TECHNOLOGY** BBR VT CONA CMI internal
**BBR NETWORK MEMBER** BBR PTE (Spain)

# Relationships ...

TANK & SILO CONSTRUCTION, UNITED ARAB EMIRATES

**Warwick Ironmonger, General Manager for Structural Systems' operations in the Middle East, and Ravindra Kumar Chauhan, Civil Operations Manager for BBR Network member NASA Structural Systems LLC, provide an overview the company's involvement in recent tank and silo projects in the Middle East.**

As a result of our good working relationship – developed during construction of LPG tanks in Abu Dhabi – Chicago Bridge & Iron Company (CB&I) appointed us as the specialist subcontractor for post-tensioning works associated with construction of the propylene storage tank within the Borouge 2 Project in Ruwais, Abu Dhabi. Meanwhile, our successful track record of LPG tank construction in Abu Dhabi led to our appointment – by main contractor A. P. Bawa – to undertake a similar scope of specialist post-tensioning works for the clinker silo being constructed as part of the Binani Cement Factory expansion at Jebel Ali Industrial Area, Dubai.

## PROPYLENE STORAGE TANK

The project included the construction of a 23,000 $m^3$ capacity propylene storage tank – with a 37.9 m internal diameter and concrete wall height of 32.05 m – the wall was typically 0.5 m thick, tapering to 0.8 m over the bottom 6.5 m. The post-tensioned wall was constructed by using conventional form shuttering and ten concrete pours, each 3.25 m in height.

Thirty two full circumference loop tendons, each divided into two semi-circular segments anchored with BBR anchorages – complying with the cryogenic (low temperature) requirements of the project specification – were detailed to satisfy the long-term horizontal force profile dictated by CB&I. The strands were post-threaded into the tendon ducts after concreting with a high speed strand pusher and using four buttresses to accommodate the stressing of the tendons via 550 t jacks.

The overall tank design dictated that the stressing should be carried out in three stages:

- Stage 1 – three top-most tendons stressed before casting of tank roof.
- Stage 2 – 19 tendons stressed after casting of tank roof.
- Stage 3 – remaining ten (lowest) tendons stressed after closing of two temporary construction openings.

Mast-climber platforms were used effectively at the buttress locations to provide access to pushing, stressing and grouting work fronts – to ensure the timely completion of prestressing activities.

## CLINKER SILO

The scheme was for the construction of one clinker silo with an internal diameter of 40 m, concrete wall thickness of 0.4 m, a 24 m high concrete wall and four stressing buttresses. There were 50 full circumference loop tendons, with each tendon divided into two semi-circular segments, with eight extra tendons positioned above the dozer opening.

Round-the-clock work for duct installation, along with the slipforming of the walls, permitted the total wall height of 24 m to be achieved in only 12 days. The strands within the tendons were post-threaded after concreting by means of a specialist high-speed strand pusher.
We used 200 t jacks which had been specially fabricated for the BBR VT CONA CMI 0706 anchorage system, for the stressing operations. All tendons, except those terminating at or trimming the dozer opening, were stressed from each end. Stressing activities for this project were successfully concluded within ten working days.

## SCOPE OF SERVICES

We were responsible for the supply of post-tensioning materials, shop drawings related to post-tensioning, designing of anti-burst and splitting reinforcement, calculation of tendon extensions and friction losses, installation of post-tensioning materials, stressing and grouting with our own specialist equipment, and associated QA / QC and engineering support.

For the Borouge 2 propylene tank, our remit was extended to include the complete design of post-tensioning, based on the long term prestress force profile provided by CB&I.

## POST-TENSIONING

For these projects, we used a total of:

- 128 x BBR CONA internal 1906 anchorages – with 10 to 18 strand occupancy.
- 248 x BBR VT CONA CMI 0706 anchorages with five strand occupancy.
- 11,000 m of 55 / 105 mm internal diameter, 0.4 mm thick galvanized iron spiral ducting as per EN 524 / 523.
- 130 t, 0.6 inch diameter low relaxation PT strand.

## GROUTING

Grouting, both at Ruwais and Jebel Ali, was carried out from ground level, with specialist grout mixing and pumping units and followed on from successful grouting mock-ups conducted at site to check the occupancy of grout.

We look forward to the continued application of our valuable experience in tank and silo construction, gained through successful involvement in prestigious and challenging projects throughout the Middle East region.

### TEAM & TECHNOLOGY

**Borouge 2 propylene storage tank**
**OWNER** Abu Dhabi Polymer Company Limited
**MAIN CONTRACTOR** CBI Eastern Anstalt
**CONSULTANT** Tecnicas Reunidas
**TECHNOLOGY** BBR CONA internal
**BBR NETWORK MEMBER** NASA (BBR) Structural Systems LLC (United Arab Emirates)

**Binani Cement clinker silo**
**OWNER** Binani Cement Factory
**MAIN CONTRACTOR** A. P. Bawa Construction LLC
**CONSULTANT** FLSmidth Designs Private Limited, India and Corporate Planners Engineering Consultants, Dubai
**TECHNOLOGY** BBR VT CONA CMI internal
**BBR NETWORK MEMBER** NASA (BBR) Structural Systems LLC (United Arab Emirates)



# ... and reputation

"THERE WERE 50 FULL CIRCUMFERENCE LOOP TENDONS, WITH EACH TENDON DIVIDED INTO TWO SEMI-CIRCULAR SEGMENTS ..."

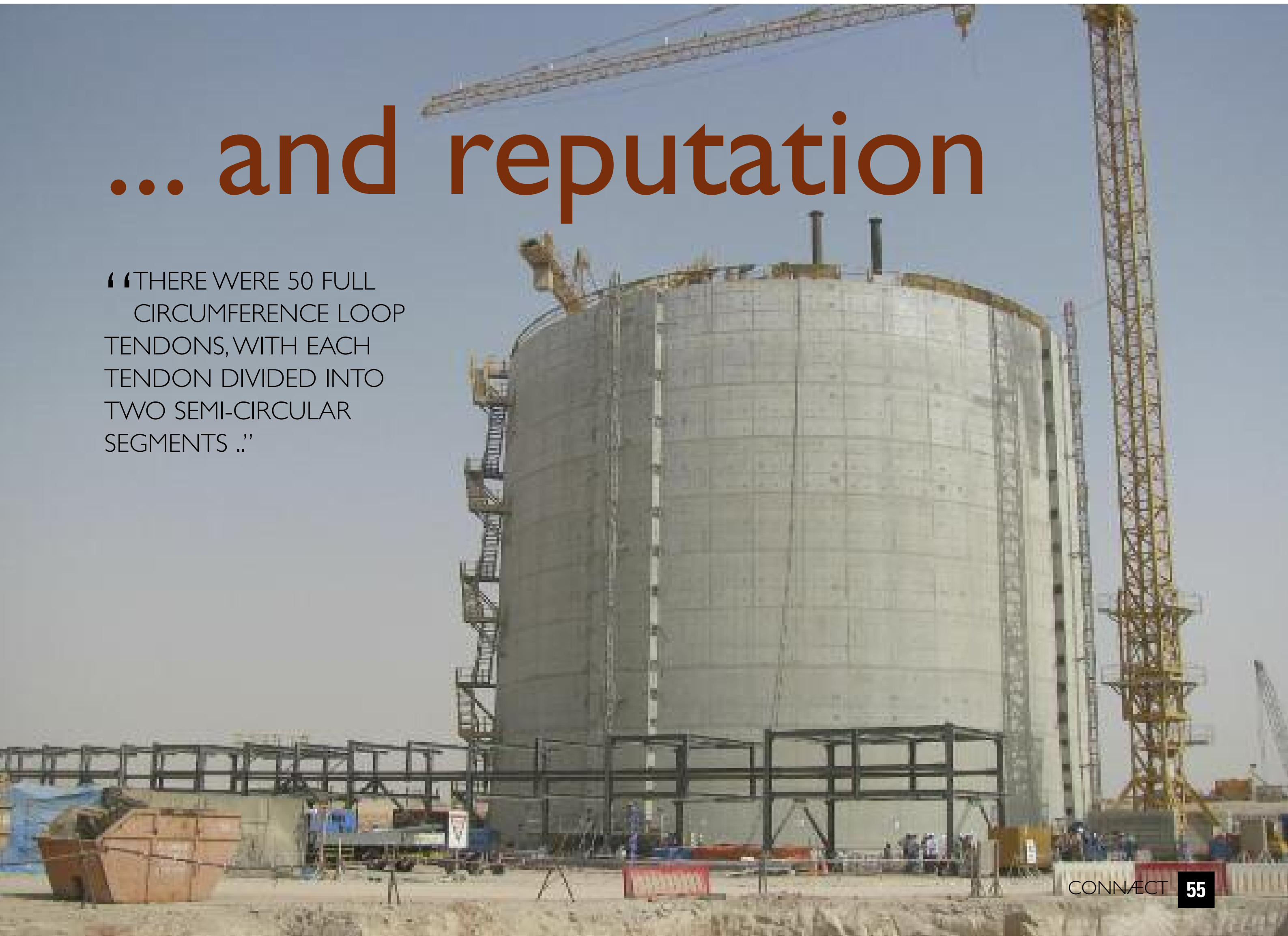


Photo courtesy of Axpo Holding AG.

# Nuclear Inspection

RINGHALS 2,
NUCLEAR POWER PLANT, SWEDEN

**Since 1969, BBR has provided the post-tensioning for 65 nuclear facilities in 13 countries. Although the company has always conducted rigorous testing of their tendons, inspections must be also made at regular intervals to ensure maximum performance is being achieved. During the 1970s, BBR Network member Spennteknikk carried out the post-tensioning work for eight nuclear power plants in Sweden and Finland, for many of which they continue to inspect and maintain the post-tensioning installation.**

The first four post-tensioning operations were performed with normal cement grouting, the next three, at Ringhals, were grouted with grease – and the last one, at Forsmark, was protected by pumping dry air through ducts. Spennteknikk supplied and installed the post-tensioning system for all these nuclear power plants.

The client required a high quality post-tensioning system and a corrosion protection system was designed with both circulating dry air and grease grouting. For Ringhals 2, 3 and 4, grease grout was chosen for corrosion protection. In order to ensure the durability of the cables and forces, an inspection program is carried out at certain intervals.

Owned by Vattenfall and E. ON Kärnkraft Sverige AB, Ringhals 2 is one of the nuclear reactors at Ringhals – Sweden's largest power plant – in the south-western part of Sweden. In total, there are four reactors at Ringhals – three pressurized water reactors and one boiling water reactor. In a normal year, Ringhals generates some 28 billion kilowatt-hours of electricity. This is approximately one fifth of Sweden's total electrical energy consumption.

The reactors are protected by an outer protection shield constructed of prestressed concrete – the walls are 600 mm thick. The post-tensioning system used was the BBRV 139 6 mm prestressing wire system, grouted with grease.

The project consisted of inspecting the cables in the outer shield, including replacement and testing of BBRV wire.

Spennteknikk has a continous agreement with Vattenfall for the inspection of the nuclear →


## Technical insight:
## High capacity tendons

With over 60 years' experience in the design and application of post-tensioning products, it will be no surprise to learn that BBR tested their first high capacity tendons for nuclear power stations in the 1960s.

The BBR VT CONA CMI system for nuclear applications has secured European Technical Approval ETA – and set a new world record in 2008 when a 73-strand tendon was successfully tested to the Guidelines for European Technical Approval ETAG 013.

Three types of BBR post-tensioning tendons – all of which have secured European Technical Approval – are typically used for the inner containment:

- Vertical tendons for wall post-tensioning
- Horizontally looped tendons or 'hoop' tendons
- Horizontal end slab post-tensioning 'cane shaped' tendons.

During the entire lifetime of the pressure vessels, the greatest attention must be paid to the protection of the prestressing steel from corrosion. The BBR Network uses three different types of corrosion protection for nuclear tendons – cement grouting, grease or wax grouting and circulating dry air.

"THE CLIENT REQUIRED A HIGH QUALITY POST-TENSIONING SYSTEM AND A CORROSION PROTECTION SYSTEM WAS DESIGNED WITH BOTH CIRCULATING DRY AIR AND GREASE GROUTING."

power plants and Ringhals 3 will be examined in 2010, along with Forsmark 3. Nuclear power plants are subject to a stringent inspection programme and Spennteknikk is the natural partner for Vattenfall for these projects.
For the continuous safety of service of large tendons, accurate measurement of the stressing force and regular monitoring are of great importance.
The inspection of the post-tensioning system includes monitoring of the stressing load for three roof cables, three vertical cables and six horizontal cables – all randomly-selected. Also included is the de-stressing and replacement of one wire in the roof cables and one horizontal cable – and, thus, stressing of these.
The wire and the grease removed must be tested and verified prior to acceptance of the inspection. To date, we have encountered no failures of either the cables or the corrosion protection. Loss of prestressing force, over the years, is now about 20% – which was as expected and this will be adjusted during a complete inspection in 2011.
Working in such restricted areas demands specially trained technicians, as well as special equipment. Security of personnel is strictly controlled and our people must also have health inspections and special HES education.
Our work on nuclear power plants gives us a unique experience and know-how, the requirements from Vattenfall are inspiring and demanding at the same time – a driving force for our quality management. ●

## Nuclear inspection procedures

- Lift-off of the anchor head with the BBR automatic stressing device to determine the actual prestressing force – this is digitally recorded by an x-y-writer.
- The tendon is subsequently released and a single tensile element is extracted for corrosion examination and further testing in the technical laboratory.
- A new single tensile element is installed and the tendon is stressed again to its original prestressing force

**TEAM & TECHNOLOGY**
**OWNER** Ringhals AB
**MAIN CONTRACTOR** Spännteknik AB, Sweden
**DESIGNER** Vattenfall AB
**TECHNOLOGY** BBRV wire
**BBR NETWORK MEMBER** Spennteknikk (Norway)

LNG TANK, STAVANGER, NORWAY

# Secure cryogenic storage

**At the new LNG processing and storage facility – created by energy provider Lyse Gass – Norwegian BBR Network member Spennteknikk has installed the post-tensioning for a new 20,000 m³ tank.**
The plant is in Stavanger, south-western Norway and, as well as the LNG tank, the project included a process area and quay. The production capacity of the plant will be 300,000 t LNG per year.
The LNG tank consists of an inner and an outer tank – the latter, a post-tensioned concrete structure, will serve as a protective shield.
The outer tank, with its 800 mm thick wall, was constructed by slipforming and we used 75 t of strand to complete the post-tensioning. For the horizontal tendons, we used BBR VT CONA CMI 1906 and for the vertical loop cables BBR VT CONA CMI 0706 tendons were installed. Standard metal ducts were used for the PT cables, except for the loops on the vertical cables. Prefabricated thin-walled pipes were purpose made to simplify the installation of strands.
In addition, we provided cryogenic test reports – as required by the client – and these were supplied by BBR Headquarters. ●

**TEAM & TECHNOLOGY**
**OWNER** Lyse Gass
**MAIN CONTRACTOR** Kruse Smith AS
**CONSULTANT** Norconsult AS
**TECHNOLOGY** BBR VT CONA CMI internal
**BBR NETWORK MEMBER** Spennteknikk (Norway)

I n 2010, BBR celebrates its golden anniversary in the stay cable technology arena, while the BBR Network has some 66 years at the leading edge of construction technology. For 50 years – and for over 400 projects – the BBR Network has been delivering engineering excellence with state-of-the-art construction products. BBR VT CEO – Marcel Poser, takes us on a voyage through the history and development of stay cable technology, onto the latest thinking on the subject. So, relax and enjoy the journey!

# Golden strands

# Evolution through TECHNOLOGY

**Cable-stayed bridges have been built in rapidly increasing numbers since 1950 and have been found to be especially suitable for medium to long-span bridges from 100 to 1000 meters, where technical and economic considerations dictate a cable-stayed solution.**

The idea of supporting a bridge deck with cables from one or two pylons has been around for a long time.
The principle of cable-stayed bridges can be tracked back to the early 1600s when the Venetian Faustus Verantius, best known perhaps for his book *Machinae Novae,* built a wooden bridge supported with chain stays. In 1784, the carpenter C. J. Löscher designed a cable-stayed bridge with an approximate 32 m span length where the entire bridge was made out of wood, including the stays.

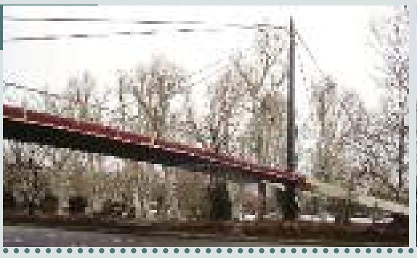
## EARLY ASSUMPTIONS

In the 19th century, the French engineer Claude-Louis Navier studied several bridge systems supported by wrought iron chains. The results of his studies showed that suspension bridges should, in general, be preferred over cable-stayed systems. From today's point of view, it can be said – with certainty – that the French engineer's final conclusions were wrong! However, at the time Navier was studying these different bridge systems, the knowledge and

1 THE 50 YEARS OF STAY CABLE EXPERIENCE WITHIN THE BBR NETWORK ACROSS OVER 400 EXECUTED STAY CABLE PROJECTS INCLUDES:

**1960 – BBR No.1**

World's first application of high amplitude fatigue resistant wire stay cables at the Schillersteg in Stuttgart, Germany.



*Dischinger's Strömsund Bridge in Sweden is celebrated as the first true cable-stayed bridge.*

equipment for achieving even distribution of the load between all the cables – which is one of the key issues for cable-stayed bridges – were simply not available.

**POST-WAR PIONEERING**

German engineers led the design of cable-stayed bridges after World War II. The Germans' challenge was to find new, innovative and inexpensive bridge designs to replace most of the Rhine river crossings which had been destroyed during the war.

Civil and structural engineer, Franz Dischinger proposed systems where the central span was supported by a suspension system and stay cables carried the outer parts.

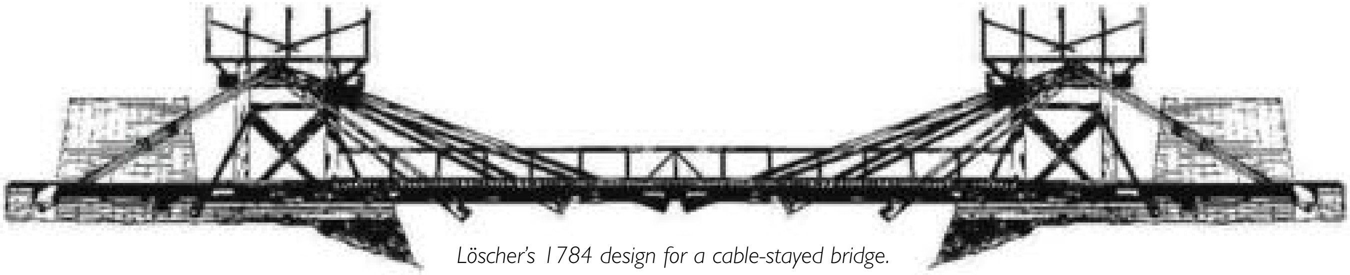
Dischinger's combined solutions were never adopted for an actual bridge, but his studies had a huge influence on the development of the true cable-stayed bridge system. It was, however, not until the 1950s that Dischinger designed the first true cable-stayed bridge – the Strömsund Bridge in Sweden which had a main span of 183 m and two side spans of 74.7 m.

The Germans further developed the design of cable-stayed bridges in the following decades and built several of them. The series of bridges near Duisburg across the River Rhine are examples of these pioneering German bridges.

In *Cable Supported Bridges: Concept and Design,* Niels Gimsing attributes the increase in cable-stayed bridge designs to the improved structural analysis tools that were available.

**FIRST FOR BBR**

While 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 has followed on with milestone-after-milestone – and today continues to set the standard in the field of stay cables.



*Löscher's 1784 design for a cable-stayed bridge.*

**1972 – BBR No.5**

World's first application of strand stay cables at the Olympic Stadium in Munich, Germany.

**1978 – BBR No.25**

World's first cable-net supported tower at Centerpoint in Sydney, Australia.

# Fulfilling the potential

**Cable-stayed structures have a great potential when it comes to meeting the increasing demand for long span structures. They offer increased aerodynamic stability and reduced costs for the abutments, with faster, easier construction and light overall structures. However, the most important factor in ensuring durability and performance of a cable-stayed structure will always be the stay cable system.**

Durable and efficient structures require high strength, high amplitude fatigue resistant, redundant and durable stay cable technology. In the past, many cable systems have been used, such as locked-coil, wire ropes and bars.By today's standards, these technologies no longer fulfill the requirements of high capacity structural applications.

### WIRE STAY CABLES

The first stay cable technology to provide the required static strength and high amplitude fatigue resistance was parallel wire cables. The anchorage system generally consisted of button heads, on the individual wires, which transfer the load into an anchor head and into the supporting bearing plate.

The usage of full or partial bond type socket anchorages, in combination with button heads on the individual wires, is a further development and is widely used. The first application of such high amplitude fatigue resistant wire cables was in the late 1950s on the Schillersteg in Germany.

Today, wire stay cables are made up of a predetermined number of parallel or semi-parallel individually galvanized wires of low relaxation grade steel and a minimum guaranteed ultimate tensile stress (GUTS) of 1670 MPa or 1770 MPa. These are enclosed in an ultraviolet (UV) resistant high-density polyethylene (HDPE) stay pipe or sleeve of circular cross-section and the voids between the individual wires and the HDPE sheathing are filled with a corrosion inhibitor. The anchorages used are, in most cases, still based on the button head invented back in the 1950s.

## World first for carbon stays

The Storchenbridge in Wintherthur (Switzerland), crossing the major east-to-west axis of the Swiss Federal Railway Network, was the world's first bridge using carbon stay cable technology. Due to its low self-weight, carbon stay cables are a promising solution for ultra long span bridges. Their extremely high fatigue resistance and the fact that carbon is non-corrosive are further advantages of this type of cable.

### STRAND STAY CABLES

High amplitude fatigue resistant strand stays found their first major application on the Olympic Stadium in Munich, Germany, with its cable supported membrane roof structure. Munich hosted the Games in 1972

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**1981 – BBR No.36 & 374!**

Sloboda Bridge in Novi Sad Serbia, which was originally opened to traffic in 1981, destroyed during NATO bombing in 1999, subsequently reconstructed and reopened to traffic in 2005. The Sloboda Bridge is the world's first cable-stayed bridge which was built twice and the world's largest cable-stayed bridge reconstruction project

and the stadium became the home of Bayern Munich, one of the world's premier soccer clubs.

Strand stay cable configurations are traditionally anchored by means of wedges, which bite into the strand and transfer the load into an anchor head and the supporting bearing plate. Epoxy and bond type anchorages have also been used in the past. Modern strand stay cables are generally made up of a predetermined number of parallel low relaxation grade steel strands with minimum GUTS of 1770 MPa to 1860 MPa enclosed in an UV resistant HDPE stay pipe of circular cross-section. The strands are galvanized, greased or waxed and individually sheathed with a continuous and wear-resistant HDPE coating, providing each strand with a triple protection system.

### SELECTION FACTORS

Wire stay cables are generally prefabricated and strand stay cables are more commonly assembled on site using a strand-by-strand installation method, thus the choice of the suitable cable system for a particular project depends on many factors.

It is often considered that prefabricated cables are best suited to smaller bridges. On site fabricated stay cables are usually suited to longer spans. However, the designer together with the specialist stay cable company must evaluate each project individually. Erection requirements, as well as the overall economics, should always be considered.

### SOLUTIONS OF CHOICE

Both wire and strand type cable systems are today's solutions of choice for modern cable stayed structures. Over the years, the ultimate tensile strength of the wires and strands has gradually been increased and will further be increased. Furthermore, the corrosion protection systems have been enhanced. To enhance the long term durability of the stay cables, the uses of epoxy coated strands might be alternatives for the future.

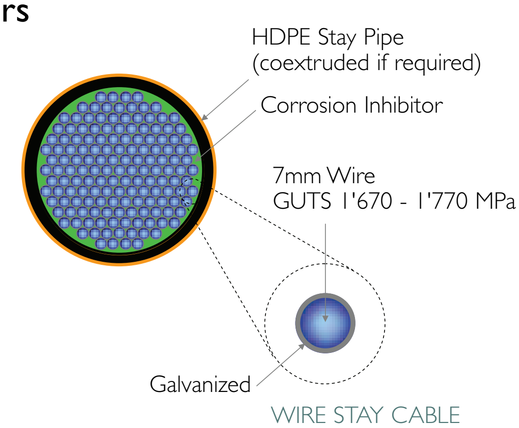
## System selection factors

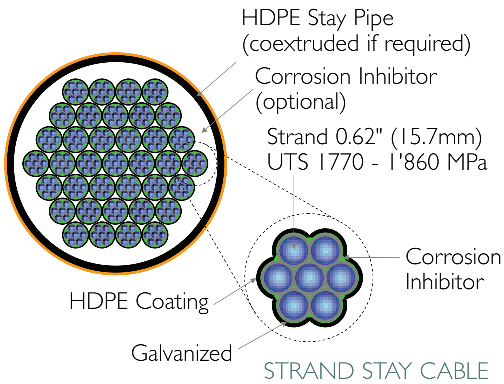
**Wire Stay Cables**

- Fabricated to a pre-determined length with length adjustability at the anchorages, requires transportation and heavy lifting equipment on site. The pre-fabrication results in a very short erection time on site.
- The cable diameter is more compact which has a series of aerodynamic advantages for very long cables.
- The fatigue resistance is generally higher.

**Strand Stay Cables**

- More labor-intensive on site, but requires only limited capacity lifting equipment.
- Requires a larger stay pipe diameter, which can influence the aerodynamic behavior.
- Replacement of single tensile elements is easier.




*Draubridge, Ptuj, Slovenia (2007) – BBR cable-stayed structure Number 391*

**1987 – BBR No.79**

ALRT Skybridge, the world's longest transit skytrain-only bridge, spans the Fraser River between New Westminster and Surrey, Canada, built.

Photograph courtesy of MacPhotogrammetry/Flickr

# Around the world ...

**In 50 years of stay cable experience, the BBR Network has carried out over 400 stay cable projects – notching up a number of 'world firsts' and establishing its position at the forefront of this technology along the way.**

Whether for transportation, energy, communications or sporting infrastructure, the BBR Network has delivered a wealth of enduring and magnificent cable-stayed structures around the world.

### THE AMERICAS

While cable-stayed bridges are extremely popular in Europe and Asia, they are really just starting to catch on in North and South America. Recently, in Boston, Massachusetts, a cable-stayed design was selected for a new bridge across the Charles River, even though cheaper options were proposed. Maybe it is an irony that, in the otherwise public transport-shy North America, the 616 m Skybridge in Vancouver is the longest cable-supported transit train-only bridge in the world.

### ASIA / PACIFIC

Cable-stayed bridges are extremely popular in many Asian countries for helping to resolve traffic congestion and to improve the infrastructure of the incredibly fast growing metropolitan areas. Japan probably has the highest density of cable-stayed bridges.
Among the booming countries nowadays is China, where a series of future world record span bridges are currently under construction.
Cable-supported structures in Asia have also been defined as purely architectural and landmark structures and are often built to commemorate former or present kings and rulers, such as the RAMA VIII Bridge in Thailand. Wedge anchored strand stay cables and compact stay pipes have been utilized in this bridge which is one of the world's largest single pylon bridges.

The longest cable-stayed bridge built in the 20th century, the Tatara Bridge in Japan, has a breathtaking total length of 1480 m and a pylon height of almost 240 m. The first major application of stay cables in Australia was in the unique supporting net structure composed of parallel wire stay cables for the stabilization of the 230 m Centre Point Tower in Sydney, constructed in the 1970s. Environmental campaigners had little to complain about when the aptly named 800 m long Green Bridge in Brisbane was constructed. It is Australia's second-longest cable-stayed bridge, after the ANZAC Bridge Sydney, and is entirely dedicated to public transport, cyclists and pedestrians.

### EUROPE

The mother continent of cable-stayed bridges and structures is Europe, with the first major applications taking place in the late 1950s.
Aesthetic qualities are also important on the European continent and this is admirably demonstrated by the scenic Sunniberg Bridge in the skiing resort of Klosters, in the Swiss Alps, which was designed by the legendary Swiss Engineer Christian Menn and was opened to traffic in 2005 by Prince Charles. This masterpiece of engineering, which fuses perfectly with the scenic surroundings, employs a button head type wire stay cable system. Characterized by its short pylons and shallow angle stays, it exhibits the essence of a technical and aesthetic solution in a prominent landmark.
In the south of Valencia, the City of Arts & Sciences designed by the internationally renowned architect and engineer Santiago Calatrava, has become one of the most celebrated features of the City. One of his latest designs, the new Serrería Bridge, now rises in the centre of this stunning complex to a height of 126 m – making it the highest point of the City.

### THE WAY AHEAD

Even as this edition of CONNAECT goes to print, construction is underway on one of our next 400 cable-stayed structures – the Sava Bridge on the Belgrade Inner City Semi-Ring Road in Serbia. With its 200 m high pylon and 376 m main span, the bridge will have the second longest stay cables in Europe – and is set to become a significant landmark for the city and for the future of the BBR Network.

101

**1996 – BBR No.197**

World's first application of carbon stay cables for the Storchenbridge in Winterthur Switzerland in 1996.

Green Bridge / Eleanor Schonell Bridge, Australia (2006) – BBR cable-stayed structure Number 387

# ... creating international icons

RAMA VIII Bridge, Thailand (2002) - BBR cable-stayed structure Number 325

Sava Bridge, Serbia (2012) - one of the next 400 BBR cable-stayed structures

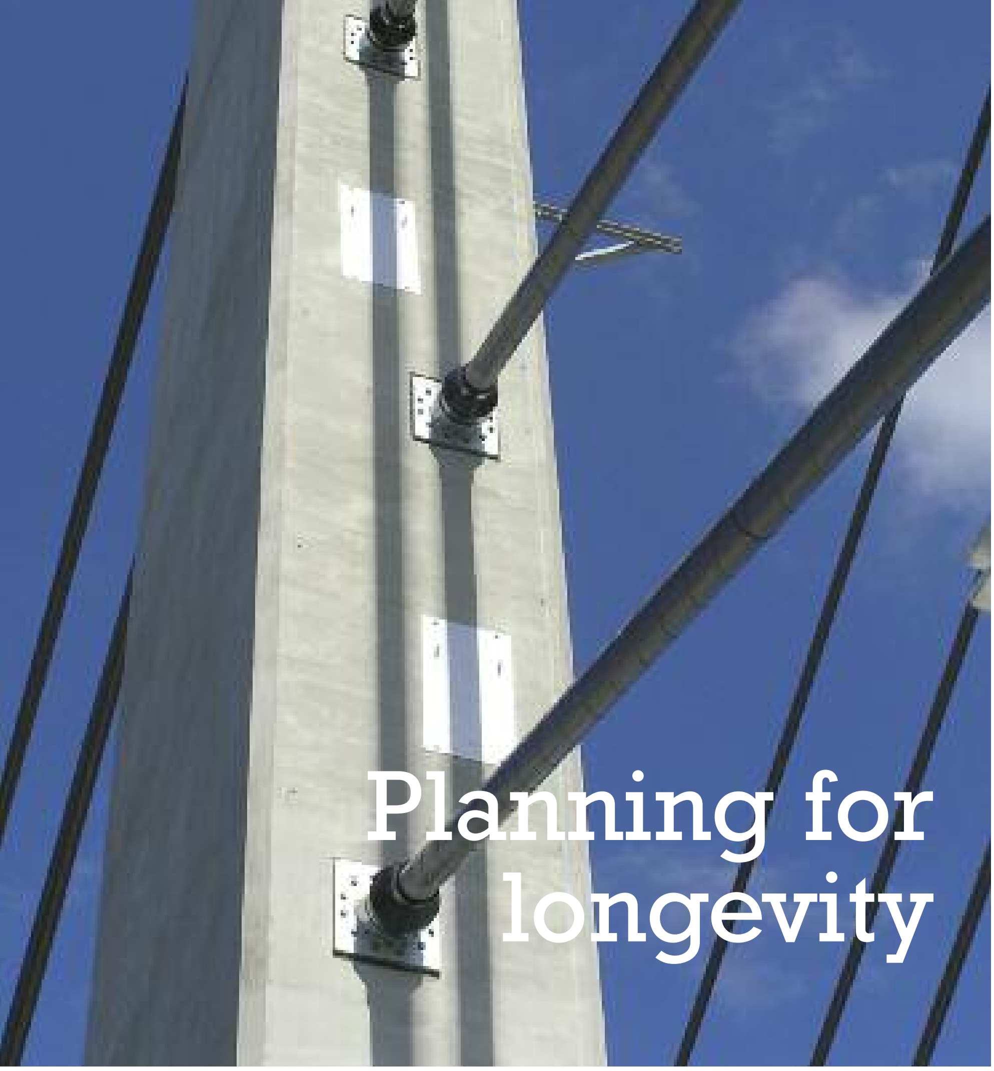
Sunniberg Bridge, Switzerland (1997/2005) – BBR cable-stayed structure Number 232

**1997 – BBR No.234**

Longest cable-stayed bridge built in the 20th century – the Tatara Bridge in Japan.

**2000 – BBR No.286**

World's first combined arch and stay cable bridge – the Seri Saujana Bridge (BR8) at Putrajaya in Malaysia.



# Planning for longevity

**Only in recent decades, have actual definitions in terms of expected design life of a structures been given. In the early days, a 20-year life was considered suitable, however today, a 100-year design life is state-of-the-art – and this is, for example reflected in the formal European Approval Testing of post-tensioning kits under ETAG 013.**

Up to 2008, the four major players executing strand and wire stay cable projects internationally, had completed some 800 projects worldwide – ranging from 70 to 400 per player. Their first projects were undertaken somewhere between 1960 and 1985 and thus the long term experience with such stay cables covers a range of between 25 and 50 years, depending on the individual company. At first sight, this long-term experience appears considerable – but after analyzing available data, it becomes clear that around 40% of the projects are not more than 10 years old. Meanwhile, BBR has the most projects (400) and the oldest references (50 years). Only 5% of the projects are more than 30 years old and the average age of all executed projects is 14 years. If the reference data of all players were considered, the average age of the structures would even be younger. So, it is not surprising that there are only very limited known major problems reported on cable stayed bridges, as the average cable supported structure is still extremely young compared to their expected life of 100 years. Most structures are nowhere near their critical fatigue life and other ageing effects are not yet visible.

## ELIMINATING RISK

Amongst the reported problems worldwide are corrosion on the cables, corrosion and leakage at the anchorages, fretting fatigue, damage of the cables and cable vibrations.

### Corrosion protection

Targeting a 100-year life requires a high level of corrosion protection for the cables – making directly exposed cable surfaces such as locked coil and bar cables obsolete for anything other than architectural applications. Additional considerations should be given to the replaceability of the key components.

### Leakages

Leakages observed at the anchorages have been addressed by specific leak tightness tests, whereas the leak tightness test, as per fib specifications, is the most suitable one and successful completion of the specific leak tightness test is mandatory.

### Prohibit grout

Given today's increased life expectation of 100 years for stay cables, the usage of grout in contact with bare or galvanized single tensile elements in the free length of the cable, over a sadle or as a bonding agent for load transfer at the anchorage should be prohibited because of:

- possible interaction of grout with galvanized single tensile elements, which may lead to hydrogen brittleness
- the poor long-term corrosion protection due to the natural cracking of the grout under the cyclic loading on the stays repetitively reported fretting fatigue observed especially on strands emended in conventional grout
- the fact that grouted stays are hardly re-tensionable

Costly special epoxy grouts and perfect injection techniques on site have shown satisfactory results for wire stays in the past – 50-year old grouted stays are still in service. However, given today's demand for independent multi-level corrosion protection – for forgiveness during installation and long-term redundancy – grout should not be used in direct contact with the strands or wires.

### Specialist repairs

Early repairs of cables that have been

301

**2002 – BBR No.325**

RAMA VIII Bridge in Bankok, Thailand, completed in 2002 and featured on the 20-baht banknote. With a 300 m main span, the bridge is also one of the world's longest single pylon cable stayed bridges

*Ormiston Road Bridge, New Zealand's first (2008), Number 393*



damaged during installation, accidents or cable vibrations events should be con-tracted to specialist stay cable companies.

**Installation specialists**

An important lesson learned on strand as well as wire stay cables – especially by owners and contractors – is that cable installation is the work of the specialist who also provides the stay cable technology. Practices of the past, where only supply of fully or partially prefabricated stay cables has been contracted to the system suppliers must be avoided.

**Cable vibration**

Even newly constructed cable stayed bridges have experienced quite severe vibrations which may result in failures of cables. A careful evaluation is therefore always required and countermeasures, such as dampers are highly recommended.

**Design of long cables**

Care should also be taken when designing long cables. Effects, such as the sag of the cable on the effective damping, rotational bending stresses and other effects can only be appreciated for long cables.

## CONTINUOUS IMPROVEMENT

To achieve the desired 100-year design life, detailed consideration of all aspects is crucial and stay cable specialist companies, such as the BBR Network, must continue to develop and promote use of the latest technology and expertise in its deployment.

**2008 – BBR No.400**

Most recent international landmark structure, the recently opened Serreria Bridge in Valencia in 2008, designed by engineer and architect Santiago Calatrava.

400

# Benchmark for TEST PERFORMANCE



**BBR stay cable systems are the benchmark in terms of test performance and BBR stay cable technology has regularly fulfilled higher testing and performance criteria – even years before such testing conditions have been adopted and specified in codes and recommendations.**

## RECENT TESTING

Impressive evidence of the leading role of BBR in relation to testing are the tests executed successfully, over the past 24 months, on the BBR HiAm CONA strand stay cable system:

- Axial fatigue and subsequent tensile test according to fib, with a stress range of 200 MPa and angular shims of 0.6 degrees at the anchorages on various small, medium and large tendons sizes.
- Static as well as axial fatigue and subsequent tensile test according to fib on the BBR HiAm CONA pin connector.
- Axial fatigue and subsequent tensile test according to SETRA, with a stress range of 200 MPa and an angular rotation of 0.6 degrees at the anchorages on a monstrous 127 strand BBR HiAm CONA cable.
- Axial fatigue and subsequent tensile test according to SETRA for extradosed applications using saddles with a stress range of 140 MPa and an upper load of 55%.
- Leak tightness test according to fib with axial, rotational and temperature cycles, while BBR HiAm CONA is the only system where the sealing can be replaced on an individual basis as part of single strand replacement operations.

## GOING THE EXTRA MILE

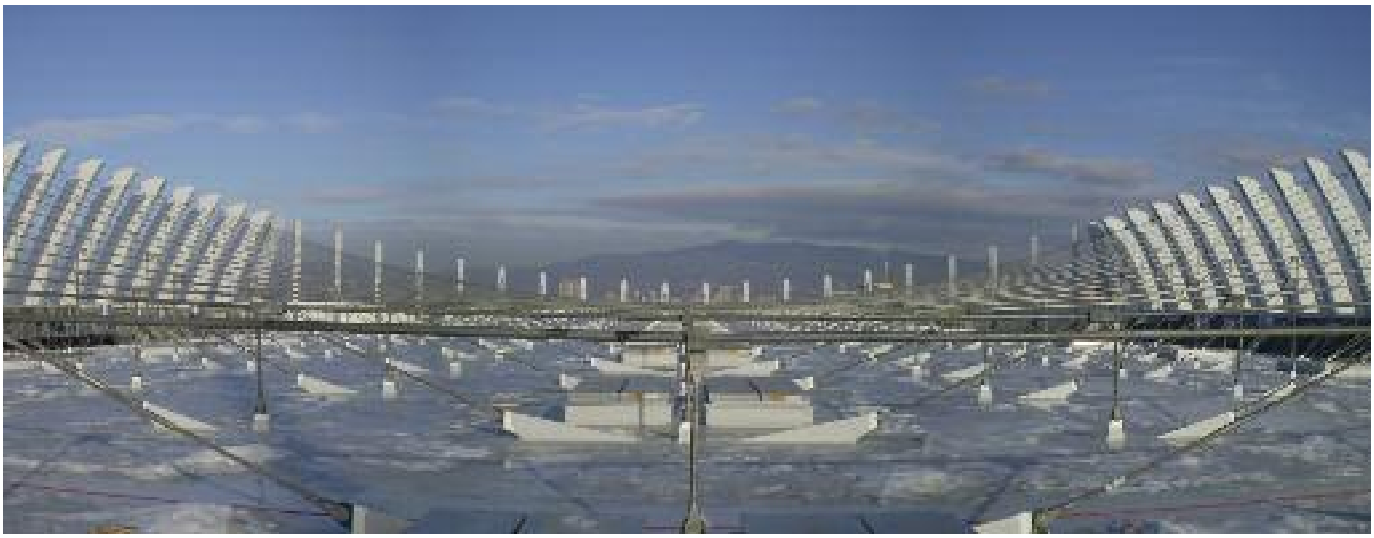
The leading position of BBR is particularly highlighted by the tests, recently executed, with parameters exceeding the traditional requirements of fib and PTI. The following is a selection of benchmark tests carried out successfully on the BBR HiAm CONA system:

- Axial fatigue and subsequent tensile tests with upper loads and stress ranges exceed the commonly specified 200 MPa stress range and 45% upper load. In such fatigue tests, we achieved a 300 MPa fatigue resistance and 55% upper load.
- Bending fatigue test with applied rotations at the anchorages of 1.2 and 2.8 degrees for 2.0 million and 0.2 million respectively.
- BBR Square Damper efficiency test with cable tensions ranging from 25% to 45% in 1st to 5th modes, on a BBR HiAm CONA stay cable model representing a 450 m cable length. This test is especially noteworthy as cables of this length with low tension experience second order effects due to large sag, which makes many common dampers ineffective – not so the BBR Square Damper.
- Multi-million cycle wear and durability test on BBR Square Damper, proving the endurance and minimal maintenance requirements of this advanced damper.

Obviously, the tests have been executed with strands of the highest tensile resistance available on the market – strands with a resistance of 1860 MPa with a cross section of 150 mm$^2$ and a breaking strength of 279 kN. Many stay cable suppliers still work with strands of 1770 MPa capacities or cross-sections of 140 mm$^2$. Compliance tests for such lower capacity strands have naturally also been executed on the BBR HiAm CONA system.

Tests in the pipeline are a series of 10 million load cycle tests with stringent parameters compared to fib and PTI requirements. Ten million load cycle testing may be relevant for the future application of stay cables for supporting wind turbine towers.

# *Grand* spectacle



**The Zagreb Arena is an enterprise of major dimensions and on a grand scale – it is a public building the like of which has not been built in Zagreb, or indeed Croatia, for decades. Months before completion, the Zagreb Arena had already become one of the landmarks of the city. BBR Adria proudly reports on their crucial contribution to the Arena's striking external appearance.**

THE ZAGREB ARENA, CROATIA

Zagreb Arena is located in the southwestern part of Zagreb and the site will also include the Arena Center – expected to be the largest shopping-entertainment center in the city. Together, they will share a series of services such as a joint parking lot, multiplex cinema, wellness center, numerous restaurants, cafes and stores. BBR Adria will also have a considerable role in the building of the Arena Center, which will certainly be reported in the next edition of *CONNAECT.*

## PROJECT LAUNCH

A public tender for the construction of a 15,000-seat stadium to host the 2009 World Men's Handball Championship was held by the Croatian Government and the City Government of Zagreb.
They selected a consortium comprised of property developers – TriGránit (Hungary) – and Ingra (Croatia) who, in turn, engaged studio UPI-2M from Zagreb, to create and produce a unique design for the Zagreb Arena. The construction of the sports hall started in July 2007 and was completed, as planned, in December 2008.

## BUILDING VISION

During the schematic design stage, the development of spatial and functional characteristics – to enable maximum flexibility of the venue – was vital. The structure is closed inwards, in the form of a shell, which reduces the span and, to a degree, provides cover for the area.
The roof structure – reminiscent of the structure of a suspension bridge – enables the slender 45 cm roof structure to cover a span of 110 m. In a way, the roof is floating over the hall. Cables and bars expand and contract with shifting temperatures, thus the position of the roof changes – together with whatever is suspended from it. In addition, over the years there will be deformation in the ribs, therefore, the roof is very flexible and getting it into the right geometric position was a challenging task.➔

## SMOOTH SEQUENCING

Resembling a giant rib cage around the building, 86 large curved concrete columns –lamellas – form the main façade and support the roof structure and the semi-translucent polycarbonate building envelope which allows various illumination effects to be used. BBR Adria prestressed all the lamellas using the BBR VT CONA CMI system. We installed 214 t of strand, together with 680 anchorages.

Within six months, the columns had been prefabricated on site, lifted with a crane, vertically rotated through 90 degrees, transported and fixed on the structure. Prestressing enabled all these maneuvers of the heavy lamellas to be performed without any additional temporary reinforcement – and just three or four days after casting the concrete.

After the ring of columns was completed, we moved onto the second part of our contract which was for embedding and stressing the main cables. The architectural cables are 100 – 125 m long, 66 mm in diameter and each has a characteristic resistance of 2,636 kN. They carry the 2,000 t heavy structure made of double-T profiles, together with 300 t of auxiliary structures and equipment. This turned out to be a very delicate job – and more complicated than originally perceived. In the third stage of our work, 567 bar tendons were connected to the main cables which were awaiting connection to the roof. Vertical bars were connected first, as they were designed to carry the roof. At the very end of roof suspension operations, diagonal bars were added to provide lateral stiffness. Next, we embedded and installed 34 stay cables – both vertical and diagonal – which were designed to give stiffness in a perpendicular direction.

Finally, after all the stages of suspended roof construction which lasted for five months, the roof could be adjusted and also some small errors fixed. Then the Arena was weathertight and ready for the final works – façade, auxiliary structure connected to the roof, ventilation, air conditioning, lighting, telescopic stands, visual identities, pavements, security, acoustics, sound and sport equipment. There were often around thousand people on the site.

That's not the end of our involvement here though – with a requirement for regular maintenance of the main cables and connecting bars, together with periodic adjustments to the entire roof, additional work for BBR Adria is assured in the future.

**"Complete co-operation – BBR Adria was perfect. Experts on the site were always available, excellent communicators, they respected and executed decisions and agreements and even worked on Sundays and holidays without any objection. My only suggestion to BBR Adria is that they should never again say they are small company – because they are great."**

**Tomislav Sindler,**
Ingra, co-ordinator for Arena roof construction

## Facts and figures

| | |
|---|---|
| Arena volume | 367,054 $m^3$ |
| Arena area | 27,337 $m^2$ |
| Span of suspended roof construction | 103.6 m |
| Height of facade rib | 28-37 m |
| Concrete volume | 95,000 $m^3$ |
| Reinforcement quantity | 9,500 t |
| Weight of façade ribs | 160-220 t |
| Weight of roof structure | 2,000 t |



## JUNGLE ACTION

Imagine a jungle of ten rotating tower cranes, four giant caterpillar cranes manipulating lamellas and stretching heavy main cables across the site, numerous machines, vehicles and personnel, working like ants around the clock ... and all the co-ordination and logistics required!

But that was not all, our Arena project was growing up under the watchful eye of both City authorities and the general public, particularly as the Championship opening ceremony drew nearer – this imposed further, unnecessary, pressure on everyone involved.

In fact, from the drawing board to the opening ceremony, the Zagreb Arena project was an extraordinary challenge. One could have sat on the upper stand of the unfinished Arena all day – with popcorn and cola – enjoying the show, like some great action movie with a happy ending!

A few months after the project had been completed, the customer satisfaction form returned from our client and surprised us a bit – we received straight 'A's' for all aspects of our collaboration and work on this project.

Meanwhile, following the Championships, the Arena is now being used for numerous kinds of sports and competitions – together with various concerts, exhibitions, fairs, conventions and congresses.

The simple, elegant and efficient structural concept of the Zagreb Arena was recognized at the World Architecture Festival in Barcelona (4-6 November 2009), where it was declared the outright winner in the 2009 structural design category. The external inward leaning ribs, braced by a ring beam, supported the suspended roof – and the pre-stressed prefabricated columns were a huge undertaking in their own right.

### TEAM & TECHNOLOGY

**OWNER** City of Zagreb

**MAIN CONTRACTOR** Ingra

**DESIGNER** UPI–2M

**TECHNOLOGY** BBR VT CONA CMI internal Architectural Cable Bar

**BBR NETWORK MEMBER**
BBR Adria d.o.o. (Croatia)

# Seismic resistant innovation

ALAN MACDIARMID BUILDING, VICTORIA UNIVERSITY, WELLINGTON, NEW ZEALAND

**The Alan MacDiarmid Building at Victoria University's Kelburn Campus is New Zealand's first multi-storey unbonded post-tensioned precast concrete building – and represents some national and world first applications of PRESSS technology. Bojan Radosavljevic presents a report and comments on BBR Contech's contributions to this exciting new technology.**

The technology is significant because it has revolutionized design in earthquake engineering and has done so by introducing advanced technical solutions for seismic-resistant precast / prestressed concrete buildings. At the heart of this innovative approach are jointed ductile connections – or PRESSS (PREcast Seismic Structural System) Technology – and the system was developed in the USA.

In a 'dry' jointed ductile solution, precast elements are jointed together by unbonded post-tensioning tendons or bars. The inelastic demand is accommodated with a 'controlled rocking' motion of the connection itself. Protection of the rocking interface means a significantly reduced level of damage can be achieved. Moreover, the self-centering from the unbonded tendons can bring the building back to its vertical position with no permanent / residual displacement.

All typical advantages of off site prefabrication (quality control, speed of erection) and prestressed elements (long span, open spaces) are also maintained.

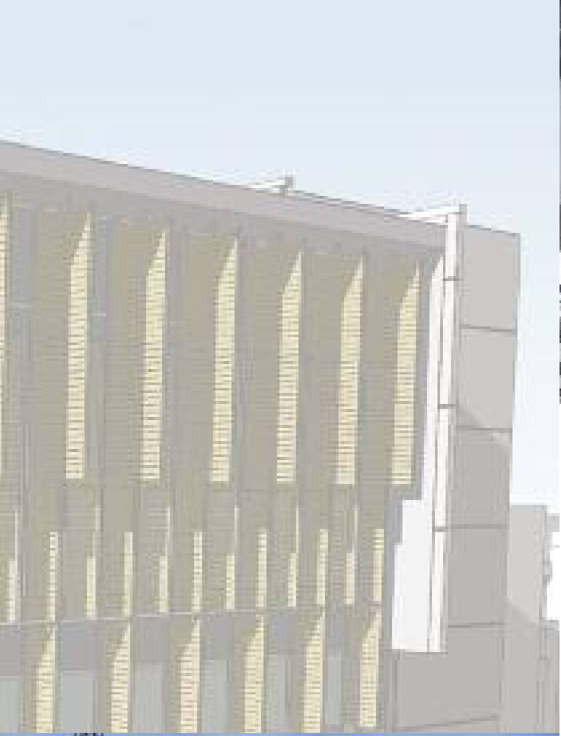
Unbonded post-tensioning divides the building's seismic actions into 'spring' and 'shock-absorber' mechanisms. This delivers advantages over conventional structures:

- The building is very stiff until the springs begin to yield at which time they become very soft.
- The springs return the building to vertical even after extreme earthquakes.
- The shock absorbers can be detailed to be removable, further reducing the whole of life cost of structural rehabilitation in high seismic areas.

Unbonded post-tensioning provides the spring action. The joints – between beams and columns and the shear walls at the ground – rock. The post-tensioning acts to clamp these joints closed and hence spring the building back to vertical. The shock absorbers – in this case, controlled yielding reinforcing bars – provide damping.

Victoria University recognized the long term benefits of this construction technology at an early stage and also understood the need for close collaboration and a capable design and construction team. There were careful checks and balances throughout the design and consenting process. Key members of the team included:

- Victoria University of Wellington – Ian Maskell, VUW Project Manager



- Dunning Thornton Consulting Limited – principal designer
- Stefano Pampanin, University of Canterbury / PRESSS Ltd – peer reviewer
- BECA Consultants – advisor to Wellington City Council as consenting authority
- Mainzeal Property and Construction Ltd – Head Contractor.

In addition to this, any identified concerns were offset by agreeing that a high-level overview would be conducted by Nigel Priestley, who was involved in much of the pioneering research in California as a co-ordinator of the PRESSS Program.

The building comprises four suspended floors of science teaching and research space built over a flexible lower entry area used for teaching and conferences.

The post-tensioning requirements for this type of structure were developed to be relatively generic and BBR Contech was appointed to complete the works using the BBR CONA post-tensioning system.

The building comprises six three-bay concrete frames carrying double-tees spanning 9.9 m. The frames span 8.4 m and because its members are post-tensioned, sizes were kept to 0.60 m by 0.45 m for the beams and 0.60 m by 0.55 m for the columns. The beams were pre-tensioned off-site for gravity loads and to minimize dead load / erection sag, then they were centrally post-tensioned through the columns using BBR CONA unbonded tendons to provide the rocking / re-centering mechanism.

There are a total of 21 beam lines containing post-tensioning in the building, each with a central BBR CONA unbonded tendon approximately 25 m long and ranging in size from 0505 -1505. The external columns are also vertically post-tensioned, each with two BBR CONA unbonded 0205 tendons to resist overturning loads and to assist with the rocking mechanism and recentering capability at their base.

Energy dissipation is provided by external devices which are bolted to the pre-cast beams and columns. This allows these 'plug-and-play' devices to be replaceable after a major event.

In the longitudinal direction, the building is braced by four 3.08 m x 0.4 m shear walls. These walls were coupled into pairs by three 0.61 m deep steel beams to provide the hysteretic energy absorption. The advantages of coupled rocking / post-tensioned walls have been extensively proven.

In this case, the two mechanisms of these hybrid systems are separated – the energy dissipation is provided by flexural yielding of the steel coupling beams, while the re-centering is given by the rocking motion at the base and the top of the shear walls. This lowers the stress on each respective joint and so allows simpler detailing. BBR Contech supplied and tensioned the 75 mm diameter bars used for the vertical post-tensioning.

An innovative feature is the incorporation of a capping wall across each pair of shear walls which allows them to rock, both at the base and at their top, for the same amount of vertical post-tensioning.

As with any 'first', this project involved extensive attention to detail – in analysis, design and understanding assembly – far in excess of conventional buildings. The capability and collaboration of all parties associated with the project is a testament to its success.

Any current price differential between PRESSS technology and conventional construction systems will close over time, as the range of advantages offered by PRESSS are recognized and quantified within life-cycle project cost analyses.

## Supreme winner

The excellence of the Allan MacDiarmid Building – as well as the teamwork and technology involved in its realization – was recognized at the 2009 Concrete Awards ceremony held by the New Zealand Concrete Society. The project was declared the winner in the Technology category, then voted Supreme Winner of all the categories and presented with the 2009 Concrete Award. Pictured here is New Zealand Concrete Society President Dene Cook presenting the supreme 2009 Concrete Award to Alistair Cattanach of Dunning Thornton Consultants who accepted the award on behalf of the entire project team.

It was a particularly successful evening for BBR Contech, as their work on the Ford Building and Ormiston Road Bridge was also recognized.

BBR Contech would like to acknowledge Alistair Cattanach, Director, Dunning Thornton Consulting Limited, Wellington; Stefano Pampanin, Senior Lecturer, University of Canterbury, PRESSS Limited, Christchurch; Mainzeal Property and Construction Ltd; and Victoria University of Wellington in the preparation and publication of this article. The permission to use content from a similar article published by The Cement & Concrete Association of New Zealand is also acknowledged.

**TEAM & TECHNOLOGY**

**OWNER** Victoria University of Wellington

**MAIN CONTRACTOR**
Mainzeal Property and Construction Ltd

**ARCHITECT** Jasmax

**STRUCTURAL ENGINEER**
Dunning Thornton Consultants

**PRESSS REVIEWER**
Stefano Pampanin / Nigel Priestly

**TECHNOLOGY** BBR CONA unbonded

**BBR NETWORK MEMBER**
BBR Contech (New Zealand)

TEMPLE OF GOD PROVIDENCE, WARSAW, POLAND

# Heavenly lifting

**The Temple of God Providence in Warsaw will be one of a kind. The structure is a huge cross on plan with a temple inside. The top of the dome will be around 50 m above ground level. BBR Polska has supplied the specialist heavy lifting know-how for this unique project.**

The four sides of the cross are formed by the four so-called 'bridges' which join four huge pylons. The 'bridges' were made at ground level and then lifted to their final location at the top of the pylons.

The weight of the 'bridge' is 780 t and the lifting height was about 26 m. The minimal distance between the 'bridge' and the pylon wall during the lifting operation was approximately 30 mm – therefore we had to take special care when operating the jacks. For this operation, we used a four jack lifting system.

BBR Polska's scope of work included concept development, general and detailed design of the lifting operation, including structures for supporting the jacks and working platforms, in collaboration with structural designers SDS Sp. z o.o., and executing four complex lifting operations.

**TEAM & TECHNOLOGY**

**OWNER / OPERATOR** Diocese of Warsaw

**MAIN CONTRACTOR** Warbud S.A.

**DESIGNER**
BBR Polska Sp. z o.o. and SDS Sp. z o.o.

**TECHNOLOGY** Heavy lifting

**BBR NETWORK MEMBER**
BBR Polska Sp. z o.o. (Poland)

# FIRST FOR INDIAN CRICKET

DY PATIL CRICKET STADIUM, NERUL, NAVI MUMBAI, MAHARASTRA, INDIA

**For the first time, long span curved cast in-situ post-tensioned beams have been adopted for a cricket stadium in India. Mr Virendra Hukum Singh and Mr Manjunath from BBR (India) Pvt. Ltd jointly report on the company's work to design, supply and install a post-tensioning system to eliminate roof supports – resulting in an unobstructed view of cricket matches for spectators.**

The international cricket stadium construction project was initiated by the Nerul-based DY Patil Sports Academy which is part of the DY Patil Education Society.

The stadium boasts all facilities associated with an international cricket stadium capable of seating 60,000 spectators. The stadium also has additional sports facilities – including five outdoor tennis courts, two indoor badminton courts, three squash courts and an Olympic-sized swimming pool. However, the most prominent feature of the new stadium is the cantilever roof which gives spectators a clear, uninterrupted view of match play. Main structural consultant, Eco Design India (P) Ltd, invited us to design a post-tensioned solution which would achieve large spans with a shallow beam depth to give sufficient headroom to allow clear sightlines for spectators all around the stadium, as required by both the client and architect. The brief also called for a lighter structure through increased grid spans and reduced steel sections – as well as cost savings.

## GENERAL DESIGN ASPECTS

This cricket stadium, designed by a leading architectural practice – Architect Haffez Contractor – features a cantilever roof supported by curved post-tensioned concrete beams, at Levels 3 and 4, around the whole circumference of the building. Level 3 and Level 4 consist of two beams of 60.20 m span in the Media Center and six beams of 53.20 m span in the cantilever roof area, with continuous support between the seismic joints. To allow stressing operations to proceed without hindrance, a five meter long blister was designed at the continuous support location.



"THE BRIEF ALSO CALLED FOR A LIGHTER STRUCTURE THROUGH INCREASED GRID SPANS AND REDUCED STEEL SECTIONS – AS WELL AS COST SAVINGS."

On Level 3, the post-tensioned beams for the Media Center consist of four BBR CONA internal 1905 tendons to the left and two tendons to the right of the continuous support, with a stressing end at a blister either side. The continuous post-tensioned beams for the cantilever roof consist of four BBR CONA internal 1905 tendons to the left and right of the continuous support, with a stressing end at a blister on either side.

At Level 4, the Media Center post-tensioned beams consist of two BBR CONA internal 1205 tendons on the left and four tendons on the right side of the continuous support, with a stressing end at a blister on either side. Meanwhile, for the cantilever roof, the continuous post-tensioned beams consist of four BBR CONA internal 1205 tendons on the left and right of the continuous support, with a stressing end at a blister on either side. The uniform post-tensioned beam size of 750 mm width and 2,500 mm depth was designed for beams in both Level 3 and Level 4.

The concrete grade adopted was 40 MPa at 28 days and 32 MPa at transfer of prestressing force to tendons. A total of 64 t of 12.70 mm LRPC HT strand was used for this project.

## POST-TENSIONING TENDONS

For stressing, LP-300 multi pulling jacks were installed at the blister from the inner edge of the beam. For single stage stressing, the designed jacking force for the 1905 tendon is 2,617 kN and for the 1205 tendon the force is 1,677 kN – 75% of UTS of the HT strand. Stressing was performed when the concrete had achieved 80% strength.

## BENEFITS

By taking advantage of post-tensioning technology for cast in-situ beam construction, the client has secured the benefit of a shallow beam depth over a large continuous span, a lighter structure – and ultimately cost-savings. Meanwhile, early deshuttering led to speedier construction and saved program time. It is clear that the customer was delighted, as we have achieved a rating of 95% in our Customer Satisfaction Report.

### TEAM & TECHNOLOGY

**OWNER** DY Patil Sports Academy
**MAIN CONTRACTOR** M/s Bitush & Rajeev Construction Pvt. Ltd
**DESIGNER** Eco Design India (P) Ltd
**TECHNOLOGY** BBR CONA internal
**BBR NETWORK MEMBER** BBR (India) Pvt Ltd

# World record capacity anchors

Recently revised dam safety standards, combined with the existing ground anchors having reached the end of their service life, have prompted a refurbishment of Catagunya Dam. Mark Seisun from Structural Systems explains how existing ground anchors are being replaced with world record capacity anchors – using BBR VT CONA CMG 9106 technology.

Catagunya Dam is owned and operated by Hydro Tasmania and is located in central Tasmania. The dam was constructed in the early 1960s and is one of a series of eight dams on the Derwent River. Catagunya Dam has significant engineering heritage value – it was the first post-tensioned dam constructed in Australia and at the time of construction was the highest dam in the world to use post-tensioned anchors. The dam is 365 m wide and 48 m high, with its spillway 126 m wide and 43 m high. The dam's power station has twin 24 MW turbines, each consuming up to 60 m$^3$ of water per second.

Recent investigations concluded that the 412 original anchors were at the end of their useful life. The replacement anchors incorporate the 9106 anchoring technology – previously developed and utilized by Structural Systems as a world first in our 1999 Canning Dam project – but, with reduced availability of anchor locations, even higher capacity was sought. This led to the adoption of 91 x 15.7 mm strand tendons in lieu of 15.2 mm strands – 279 kN versus 261 kN MBL – setting new world records for permanent ground anchors, with an MBL of 25,389 kN, test load of 19,415 kN (1,980 t) and lock-off load of 17,772 kN (1,812 t).

Structural Systems is at the leading edge of development and execution of high capacity anchors, having built an extensive portfolio of projects and high acclaim, with other records of the longest ground anchor (142.02 m) and the heaviest ground anchor (over 16.5 t) on the Canning Dam project.

The works incorporate 92 91-strand vertical anchors up to 77.8 m long, embedded up to 30 m into hard dolerite rock below the dam. The 53 spillway anchors are located 8.5 m below the crest on the 56 degree slope, and the remaining 39 are in the abutments.

The anchorages developed and incorporated are BBR VT CONA CMG 9106, fitted with

low friction strand entry transitions and external threading for future monitoring, utilizing a purpose built load cell, at approximately five year intervals throughout the anchor's life.

The use of the 9106 anchoring technology for the project has resulted in key benefits for the client – reduced costs and construction duration, whilst retaining the dam's engineering heritage value through an anchored solution.

Since the dam already contains 412 ground anchors, finding space for the replacement anchors amongst the existing ones was challenging. The 92 high capacity 9106 anchors, replace the obsolete anchors and also provide a significant increase to the dam's safety against flood and earthquake.

Catagunya Dam poses several significant installation challenges – including the installation of anchors where the spillway is five meters below the only access via the abutment. The solution involved the re-engineering of the installation frame to operate straddling the two levels.

Additionally, the installation of the longest anchors (77.8 m) is on a short abutment with inadequate approach distance, requiring a solution where a roller system is deployed to bend the anchors around a horizontal 105 degree corner prior to reaching the installation frame.

Each of the anchor's 91 strands are greased and sheathed over the free length, with the remaining 11.4 m of bare bond length strand secured via grouting to the neighboring rock. A heavy duty HDPE corrugated sheath, developed specifically for the project, provides primary corrosion protection in a flexible, but impermeable membrane encapsulating the entire anchor over the 100+ year design life.

The anchors are fabricated on site using specialist equipment to open each strand, fully greasing each wire, then reforming the strand and installing it into a 20 mm HDPE sleeve over the free length. To maximize load transfer into the surrounding rock, the bare bond length is cleaned and assembled to create an hourglass effect.

The completed 9106 tendon is transported to the dam on purpose-built trolleys. Initially, the corrugated and subsequent smooth polyethylene sheathing is installed into the anchor hole by fusion welding of the 7.5 m individual lengths.

Installation of the tendon into the installed sheathing is achieved with a custom frame. A large braking winch controls the rate of anchor descent. The anchor is suspended in the hole and grouted in three stages with Class G Oilwell Cement in the bond length and GP Cement for the free length. After 28 days of grout curing, the anchors are stressed to their test and lock-off loads with a 2,200 t capacity hydraulic jack.

The anchoring works commenced in January 2009 and are scheduled for completion in June 2010 and, although the works are in their early stages, both the Structural Systems team and Hydro Tasmania client are very satisfied with the progress to date – and highly confident of successful project completion, achieving the project's safety, budget and program goals.

**TEAM & TECHNOLOGY**

**CLIENT & MAIN CONTRACTOR**
Hydro Tasmania

**TECHNOLOGY** BBR VT CONA CMG ground

**BBR NETWORK MEMBER** Structural Systems Limited (Australia)

MALIAÑO BRIDGE, SANTANDER, SPAIN

# Delivery for docks

**This road and rail bridge, connecting Maliaño and Raos docks, has been constructed to enhance trade in the Port of Santander – and relieve one of the town's major streets from around 200 heavy vehicle movements per day. Local traffic and residents will benefit too – and harbor front street, Marqués de la Hermida, can now be transformed into a seafront promenade. David Olivares Latorre of BBR PTE describes the project.**

The 275 m composite steel bridge has three spans – the central span is a twin bascule bridge with 36 m long deck sections. This central span is supported on two massive reinforced concrete blocks and anchored on piled foundations.

We were commissioned to position the four deck sections – perhaps the most interesting part of the entire project – involving two 100 m long side spans and the two central bascule sections.

By working with tide timetables, the deck stretches were positioned using the rising and falling tides – which, on some occasions, created a height differential in the water level of over three meters.

The composite steel decks were assembled, adjacent to the bridge superstructure, over a specially-equipped barge – ready for shipping. For the two 100 m end spans of the bridge, we used four 200 t elevation jacks placed at strategic locations. The bridge sections were loaded onto a barge and positioned in their correct places at high tide. While the tide was still at its peak, each deck section was secured in its final position with the help of topographical instruments. Then, as the tide slowly ebbed, the structure came to rest on the vertical jacks and it was moved with a manual pulling operation.

The same procedure was followed for the two central bascule sections – with one notable addition, in the middle of the bridge, the two central bascule decks needed millimetric precision to create a perfect join between them in the centre of the bridge. As manual pulling was not efficient enough, we welded two 20 t hydraulic traction jacks to the structure and these provided very effective horizontal movement.

**TEAM & TECHNOLOGY**

**OWNER** Santander Port Authority

**MAIN CONTRACTOR** FCC Construcción S.A.

**DESIGNER** MC-2

**TECHNOLOGY** Heavy lifting

**BBR NETWORK MEMBER**
BBR Pretensados y Técnicas Especiales, S. L. (Spain)

INFRASTRUCTURE PROTECTION WORKS, DEAD SEA, JORDAN

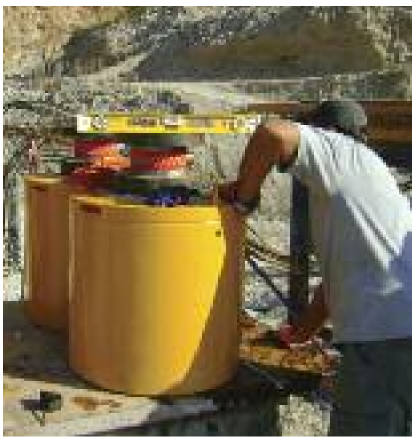
# Dealing with deluge danger

**In April 2006, a major flood took place which left massive damage and erosion in its wake and also threatened Mujib Bridge and Mujib Pump House. The city of Amman relies on the pump house to deliver between 40 and 50 million cubic meters of fresh water each year. BBR Network member, Marwan Alkurdi & Partners, was contracted for specialist engineering works designed to protect the vital infrastructure.**

The objective of the project was to protect the area under Mujib Bridge with adjacent 1.2 m diameter piles, up to 15 m deep – for a total length of 3,600 m, as well as providing a concrete raft supported on 1.2 m diameter 20 m deep piles under the bridge.

Other special works included reconstruction of the Ogee weir using High Performance Concrete (HPC), protection of the side of the Wadi with 15 m deep 1.2 m diameter adjacent piles for a total length of 7,900 m and the protection of the downstream area of the Irish Crossing with 1.5 m boulders.

As required by the client, a preliminary pile load test was carried out on the foundation piles for the protection works at the bridge and the carrier pipes at Mujib. This involved a vertical test load to 13,400 kN – twice the vertical working load which had been calculated.



For this high load test, we had to design and construct four reaction piles and used 16 anchor heads. The load was imposed on the test pile head by means of two hydraulic jacks with a combined capacity of 22,000 kN and the load was measured with a load cell. A cross-check of load measurement was carried out via pressure gauge against a calibration table for the hydraulic jack.

After completing the test and analyzing the results, the final settlement – at working load (6,700 kN) and after a holding time of 60 minutes – was 1.83 mm, while the final settlement at a test load of 13,400 kN, after 360 minutes, was 5.85 mm.

The residual settlement after the first cycle at 6,700 kN was 0.81 mm and, after the second cycle at 13,400 kN, was 2.35 mm.

**TEAM & TECHNOLOGY**

**CLIENT**
Ministry of Public Works and Housing

**MAIN CONTRACTOR**
Marwan Alkurdi & Partners Co. Ltd

**DESIGNER**
Dar Al-handasah (Shair and partner)

**TECHNOLOGY** Heavy lifting

**BBR NETWORK MEMBER**
Marwan Alkurdi & Partners Co. Ltd (Jordan)

WIND FARM, LAKE VÄNERN, SWEDEN

# WIN-WIND SITUATION

**Wind energy as a power source is an attractive alternative to fossil fuels because it is plentiful, renewable, widely distributed, clean – and produces no greenhouse gas emissions. Wind power accounts for about 1.5% of worldwide electricity usage and is growing rapidly, having more than doubled between 2005 and today.**

Recently, a wind farm has been built in Lake Vänern – the largest lake in Sweden. **Spännteknik,** the BBR Network member in Sweden describes their role in delivering the Vindpark Vänern wind energy project.

Covering an area of 5,655 km$^2$, Lake Vänern is the third largest lake in Europe, located in southern Sweden. The wind farm site is about 8 km from the lake shore and, together, the ten new 90 m tall wind turbines will provide an installed energy capacity of 30 MW – it is estimated that annual output will be 90 million kWh.

Our contract was for provision and installation of rock anchors for the pylons. Foundations were needed at a depth of between 3-13 m – although the lake is, in places, up to 106 m deep – and, by using divers, the key tasks were executed successfully.

The round 6 m diameter foundations had been prefabricated in 1 m high sections which had recesses for the cables. Each foundation was

# Technical insight:

## Post-tensioned concrete windmills

To meet the ever increasing demand, wind energy towers will need to become taller – and post-tensioned concrete plays an important role in realizing the full potential of wind energy. Concrete tower solutions are adaptable and durable and offer long life performance with minimum maintenance. The use of precast or in-situ PT concrete, rather than steel, in the construction of wind farms offers several advantages to owners and operators.

- Reduced maintenance costs and long-life performance – through comparative durability of concrete over steel.
- Up to 15% higher energy production – PT concrete pylons can be 30-40 m higher.
- Lower transportation costs – casting is not highly specialized and can be carried out near the site.
- Design and construction flexibility – versatility of concrete enables design solutions with no restrictions on height or size.
- Dynamic performance – PT concrete has inherently high damping properties and can deliver fatigue resistance solutions with less noise emissions.

Taller wind towers need greater structural strength and stiffness to carry both the increased turbine weight and bending forces from wind action on the rotors and the tower and also to avoid damaging resonance.

Key issues are the minimization of material content and structural weight and reduction of construction time. In-situ slipform construction overcomes the problems of transporting large tower rings or sections and need for large cranes for erection.

The ability to pre-stress concrete means that individual wind tower structures can be tailored to provide optimal levels of stiffness and dynamic performance using post-tensioned tendons.

Ducts can be incorporated into both precast concrete units and in-situ concrete – either located within pylon walls or externally on the inner wall of the pylon structure. This facilitates thin, lightweight wall construction with simple access for inspection and future capacity upgrades.

A combination of internal and external tendons can be considered whereby, for instance, external tendons stabilize the tower from the base up to a defined stage and are anchored in a corbel. Internal tendons are stressed at full height from the top corbel to the base segment.

The move towards taller wind towers is tipping the balance towards PT concrete design solutions with their many advantages.

BBR VT CONA CMX products – ground anchors, band systems, internal and external post-tensioning – are well-suited to the construction of precast elements or in-situ concrete method used for wind farms. With the know-how of BBR Network members, concrete pylons could reach heights of 120 m!

anchored by 16 BBR CONA 1906 rock anchors – with a length of 25-28 m, depending on the water depth.

Our scope of work was to drill holes in the rock through the recesses in the foundations, perform a water tightness test and, if necessary, tighten the holes by cement grouting. The next step was to install, grout and stress the cables.

The cables consisted of 1906 PE-coated strand – this allowed us to grout the whole cable length, both fixed and free, in one operation.

As Lake Vänern is such a massive lake – in fact, almost an ocean – it was a tough place in which to work, especially in the sometimes very heavy wind conditions. On one occasion, we lost both a heavy compressor and our living quarters in a storm!

We have successfully completed our task – the windmills are installed and we are looking forward to our next green energy challenge.

**TEAM & TECHNOLOGY**

**OWNER / OPERATOR** Drift AB / Kraft AB

**MAIN CONTRACTOR**
PEAB Sverige AB, Sweden

**DESIGNER**
Inhouse Tech. AB

**TECHNOLOGY**
BBR CONA rock anchors

**BBR NETWORK MEMBER**
Spännteknik AB (Sweden)

SEGMENTAL PONTOON, LUMUT PORT, PERAK, MALAYSIA

# Floating concrete jetty

A segmental precast pontoon has been constructed at Lumut Port in Perak, Malaysia. The site faces the Straits of Melaka and the finished pontoon forms part of the jetty of the sea sanctuary resort. Yok-Lin Voon of **BBR Construction Systems,** the BBR Network member in Malaysia, explains how the reinforced concrete floating pontoon was built.

The pontoon is 7 m wide, 30 m long and 2.9 m in depth. It is comprised of ten hollow segments which needed to be assembled and then stitched together using epoxy and post-tensioning. The precast segments were manufactured off site, then transported to a dry dock where they were assembled and stitched together. We were invited to install the post-tensioning works for the pontoon, as we had the know-how to complete this challenging task successfully.

Each segment is designed as a concealed hollow box. Even if one box were to be partially filled with water, the water would not be able to pass into adjacent boxes – a Titanic-scenario could never happen here!

The 300 mm x 300 mm piles, acting as sleepers, were laid on the dry dock floor, spaced 1.5 m apart, to support the rail piles. Each concrete segment was lowered by a 200 t crane onto four 150 t jacks, where the levels were adjusted to suit the rails.

Then, the jack pistons were lowered to transfer the weight of the segment onto sliding steel plates resting on the rails which had been lubricated with grease. The alignment of the sliding segment with segments already assembled was maintained by guide plates which could slide over the top flanges of the guide rails. Epoxy paste was applied to the vertical face of the segment. Then the segment was pulled towards the previously assembled segments by stressing four 12.7 mm diameter temporary strands simultaneously using monojacks – each pulling about a 9 t force.

The permanent tendons are 59 BBR CONA single 15.7 mm diameter strands. The strands used were greased and PE sheathed to protect them from the marine environment. The unbonded strand was threaded through ducts cast into the segments. After stressing, the duct was cement grouted for additional protection against corrosion.

Finally water was let in, filling up the dry dock – and the completed pontoon was floated out to sea.

**TEAM & TECHNOLOGY**

**OWNER**
Marine Sanctuary Resort Sdn Bhd

**MAIN CONTRACTOR** Marina Island Construction Management Sdn Bhd

**CONSULTANT** Perunding Aziz Sehu Sdn Bhd

**TECHNOLOGY** BBR CONA unbonded

**BBR NETWORK MEMBER**
BBR Construction Systems (M) Sdn Bhd

# Sky's the limit

PEOPLE MOVER SYSTEMS, CHANGI AIRPORT, SINGAPORE

**At Singapore's Changi Airport, a new S$135 million Automated People Mover System (PMS) has replaced the existing sky-train service connecting Terminals 1 and 2 and now accommodates demands from the new Terminal 3. The PMS carries passengers between all three terminals on a total of 6,400 m of single lane, double lane and by-pass shuttle configurations guideway, connecting six stations integrated within the terminal buildings.**

Construction was carried out in two phases. The first phase (Phase 1A) started with the closure of one of the existing sky-train lanes connecting Terminal 1 to Terminal 2.

The client's contractor then retrofitted this guideway for the new systems. Construction

of the new guideways (Phase 1B) which connect Terminal 3 to Terminal 1 and Terminal 2 was carried out concurrently. The second phase started after the retrofitting works during Phase 1A had been completed. All existing sky-train services were then stopped and the client's contractor retrofitted the remaining sky-train infrastructure.

The up-stand beams – post-tensioned with BBR CONA internal – spanned between 9.6 m to 25.4 m and support the cantilever slab, running plinth, M&E equipment and the movable load from the moving carriages. We used BBR CONA flat for the post-tensioned slab which spanned up to 12 m and cantilevered up to 4.8 m – the slab thickness varies from 250 mm to 400 mm. The nature of this project demanded that we should consider additional factors during the design stage:

## Structure Systems

- **Single lane guideway** – post-tensioned beams were integrated into the structure as one of the external parapet walls, supporting the RC cantilever slab.
- **Double lanes guideway** – post-tensioned beams were integrated into the structure as the central divider, supporting the balanced RC cantilever slab.
- **By-pass shuttle / washing bay** – post-tensioned beams were integrated into the systems as the central divider and the external parapet walls, supporting the post-tensioned slab.

- Torsional moment caused by the curvature in plan for the PT beams.
- Torsional moment caused by the moving carriages running on the RC cantilever slab.
- Cyclic loading and dynamic factor caused by the moving carriages.
- Concrete cover for fire protection and exposure to outdoor weather.

With the opening of Terminal 3, the capacity of Changi Airport has increased by an additional 22 million passengers a year – and the new PMS is ready to welcome them all!

**TEAM & TECHNOLOGY**

**OWNER**
Civil Aviation Authority of Singapore (CAAS)
**MAIN CONTRACTOR** Evan Lim & Co. Pte. Ltd (Terminal 1 & 2, Guideway)
& Shimizu Corporation (Terminal 3)
**C&S CONSULTANT** CPG Consultants Pte. Ltd. (Airport Development)
**TECHNOLOGY** BBR CONA internal
BBR CONA flat
**BBR NETWORK MEMBER** BBR Construction Systems Pte Ltd (Singapore)

# Mega year in Asia

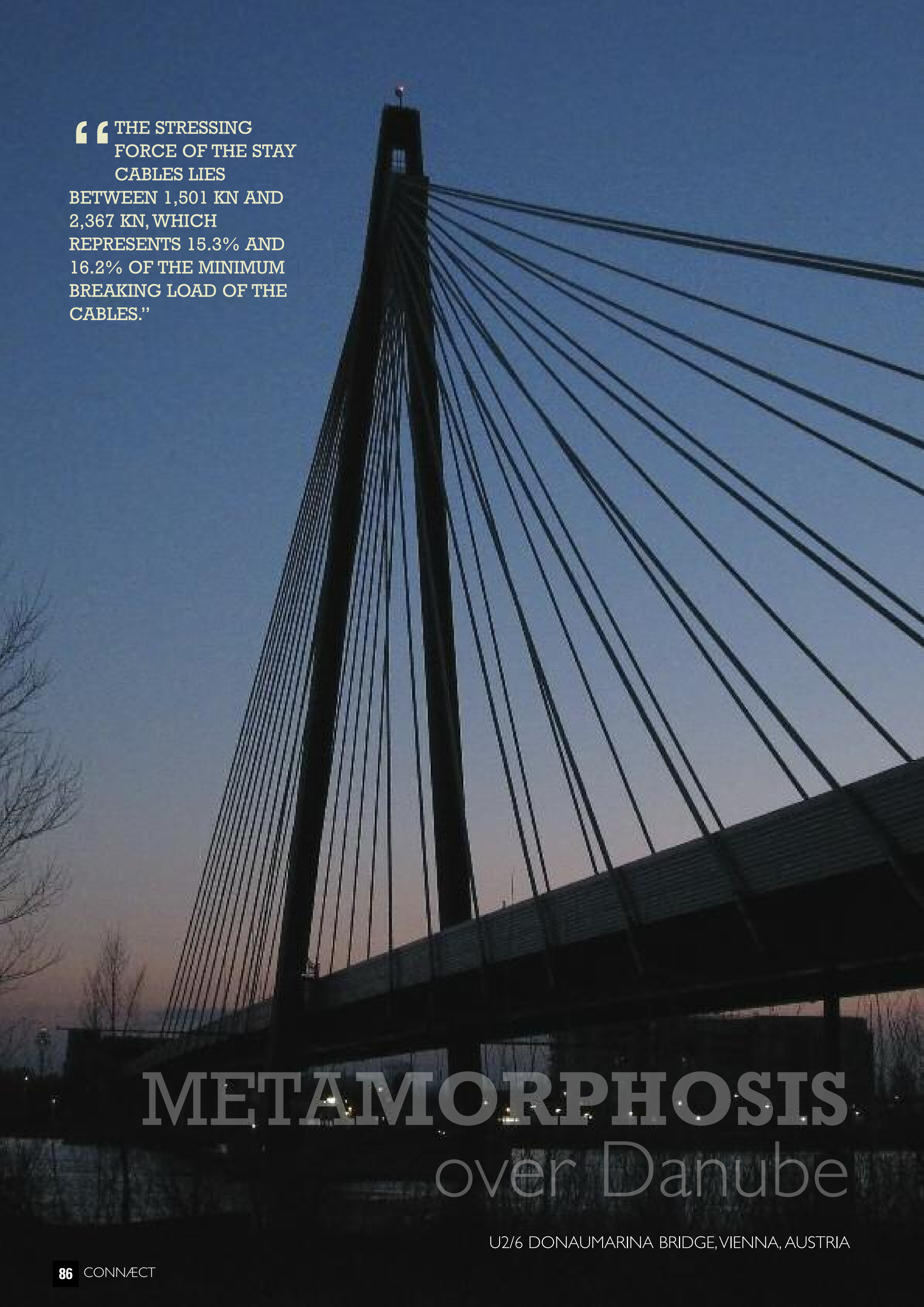
**Recently, heavy lifting and transport solutions specialist, Mammoet has been particularly busy in Asia. In a five month period, they undertook three major jack-ups with weights of up to 14,000 t and lifts of up to 23 m. The latest weighing technology – BBR WIGAbloc – was used to determine the exact loads for a safe and optimized operation.**

The SuTuVang CPP Deck project in Batam, Indonesia, involved the construction of a platform at 5.5 m above ground level and about 170 m from the quayside. The platform was jacked up using BBR WIGAbloc weighing equipment for this mega load-out of 14,000 t. This giant construction was supported by ten legs, each covering three BBR WIGAbloc load cells – with a 6,000 kN capacity each – in a triangular configuration. The unique tilt capability of the BBR WIGAbloc design distributed the load equally over the three points, ensuring an accurate loading for each leg.

The two other projects were the Angel CPP Deck (8,000 t, 23 m) in Malaysia and in Singapore, the Jurong Semi-Sub 1088 (10,000 t, 19 m).

BBR WIGAbloc load cells are measuring instruments for compression forces and come in a range from 5 to 20,000 kN.

SPECIAL APPLICATIONS



> "THE STRESSING FORCE OF THE STAY CABLES LIES BETWEEN 1,501 KN AND 2,367 KN, WHICH REPRESENTS 15.3% AND 16.2% OF THE MINIMUM BREAKING LOAD OF THE CABLES."

# METAMORPHOSIS over Danube

U2/6 DONAUMARINA BRIDGE, VIENNA, AUSTRIA



**Vienna's 'Donaumarina' cable-stayed bridge was built in the late 1990s to fulfill three different purposes, reports Jürgen Diatel of VORSPANN-TECHNIK, the BBR Network member in Austria.**

During lifting of the nearby A23 motorway bridge, the bridge was used as an alternative route for car traffic to cross the River Danube. In the second phase, which lasted almost ten years, only public buses and emergency vehicles were permitted to use the bridge. However, right from the beginning, the superstructure was designed as a metro bridge for the extension of the U2 metro line – and its final metamorphosis was achieved in 2008.
The Donaumarina Bridge is a steel construction, with an A-shaped pylon and a total length of 343.5 m and a 186 m main span. The 139.5 m back span has two pressure props 18 m away from the counter-bearing to reduce the tangent angle between the main span and the concrete side spans. Two pin-ended columns in the back span – 46.5 m from the counter bearing – transfer tensile forces from the structure into the foundation.

## NEW STAY CABLES

Steel strands with a nominal cross-section of 150 mm² and a maximum characteristic tensile strength of 1,770 N/mm² were used for the stay cables. For corrosion protection the strands are greased and have a factory-manufactured HDPE sheathing. They were delivered to site in coils with a maximum weight of 3,454 kg. Twenty stay cables, of two different types, were installed – each consisting of a combination of monostrands and compact mono bands. Stressing was carried out from the tower head of the pylon – using multi-strand jacks capable of applying a maximum stressing force of 10,000 kN. The hollow space between the strands was filled with cement grout, as an additional corrosion protection layer and for fire protection.

## PREFABRICATION

The prefabrication of the new stay cables was completed on the bridge deck of the back and side spans. However, in late April 2008, nearly all the monostrands which were stored on site, were set alight in an arson attack – the perpetrator who committed this offence was never caught. Only three coils, which had already been lifted onto the bridge deck and placed in uncoiling frames, were not destroyed – 20 steel coils had been destroyed in the incident. →

After the replacement of the prestressing steel, the strands where uncoiled and pulled into the welded HDPE tubes. For a more distinctive architectural appearance, the tubes have a grey colored outer layer which is achieved by co-extrusion during tube production – this was a VT invention!

### INSTALLATION AND STRESSING

Stay cable anchorage blocks with external threads and fixed steel trumpet pipes were mounted on both ends. The ring wedges and wedge retaining plates were assembled afterwards. The stay cables were lifted by using mobile cranes. First, the upper cable ends were inserted into the penetration pipes and fixed with stay cable anchorage nuts – a similar procedure was followed for the lower anchorages near the bridge deck. The stressing force of the stay cables lies between 1,501 kN and 2,367 kN, which represents 15.3% and 16.2% of the minimum breaking load of the cables. Four cables – two upstream and two downstream – were stressed simultaneously.

The stay cables were filled with cement grout of a 30 N/mm² minimum compressive strength.

Finally, the stay cable anchorages were covered with corrosion protection bands and the remaining overlaps of strands were covered with a PE-coating and PE-caps were installed.

**TEAM & TECHNOLOGY**

**OWNER** Wiener Linien, Vienna, Austria

**MAIN CONTRACTOR**
Porr Technobau und Umwelt AG

**CONSULTANT** Büro Pauser ZT GmbH

**TECHNOLOGY** VT stay cables

**BBR NETWORK MEMBER**
VORSPANN-TECHNIK GmbH & Co. KG (Austria)

## **In Focus:**
## Vienna's underground network

The metro – or U-Bahn – in Vienna consists of five railway lines, some of which have their origins in the late 1800s. The first section of the modern metro system opened in 1976 and, today, it is run – along with the city's bus and tram network – by Wiener Linien who are progressively extending the U2 metro line. The upgrading of the Donaumarina Bridge is part of the third phase of development – and, by 2019, Vienna's underground network will have extended by a further 20 km, to almost 90 km of track. Most recently, the U2 line was extended to serve the Ernst Happel Stadium and completed in time to transport fans to the seven games of the UEFA Euro 2008 football tournament which were hosted here. The level of investment earmarked to complete the major U2 extension scheme is in the region of €9 billion. The infrastructure operator believes that the new line will act as a driving force for the local economy – and reports that its construction has already generated some 24,000 new jobs.



FACTORY ROOF STRENGTHENING, PABIANICE, POLAND

# STRONG SOLUTION

**When the steel roof girders at the Philips Lighting factory in Pabianice needed strengthening, BBR Polska devised an effective solution which allowed normal business to continue. Project manager, M. Sc. Bartosz Łukijaniuk takes up the story.**

This problem had occurred in two factory buildings where 30 m long steel and concrete girders which had been installed in the 1970s – and prestressed with internal tendons. Company management discovered that the girders were deflecting too much and sought specialist advice. The expert's opinion was that the old tendons were losing their stressing force because of corrosion and that the girders needed strengthening. Suddenly, a seemingly simple situation had become complex – the roof needed repairs, but production in the factory could not be stopped for more than two or three days.

So, the BBR Polska team came up with the idea of using external tendons to take over the forces from the old rusty tendons and restore the girders to their original status. Our design required only small additions to the steel structure – for example, anchorage blocks to be welded to the girders. A sensor has been installed on each tendon to allow future monitoring of the structure.

The design was carried out by SDS (Structural Design Service) in co-operation with BBR Polska.

In the first building, installation of the additional steel elements was completed without stopping factory production – even for one day. However, factory management themselves decided to halt production for two days – during which time we had to stress all tendons ... and we did it! Now, we are working on the second factory building – perhaps the subject for a further report in the next edition of *CONNAECT.*

**TEAM & TECHNOLOGY**

**OWNER** Philips Lighting Poland S.A.
**MAIN CONTRACTOR** Mostostal Warszawa S.A.
**STRUCTURAL ENGINEER** Structural Desgin Service (SDS) / BBR Polska Sp. z o.o
**TECHNOLOGY** BBR CONA external
**BBR NETWORK MEMBER** BBR Polska SP z o.o (Poland)

BLOOMINGDALES STORE, DUBAI MALL, DUBAI, UNITED ARAB EMIRATES

# Testament to PT flexibility

**The US$722 million Dubai Mall, currently under construction, is set to be the largest mall in the world, as well as the counterpart to the Burj Dubai – the world's tallest tower. BBR Network Member, NASA Structural Systems LLC, reports on a special contract to accommodate the needs of the famous US department store, Bloomingdales which has ventured to open its first store outside of the United States.**

When completed, the Dubai Mall will be larger than 50 international soccer pitches and is expected to attract over 35 million visitors in its first year of operation. The mall features 1.6 million square meters of retail space which includes 1,400 shops.

Bloomingdales requirement of 146,000 $ft^2$ of floor space over three successive levels of the Mall complex necessitated strategic slab openings to be created within the existing post-tensioned (PT) floor slabs for the installation of escalators. BBR Network Member, **NASA Structural Systems LLC,** was engaged by fit–out contractor Al Tayer Stocks LLC to carry out the specialist works which involved the chemical anchoring of the post-tensioning tendons along the critical perimeter of the slab, saw-cutting, waste management and removal, corrosion protection of end reinforcement, making good of slab edge openings and installation of structural steel support beams.

Work was completed successfully within a tight time frame which enabled follow-on trades to commence work and meet the store opening date of February 2010. The flexibility of post-tensioned floors to support post-construction planning was again proven by NASA Structural Systems – even to hard-nosed conventional reinforced concrete purists!

**TEAM & TECHNOLOGY**

**OWNER** Bloomingdales
**MAIN CONTRACTOR** Al Tayer Stocks LLC
**CONSULTANT** Meinhardt (Singapore) Pte Ltd
**TECHNOLOGY** MRR range
**BBR NETWORK MEMBER** NASA Structural Systems LLC (United Arab Emirates)

# Reviving the Angel



**BBR Network member Structural Systems UK Limited has recently been helping to breathe new life into an existing building in London by carrying out strengthening work – giving the structure a new life and purpose.**

Occupying a prime spot at the corner of Islington's Upper Street and Pentonville Road in London, the Angel Building – a former British Telecom telephone exchange and offices – is currently being redeveloped. The scheme will provide ground floor retail space with modern office facilities above.

Loads to be factored into our design work for the strengthening included the construction of a new steel fifth floor, an external terraced area and the installation of a BMU (Building Maintenance Unit) to track around the building edge. There were also additional service penetrations, typically 2 m x 1 m lightwells in the fifth floor, as well as other service penetrations through all floors as part of the renovation work and the formation of five 5 $m^2$ staircase openings.

One unusual detail of the construction is that, above first floor, the structure is two-way spanning flat slab – whereas at first floor it is a one-way spanning slab with drop beams.

Structural Systems was appointed by BAM Construction to carry out the strengthening works using FRP material in association with a BL5800 adhesive. Specialist epoxy mortars were used to carry out substantial substrate repairs and a flow-able epoxy grout was used for filling in the redundant gullies.

We designed and installed all of the FRP components and the installation was carried out by our own specialist installers. We also carried out some of the initial structural investigations to confirm the monolithic nature of the fifth floor slab, as the falls which were present could have been a screed finish.

It turned out that the falls formed part of the roof structure, so this involved some complex planning to get all the FRP areas reduced down to a common level. Our engineers also designed some areas of slab in-fill to overcome some of the falls issues.

We were selected for the project because of our proactive approach during the initial phases, offering design and operational solutions at every stage. The eventual final design was carried out in-house, as were the full installation works, all of which were covered under a single warranty, which was also attractive to the client. The client was looking for a flexible organisation with a proven track record who could deliver the whole package, as well as work with other trades during the initial program phase.

**TEAM & TECHNOLOGY**

**OWNER** Derwent London plc
**MAIN CONTRACTOR** BAM Construction
**DESIGNER** Price Myers Consulting Engineers/Structural Systems UK Ltd
**TECHNOLOGY** MRR range
**BBR NETWORK MEMBER** Structural Systems (UK) Ltd

THE ANGEL BUILDING, LONDON, UK

# Century of progressive technology

**With the world's largest single span of reinforced concrete, Grafton Bridge was at the forefront of construction technology when it was completed in 1910. BBR Contech Project Manager, Hugo Jackson reports how – 100 years on – the bridge is being strengthened as part of the Auckland Central Connector Project with state-of-the-art carbon fiber composites – again placing this iconic structure at the forefront of latest construction technology.**

The bridge, which occupies a dramatic position across Grafton Gully in Auckland, was part of a program of regional road building and symbolized both the creation of a 'Greater Auckland' and state leadership in the development of technology. Sanctioned by ratepayers at the very end of the British colonial period (1840-1907), it also displayed the new Dominion's ability to lead the world in its progressive outlook.

The bridge has a large central span of 98 m, with three smaller spans on its eastern approach and six on its west. It is 296 m long and stands 43 m above the gully floor. It is built entirely of reinforced concrete, with the girders in its approaches being claimed as the longest continuous segments in the world at the time.

The structural upgrade, being carried out by main contractor Brian Perry Civil, will provide earthquake resistance and additional load-carrying capability. The structural and seismic upgrade will not change the way Grafton Bridge looks or change its heritage status.

In the original design of this bridge structure, no allowances were made for earthquake resistance. Now, the bridge will be strengthened to withstand a one-in-1,000-year earthquake, in accordance with modern earthquake design standards. In addition, the structural upgrade will mean the bridge can carry increased bus traffic, and be future-proofed to handle new transport technologies, such as light rail.

The work being undertaken includes:

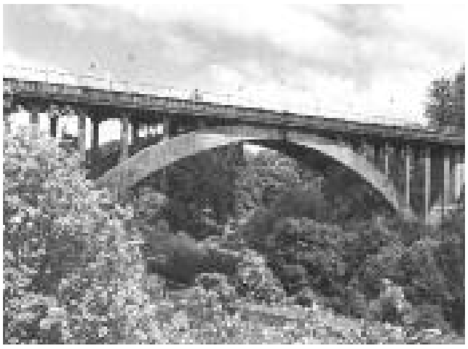
- Strengthening the bridge columns, using steel bar reinforcements – a technique also used on the Auckland Harbor Bridge.
- Strengthening the bridge beams, by applying a carbon fiber material to the existing concrete beams.
- Installing new, reinforced concrete shear keys and deck lineage to resist horizontal earthquake forces.

## Grafton Bridge CV

Grafton Bridge is of national and international significance for its use of advanced concrete technology – and is also considered of international importance as an engineering structure of unique value.

- Longest reinforced concrete arch in the world when completed in 1910.
- Category I – highest classification – given by New Zealand Historic Places Trust in recognition of its outstanding technological merit and magnificence as a townscape element.
- Recognized in 2004 by the American Concrete Institute publication, *Concrete: A Pictorial Celebration* – featuring landmark concrete achievements.
- Awarded the inaugural New Zealand Concrete Society Enduring Concrete Award in 2008.

## GRAFTON BRIDGE, AUCKLAND NEW ZEALAND



- Repairing cracks in the existing concrete and removing algal growth.
- Applying a 'modified cementitious coating' to prevent further corrosion. The coating provides protection from concrete carbonation.
- Replacing joints and bridge bearings.

BBR Contech was engaged by principal consultant Beca Infrastructure in 2007 to conduct load testing of the existing bridge. As a result of this testing, a scheme to strengthen the bridge using fiber reinforced plastic plates was developed.

In 2008, a contract was let to Brian Perry Civil to perform a number of strengthening and preservation works. BBR Contech was engaged as a specialist to supply and apply nearly 600 m of FRP strip and plates. The systems are pre-manufactured ultra high strength carbon fiber laminate plates approximately 1.5 mm thick and 100 mm wide which are adhered to the prepared concrete surface with a specifically developed epoxy adhesive. Strips were applied to the underside of the beams to provide additional mid-span moment resistance. The plates were installed, in pairs, around the beams and up into the deck slab, to improve shear performance.

This project was completed well ahead of schedule in late 2009 and will ensure this grand old lady will continue to serve Aucklanders for many generations to come.

**TEAM & TECHNOLOGY**

**OWNER** Derwent London plc

**MAIN CONTRACTOR** BAM Construction

**DESIGNER** Price Myers Consulting Engineers / Structural Systems (UK) Ltd

**TECHNOLOGY** MRR range

**BBR NETWORK MEMBER**
BBR Contech (New Zealand)

# WINNING WAYS

## WHARF UPGRADING, NEW ZEALAND

**Undertaking challenging remedial projects is a particular strength of our New Zealand-based BBR Network member, BBR Contech – an area of special expertise relates to repair work on wharves.**

**While the company has vast experience and capability in the maintenance, repair and retrofit of a wide range of concrete structures – including bridges, electricity utilities, water and wastewater facilities, buildings, dams and towers – several recent wharf projects, presented here, illustrate the breadth of expertise developed over many years.**

### KINGS WHARF UPGRADE

Kings Wharf has also been in operation for around 100 years and was one of the original wharves servicing the Port of Wellington. It is now used by Strait Shipping to marshal and load hundreds of thousands of tonnes of livestock and cargo freight between the North and South Island all year round.

**Deck & beam deterioration**

The timber wharf deck and supporting beams were showing signs of deterioration. With the piles still in sound condition, CentrePort investigated solutions to apply a structural overlay to effectively replace the existing timber deck. A low shrinkage concrete overlay was required and advice was sought from Allied Concrete Limited.

**PT slab solution**

Based on the wide experience and long track record of post-tensioned floor slabs and a close relationship with BBR Contech, Allied Concrete proposed that the structural overlay could be provided by a post-tensioned slab – utilizing the existing timber deck as permanent formwork.

**Collaborative input**

Working in close collaboration with CentrePort, Holmes Consulting and full delivery floor contractor Conslab, BBR Contech prepared a design / build post-tensioned overlay proposal for the 7,000 $m^2$ wharf. BBR Contech again received valuable design input from Australian BBR Network member Structural Systems and the final configuration comprised an overlay completed in four separate pours, each measuring approximately 60 m x 35 m.

**Special PT considerations**

The post-tensioned overlay required some special considerations for deflection of the existing timber deck and the final layout comprised a 180 mm thick flat slab and BBR CONA flat 0405 tendons.

The post-tensioned overlay was completed in stages to allow suitable preparation of the existing deck. The finished deck sections were progressively handed over to CentrePort to ensure there was only minimal disruption to ongoing shipping operations.

# with wharves

### CENTREPORT – WELLINGTON PORT COMPANY

CentrePort Wellington is a pivotal port facility located in the geographic centre of New Zealand in a natural sheltered deep water harbor. It offers direct nationwide access to the major highways and main trunk railway. Key coastal shipping and inter-island ferry services are also located within the port precinct.

The port has large number of important infrastructure assets including wharves, warehouses and cold store facilities and BBR Contech has a long association with the port company in maintenance and new construction.

**Thorndon Container Wharf**

Thorndon Container Wharf is the main container handling wharf in the port. It is a large wharf operating two berths, each measuring some 300 m in length, and covering a total area of approximately 15,000 $m^2$.

BBR Contech is carrying out the work in a joint venture with world leaders in cathodic protection technology, Savcor ART of Australia. The work has been staged by CentrePort and the current contract involves concrete repair and cathodic protection to the second shipping berth of Thorndon Wharf. The facility must continue to function as a fully operational container wharf, whilst rehabilitation works are being carried out.

**Cathodic protection**

The rehabilitation design calls for the application of an impressed current cathodic protection system to the front crane beam, rear abutment wall, transverse deck support beams and selected piles – with preventative maintenance coatings applied to the entire under-wharf surface area. The deterioration of concrete elements is worst at the front and rear of the wharf – the majority of work is concentrated in these zones.

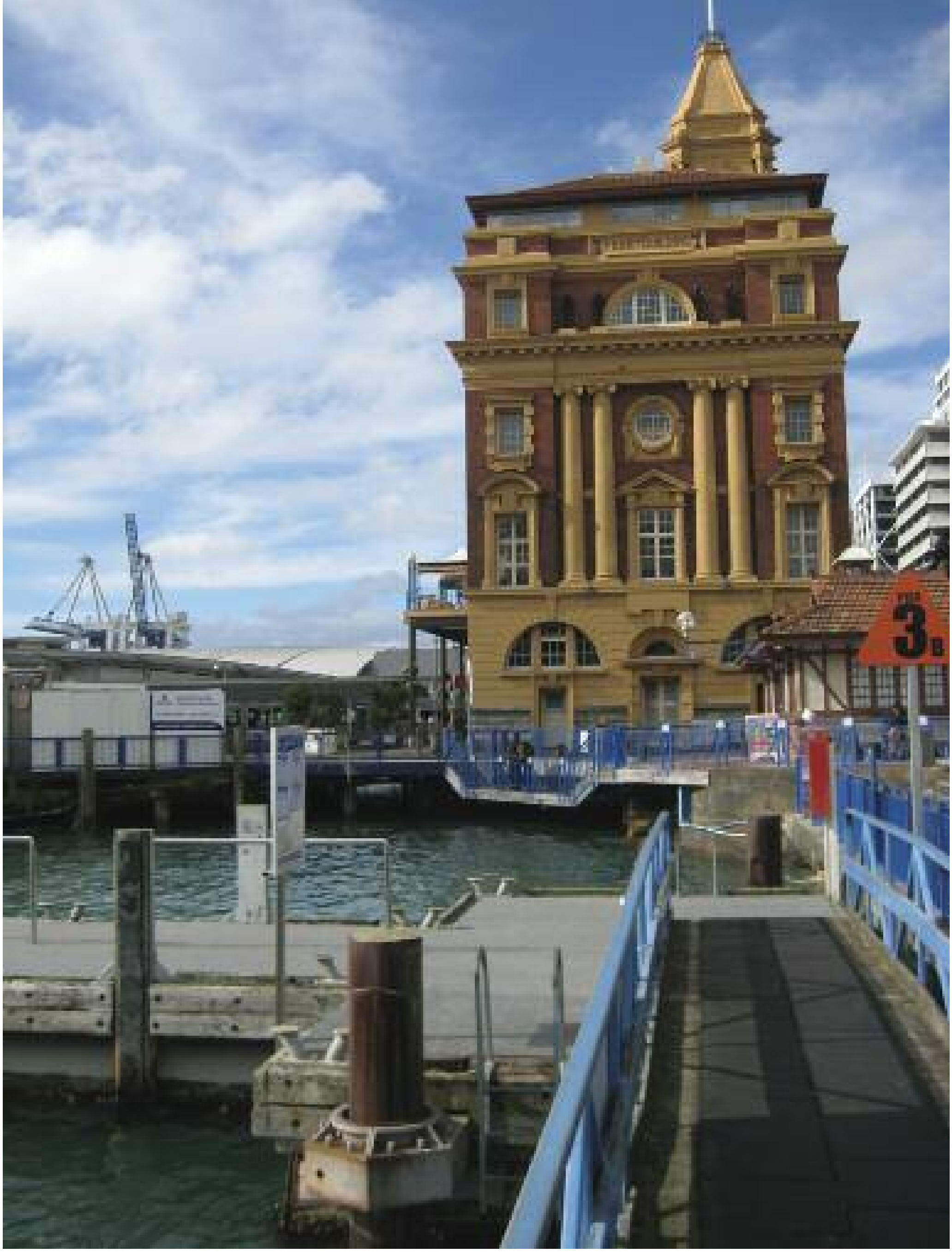
**Other techniques**

Hydro-demolition techniques are again being employed for concrete removal and concrete reinstatement is being carried out using proprietary gunite materials. Not all elements are receiving impressed current cathodic protection and some of the concrete elements are being repaired by conventional concrete repair methods in conjunction with sacrificial anodes attached to rebar prior to the application of repair mortar.

**Long term solution**

In addition to Thorndon Container Wharf, the Joint Venture is also employed to make similar repairs to Dock Wharf, another important wharf asset which services the busy Interislander passenger and car ferry – the main link between the North and South islands. When completed, these two projects are designed to provide long-term protection and life extension for these critical infrastructure assets for more than 30 years with minimal ongoing maintenance or further deterioration. ➔

" THIS IS AN IMPORTANT PROJECT AND MUCH OF THE EXISTING SUB-STRUCTURE HAS TO BE TEMPORARILY SUPPORTED DUE TO THE DEGREE OF DETERIORATION."



## DOWNTOWN AUCKLAND

The Auckland Downtown Ferry Terminal is the hub of Auckland's ferry network – a network that began in 1905 and which connects Auckland's CBD with the wider Auckland area. After 100 years of service, the historic piers that make up the Downtown Ferry Terminal now require repairs to the structural fabric beneath the deck to maintain them in a safe condition for the continued use of Auckland's ferry commuters.

### Work underway

Concrete repair work commenced on Piers 1 and 2 adjacent to the historic ferry building in mid-2008 and is expected to continue into 2010. The concrete piles, deck beams, cross-bracing and deck soffit are badly deteriorated and the repairs are designed to reinstate the damaged areas and restore the integrity of the elements.

### Repair techniques

The repair techniques employed include guniting and forming and pouring using high performance micro-concretes. All defective concrete is removed using hydro-demolition to minimize the noise associated with traditional concrete breakout. This is an important project and much of the existing sub-structure has to be temporarily supported due to the degree of deterioration.

**TEAM & TECHNOLOGY**
**Auckland Downtown Ferry Terminal upgrade**
OWNER Auckland Regional Transport Authority
STRUCTURAL ENGINEER URS New Zealand
TECHNOLOGY MRR range
BBR NETWORK MEMBER
BBR Contech (New Zealand)

**TEAM & TECHNOLOGY**
**Kings Wharf upgrade**
OWNER CentrePort Ltd
STRUCTURAL ENGINEER
Holmes Consulting Ltd
CONTRACTOR Conslab Ltd
TECHNOLOGY BBR CONA flat
BBR NETWORK MEMBER
BBR Contech (New Zealand) (construction)
Structural Systems Ltd (Australia) (slab design)

**TEAM & TECHNOLOGY**
**Thorndon Container Wharf and Dock Wharf**
OWNER CentrePort Ltd
STRUCTURAL ENGINEER & CP DESIGNER
GHD Consultants
CONTRACTOR Savcor-Contech Joint Venture
TECHNOLOGY MRR range
BBR NETWORK MEMBER
BBR Contech (New Zealand)

WOURI RIVER BRIDGE, DOUALA, CAMEROON

# PRESERVING VITAL LINK

The bridge over the Wouri River between Douala and Bonaberi was built in 1954 and was the world's largest multi-span bridge at that time, reports Jean-Marc Verplaetse of French BBR Network member **ETIC.**

Over the years, the very humid climate had caused severe corrosion leading to concrete cracking and broken PT strands. As the only bridge in Douala province, it has an important economic role to play in the region. So, to keep traffic and trade moving until a long-awaited second bridge can be constructed, retrofitting works were vital.

There are 16 spans – each 42 m long span consists of 10 post-tensioned 'I' beams joined by four post-tensioned transversal cross-beams. Pier caps are also post-tensioned. Around 20% of the post-tensioning strand – originally supplied by another manufacturer – was broken and there were many cracks in the lower parts of the concrete beams and crossbeams.

It was decided that the following external additional post-tensioning cables should be installed:

- **Longitudinal additional post-tensioning** – four unbonded BBR CONA single 06" cables on each side of the beams
- **Additional transversal post-tensioning** – four unbonded BBR CONA single 06" on each side of the crossbeams
- **Pier caps** – on four piers, eight unbonded BBR CONA single 06" on each side of the pier cap

Among the technical challenges that our team had to face included having to redesign the bridge from measurements taken, as there were no technical drawings and working in a live traffic situation – we executed most of our work from the river which had strong currents and was subject to tidal flow.

Our retrofitting project was completed to the full satisfaction of the Ministry of Public Works. The bridge has now regained at least some of its former youth and can be used safely for many future years, until that illusive second bridge over the Wouri River finally arrives …

**TEAM & TECHNOLOGY**

**OWNER** Ministry of Public Works of the Republic of Cameroon

**CONTRACTORS** UDECTO (Togo) for retrofitting of foundations, concrete surfaces, roadway and parapets

ETIC International (France) – for retrofitting of post-tensioning.

**CONSULTANT** EGIS France

**TECHNOLOGY** BBR CONA external

**BBR NETWORK MEMBER** ETIC (France)



SEISMIC RETROFITTING OF SCHOOL, NEW DELHI, INDIA

# Back to school

**As a part of an earthquake disaster management plan in India, a number of important structures which will form a lifeline in the wake of such an event, have been identified for seismic retrofitting. These 'lifeline buildings' will accommodate the most essential facilities needed for saving lives and carrying out rescue operations. Mr Veeramani, project manager for BBR (India) Pvt Limited, describes the execution of a pilot project in New Delhi.**

Ludlow Castle School accommodates about 1,700 students and has been listed for use as an emergency shelter in the wake of an earthquake. This 40-year old building, on the banks of River Yamuna, has three floors and is of brick / masonry construction.

Masonry buildings are brittle structures and one of the most vulnerable during seismic events. Our retrofitting measures are based on the national BIS codes. The technique adopted was to strengthen vulnerable points by providing additional cast-in-situ Ferro cement plating on the masonry wall face with a containment system, along the critical load paths – thus strengthening and integrating the whole structure.

The various measures adopted were:

- Encasement of all wall openings – including the doors and windows.
- Lintel level seismic belt on both sides of every wall.
- Sill level belt on both sides of every wall.
- Vertical reinforcement – consisting of weld wire mesh or reinforcing rod – at every wall junction.
- Since vertical bars at the jambs of windows and doors were not present, seismic belts were provided all around the openings.

The materials used include cement, galvanized steel, non-shrink high strength flowable micro con-crete, epoxy resins grout and mechanical anchors.

The project is a model program for seismic evaluation and retrofit which can be replicated throughout India.

**TEAM & TECHNOLOGY**

**OWNER** Public Works Department, Delhi

**MAIN CONTRACTOR** M/S BBR India Pvt Ltd

**DESIGNER** Committee of Expertise formed by Govt. of India / Team from GEO Hazard International working towards global earthquake safety

**TECHNOLOGY** MRR range

**BBR NETWORK MEMBER** BBR (India) Pvt Ltd

**Spanning parts of south-eastern Europe, the Middle East and North Africa, the Ottoman Empire became a world power at the very centre of interaction of the eastern and western worlds – this diverse dynasty endured for six centuries. Today, after a set-back, a superb leisure resort reflecting this heritage is a step nearer to completion with help from NASA Structural Systems – the BBR Network member in the United Arab Emirates. Rob Sutherland, their Remedial Business Manager reports.**

The Rixos Ottoman Palace Hotel is a five-star, seven storey hotel and villa project, designed by renowned Turkish architect Kürsat Aybak to blend the rich lifestyle of ancient Turkish culture with modern day luxury. There are 410 rooms and a further 38 villas, each having its own individual swimming pool and garden. It is located on the crescent of The Palm Jumeirah – an artificial island created by Dubai government-owned developer Nakheel.
When construction started, good progress was made and the project was expected to be completed in record time. Unfortunately, several months into the construction program, a fire broke out causing damage to the basement and ground floor areas. Afterwards, there was concern about the structural integrity of part of the building and local regulatory authorities required an independent assessment. Tests included hammer sounding, ultrasound pulse velocity and petrographic inspection / analysis to determine and confirm the depth of concrete affected in each structural member.
The net result was the appointment of NASA Structural Systems LLC to undertake rectification work on the fire-damaged basement and ground floor. This was to be the first remedial project for the Structural Systems Group in the Middle East region – having only launched our Middle East Remedial Division a few months earlier. Our workscope included the complete supply, supervision and installation of materials for the refurbishment work.
Lateral bracing was installed in the basement and ground floor areas to support the columns, preventing them from buckling during the period of demolition and replacement of the ground floor slab.
The surface of the columns requiring jacketing were then roughened by scabbling. Cores were drilled through the slab above, adjacent to the perimeter of the beam, to allow pouring of a high early strength micro concrete. New reinforcement was fixed, shutters were set in place and the grout was poured though the core holes above. After an initial curing period, the shutters were removed from around the columns – with further curing achieved by wrapping the columns in wet hessian, in line with best practice.
A 'crash deck' – including high density styrene sheeting to act as a sandwich between the form ply and the concrete – was then constructed over falsework to the soffit of the basement to allow the concrete cutting to be carried out from the ground floor deck.
The concrete slab was cut into 1 m x 1 m sections and removed from site manually – via the basement – by lowering the sections through a specially constructed opening in the formwork. The styrene was then removed and

## Scope of works

- Enlargement and making good of some 33 columns (column jacketing) in order to restore their shear capacity.
- Repair to staircase walls, including removal of crazed and spalled concrete and reinstatement using proprietary repair material.
- Installation of temporary lateral bracing beams.
- Construction of falsework to support and enable cutting and removal of the fire-affected concrete slab sections.
- Removal of 1,600 $m^2$ x 300 mm thick concrete floor slab by concrete cutting.
- Slab reinstatement, including connection of new reinforcing bars to existing bars by using couplers.
- Installation of bearing angles at column locations.

# REMEDY FOR RIXOS

the crash deck reconfigured to the correct line and level. Existing reinforcement at the slab edge was exposed so that special couplers could be connected to provide necessary continuity of the reinforcement.

Several ground floor beams required a 70 mm thickening. High pressure water-blasting was used to roughen the surface of the beams, appropriate core holes were drilled through the slab, with shear pins and reinforcement epoxied into place. The beams were then formed using traditional formwork and cast by pouring high early strength micro-concrete to just below the soffit. After formwork was removed, structural repair mortars were hand-applied to complete the thickening operation.

Once the enlargement of the columns and beams had been completed and reinstated concrete had reached a 28-day compressive strength of 40 MPa, the lateral bracing was removed – leaving the building structurally intact. The project was completed successfully by NASA Structural Systems to a high quality – meeting the exceptional standards of the Ottoman tradition and, indeed, our client!

**TEAM & TECHNOLOGY**

**OWNER** Zabeel Properties

**MAIN CONTRACTOR** ZSML Construction

**CONSULTANT**
Shadid Engineering Consultants

**TECHNOLOGY** MRR range

**BBR NETWORK MEMBER** NASA (BBR) Structural Systems LLC (United Arab Emirates)

# In the public arena

**Now, as in ancient times, national or civic pride often finds expression in the design and construction of a stadium or arena – the projects demand both architectural elegance and the highest quality of functionality. BBR Technology and know-how is ideally suited to the realization of these unique, flexible and durable structures – and continues to be applied in the creation of venues for many audiences around the globe.**


WEMBLEY STADIUM, LONDON, UK

Stadium construction has its roots in ancient Greece where the oldest known is at Olympia in the Peloponnese and was home to the Olympic Games from 776 BC.
In fact, the word 'stadium' comes from the Greek word 'stadion' which was a measure of length equating roughly to 180-200 m. The Games originally consisted of a single sprint event along the length of the stadium – and thus the length of the Olympia stadium became the standard for running tracks in subsequently built Greek and Roman stadia. The origin of the word 'arena' has, however, a more grisly origin – it comes from the Latin word for 'sand' which was used as a floor surface in ancient arenas to absorb the blood of injured competitors. Through the pages of this and earlier editions of CONNAECT, it can be seen that BBR Technology – along with the engineering expertise, ingenuity and passion of the BBR Network – remains instrumental in creating or reconfiguring sporting and entertainment venues in many countries.


BERNABÉU STADIUM, MADRID, SPAIN

## POST-TENSIONED STADIA SOLUTIONS

Post-tensioning allows the construction of imaginative yet practical forms and its use is particularly relevant to stadium or arena schemes. Recently, in the Polish city of Łódz, we created a ring beam – post-tensioned with BBR CONA internal and external systems – to support the enormous dome-shaped roof of a new sports arena.

When the new Wembley Stadium was built, near London, UK, internal structural post-tensioning was a logical choice for this important national venue.

In this and previous editions of CONNAECT, you will already have read how BBR post-tensioning systems have contributed to the realization of the DY Patil Cricket Stadium in Navi Mumbai, India, the Arena Zagreb and the Magic Box Athletic Complex in Madrid. However, perhaps the most unusual application, so far, for our BBR CONA internal post-tensioning system has been in the construction of the five storey grandstand for the Marina Bay Floating Stadium in Singapore – which also features the world's largest floating stage and football pitch.

## CABLE-STAYED ROOFS

Stay cable technology opens the door on a whole new range of possibilities for architectural creativity, as well as functional features and considerations. Cable-stayed solutions have been provided for arenas and stadia in Malaysia, Australia, Germany and the United Arab Emirates.

For Penang Indoor Stadium in Georgetown, Malaysia, we designed and installed a stay cable system, using BBR CONA stay cables, to support the trusses of the roof which has a main span of 106 m.

In 1981 and 1995, two Australian sporting facilities were constructed with iconic stay cabled roofs – the National Indoor Sports Centre in Canberra and the Athletics Centre in Sydney. And, in 1982, for Abu Dhabi's National Day Parade Grandstand, we used BBR CONA stay cables to support the roof canopy.

## HEAVY LIFTING

The BBR Network also helps to provide an imaginative and sustainable approach to the construction of stadia and arenas with the use of heavy lifting techniques. These assist the post-construction reconfiguring of venues such as Sydney's Olympic Stadium and the expansion of Bernabéu Stadium, home to one of the world's most popular and glamorous football teams – Real Madrid.

## MMR TECHNIQUES

And finally, our range of MMR technology and skills are applied to accommodate renovations, modifications or changes of use which become necessary or desirable over time. In the UK, our know-how has helped to rejuvenate a world famous venue – the All England Lawn Tennis & Croquet Club in Wimbledon, UK. Before the new sliding roof could be installed over the famous Centre Court, beams needed strengthening to accommodate the new loads which would be imposed on the structure.

## LANDMARK STRUCTURES

On the following pages, BBR Network members have provided detailed technical information about their work on three stadia – in Sydney, Munich and Singapore – which continue to delight and proudly serve the communities in which they stand.


MARINA BAY, SINGAPORE

STADIUM AUSTRALIA RECONFIGURATION, HOMEBUSH, NEW SOUTH WALES, AUSTRALIA

# Green engineering

**Stadium Australia – now renamed Telstra Stadium – was the centerpiece of the Sydney 2000 Olympic Games. It is unique in that it was designed and constructed to be reconfigured for smaller crowd sizes after the Games – a move necessary to preserve atmosphere and intimacy of more local events. Mark Sinclair of Structural Systems Limited outlines his company's leading role in this pioneering scheme.**

For the Olympic Games, the design brief and bid to the International Olympic Committee specified a stadium capacity of 110,000 spectators – although the actual finished capacity was closer to 115,000.

To meet longer term requirements, such as hosting Rugby League, Rugby Union or Soccer matches – the stadium was initially designed with the ability to be reconfigured into 'Post Olympic Mode', seating approximately 80,000 spectators. It was important to allow for this reconfigurability at minimum initial cost, and still give the option of 'permanency' in either situation.

Construction and subsequent reconfiguration of the stadium was undertaken by Multiplex, with the design by Sinclair Knight Merz (SKM).

## RECONFIGURATION PROJECT

The stadium is generally a reinforced or post-tensioned structure and it is the facility to reconfigure after the initial purpose which makes it unique. The key feature is that, after the initial field shrinking, the lower tiers of the East and West Stands can be brought forward to better accommodate spectators for sports requiring a rectangular field.

The post-Olympic reconfiguration is a significant project in its own right and was costed at around $80 million.

## RELOCATING NORTH & SOUTH TIERS

We were engaged by Multiplex to slide seven post-tensioned pieces of the lower tiers forward

by 15.575 m – there were four pieces each weighing 2,000 t and three weighing 700 t. The lower tiers sit on a series of ground beams, with supporting piles as required. Beam layout was such that, during reconfiguration, the columns for each section to be slid would travel along these ground beams. Where required, piles were located at the initial and final position of any column. A short removable steel stub column was incorporated at the base of each column – this was easily removed to allow substitution of a sliding mechanism. The relatively small financial outlay associated with the removable column stub, foundations and beams during the initial construction, allowed later reconfiguration at a reasonable cost.

To enable the fixed stand to slide, it had to be released from adjoining structures and from its foundations. Minor pieces of the semicircle at each end were removed – like portions of a cake – so there would be space available for the major pieces to fit back together after sliding forward and forming a tighter radius. A minor infill was completed after the sliding was finished.

We developed a mechanism for this, borrowing heavily from the systems used to incrementally launch bridges. We completed full design and analysis in-house. There were several aspects to be resolved and the key items were:

- Lifting and parking system
- Sliding track
- Sliding mechanism
- Guidance system
- Pulling mechanism
- Column bracing.

➔

## Major stages of reconfiguration

- **Removal of the running track and long jump facilities.**
- **The playing field was then centered, as it had been off-centre because of the long jump facility.**
- **Removal of the temporary upper North and South Stands.**
- **Release and moving forward of the North and South Stand lower bowls by 15.575 m.**
- **Construction of infill pieces between launched segments and behind the new forward location.**
- **Demolition and rebuilding forward of the North and South Stand upper bowls by 15.575 m.**
- **Fitting of the moving tier system to the lower East and West Stands. These 100 m x 30 m stands can then be driven forward by 15.575 m depending upon the code of football to be played. Reconfiguration takes less than one day. Initially these stands were planned for a one-off move in the same way as the north and south stands.**
- **Construction of a roof at the northern and southern ends, between the two main arches.**
- **Reinstatement of the external concourse on completion of all construction works.**

The site works were undertaken within a very tight program and all seven launches were completed within a five week period between early May 2001 and mid June 2001 – some four weeks ahead of the critical program requirements.

## MOBILIZING EAST & WEST TIERS

The lower tiers of the East and West Stands are required to move 15.575 m forward for 'NRL' football games from their home 'AFL' position. This was to be a world first – where a permanent concrete structure was to be made mobile at the push of a button.
During the initial stadium construction, a movement system for these stands had been developed. Multiplex enlisted Structural Systems to project manage, procure and install the moving tier systems without any design or costings – with only about five months to complete the works.
Each stand is approximately 31 m deep, 10 m high, 100 m long, weighs around 2,500 t and seats 7,500 spectators. Design development progressed, based on some original concepts, but now required a full design to be completed. A very close relationship formed between Multiplex, SKM and Structural Systems.
In turn, specialist subcontractors were engaged to manufacture the bogie system,

provide the necessary operational controls and install considerable structural steelwork. Eilbeck Cranes, Control Techniques and Allmen Industries formed the core of external suppliers to the project, with Structural Systems undertaking installation of the rail and bogie systems.
The team succeeded in achieving all of the deadlines set – proving their abilities and dedication to the project.

**TECHNICAL OVERVIEW**

Both tiers are effectively identical except that the West Stand incorporates a players' entry tunnel and underneath, on Level 0, it has various players' rooms. There are 14 almost identical raking beams which are supported in three places and where a temporary leg is installed to cater for live load.
On Level 0, there are two columns, SC1 and SC2, where a single rail carries a tandem wheeled bogie – SC2 being powered. On Level 1, a single axle, twin wheel bogie (SC3) runs on a pair of rails. In the forward position, this bogie straddles the recess for the raker beam when in the rear position.
The stands' live load is transmitted through temporary props, TP1 (long prop) in the forward NRL position and TP2 (short prop) when in AFL position. A hydraulic jack has been incorporated in the base of each prop.
Earthquake resistance is provided at Level 0 by lateral restraints in bays 7 & 8 and longitudinal reaction through bays 2 & 13.
When in the forward NRL position, three drop-in temporary bridges permit access from the Level 2 members' facilities to the top of the tier. When in AFL mode, these bridges retract, fold and store against the underside of the level 3 overhanging roof.
The stands have a steel-framed carriage – added since the Olympics – to the entire length. These front nine rows of seats are fixed to the moving concrete stands and travel in-and-out accordingly.

Preparing the stands for moving requires a significant number of activities but, in general terms, just a relatively small crew can reconfigure the stands in approximately eight hours.
While the use of concrete in structures is well-documented, normally structures are fixed with no intention of having them move around. The entire lower tier at Stadium Australia was initially conceived and built to allow for later transpositioning.
The lower tiers of the North and South Stands were moved in a one-off operation, while those on the East and West Stands have been configured to move in or out, requiring only a few people and taking a relatively short period of time.
The technology incorporated into the construction, manufacture and control systems enable a brittle and heavy structure to be gently relocated without damage or difficulty.
The integration of the technology applied in this instance to a concrete structure is unique and provides the spectators with the best possible seating arrangement, regardless of the type of sport to be played.
This stadium is a perfect example of how innovative and timely engineering collaboration can adapt structures to perform altered functions, ensuring longevity, value for money and reduced environmental impact. ●

## Transformation process

- Removal of tray sections of grass, called sod pans, to expose rails in trenches which are below grass level.
- Securing of barriers, closing some access ways, releasing props, removal of earthquake systems. Removing temporary infill sections.
- Checking of electronics, verification of 'safe to proceed'.
- Moving stand, operating roller shutters at mid-distance.
- Making safe for access, securing against earthquake, setting props, fitting three Members' Bar Level 2 bridges. Shut down drive system.

# Pioneering roof construction

**The roof of the stadium built in Munich for the 1972 Olympic Games saw the first large scale application of the then newly-developed BBR High-Amplitude (HiAm) parallel strand stay cable system. The structure has now been a landmark on the Bavarian skyline for approaching 40 years.**

The concept was developed from the winning entry in a design competition which accommodated all the individual areas for the various sports under a single lightweight, transparent roof – forming an aesthetically pleasing canopy over the whole venue.

## DESIGN CHALLENGE

The design challenge was to create a 75,000 m² roof which featured large column-free spaces. Architects Behnisch & Partner, Frei Otto and engineers Leonhardt & Andrä met this challenge by presenting a post-tensioned cable-net construction – which was unrivaled in meeting all requirements. Skillful management of the pre-stressing forces achieved a perfect adaptation of the shape of the Olympic roof to the requirements of the architect and the site conditions – its flexibility being superior to other construction methods.

## ADVANTAGES OF PT CABLE-NET STRUCTURES

Post-tensioned cable-net structures have advantages over other types of construction where long spans are required while allowing sufficient build height for substantial curvatures of the net surface and where falls planes can be designed such that the cable tension does not have to be increased considerably to compensate for an extensive sag of the net structure.
So, a post-tensioned cable-net construction is the perfect solution for producing long free cable lengths and where column-free space or structural transparency is important.

## FIRST FOR BBR HIAM

For the first time, the newly developed 0.6" diameter BBR High-Amplitude fatigue resistant parallel strand stay cable system was used for the 244 main stay cables carrying the roof structure.
To keep the sag and, hence the deformations, to a minimum, the designers had specified parallel strand cables for the 244 main stay cables in place of locked coil cables. Parallel strand and wire cables have significant higher moduli of elasticity in comparison to locked coil cables. This has a favorable effect on the deformation behavior of cable-stayed structures – and, in some cases, the realization of these structures even depends upon it.
In spite of the great number of main stay cables, the designers were able to get by with just four different cable types, having 31, 55, 85 and 109 single 0.6" diameter strands per cable. As a result of the different cable lengths – between 4.5 m and 129 m – and also of the different anchorage types, a great variety of cable types had to be manufactured, thus hardly any two cables were identical.

## ANCHORAGE

The patent-protected HiAm anchorage system was developed in collaboration with the consulting engineers Prof. F. Leonhard and Dr. W. Andrä, Lechler Chemie and BBR Headquarters.
The ends of the strand bundle are fitted with BBRV button heads and are anchored in a steel cylinder with a conical inner surface, in which the cavities are filled under vibration with epoxy mortar, small steel balls and zinc dust, whereupon this filler material is cured by heating. When adequately dimensioned, this anchorage type reaches not only the statical but also the dynamic resistance of the basic wire or strand material – which for cable-stayed structures is of particular economical relevance. In addition, this anchorage type possesses matchless corrosion protection in the anchorage zone.

OLYMPIC STADIUM ROOF, MUNICH, GERMANY

## LANDMARK LARGE SCALE TESTING

The first large scale tests on cables equipped with BBR HiAm anchorages were executed at the Otto-Graf Institute in Stuttgart. Meantime, within a surprisingly short time, the Federal Swiss Laboratory EMPA had installed a facility for the dynamic testing of large size stay cables. It was a landmark in the history of testing technology because this new test facility made it possible, for the first time, to achieve maximum loads of 6,700 kN and amplitudes of up to 2,500 kN.

## CONSTRUCTION ASPECTS

The cable-net has square meshes with junction point distances of 750 mm. With its flexible nodes, the net can be easily adjusted – like a folding grille – while laying on the ground.

For the roof of the Olympic Stadium a total length of approximately 400 km of rope was needed. Whilst these ropes needed to be flexible for the installation and therefore made out of thin wires, they also needed →

Photograph courtesy of Kevin Lazarz

to be rather thick-wired for improved corrosion behavior.
The first choice for the cable-net was a 19-wire strand with thick galvanized wires, with diameters of 2.3 and 3.4 mm. With these features, the net has a double safety factor against rupture and can carry service loads of 150 kN/m.

**ERECTION OF STRUCTURE**
After the foundations had been completed, first the high pylons were erected and then the complete net construction including boundary cables, strand bundles and small masts were assembled on the ground for each portion of the roof.
After that, all junction points were hauled to their final positions by means of the hang-up cables and anchoring cables or were superimposed directly on the support pylons. During this process, all movements had to be carried out at equal distances from the geometrical centre of the roof.
After all anchoring cables had reached their final position in the foundations, the position of all junction points and marked nodes – as well as the tension in the net ropes, anchoring cables and pylons – was measured. When major tension variations were observed, corrections were made to the rope length at the turn buckles and anchoring cable anchorages. As a rule, variations in the tension of +/-15% were tolerated – provided that it could be demonstrated with an additional statical computation that this was acceptable in terms of structural stability.
After erection, it was clear that the efforts of the exact cutting and the precise fabrication were worthwhile, because only a few corrective measures were needed to bring the roof into its planned position.

"THE EXACT CUTTING AND THE PRECISE FABRICATION WERE WORTHWHILE, BECAUSE ONLY A FEW CORRECTIVE MEASURES WERE NEEDED TO BRING THE ROOF INTO ITS PLANNED POSITION".

**In 1992, the Yishun Stadium opened its doors and was host to the karate event during the 1993 SEA Games in Singapore. Since then, it has served as home ground for a number of football clubs. The spectator experience is enhanced by the cable-stayed roof.**

In the northern part of Singapore, at the end station of the rapid transit line Singapore – Yishun, a new sports complex was erected consisting of an indoor and an outdoor stadium. Great importance was placed on aesthetic quality in the design of the sports complex, thus the architect decided to use a cable-stayed roof design.
All three roofs, although different in size, were designed according to the same structural concept – a rectangular grid of space trusses suspended by stay cables.
Of the three, the most demanding from the statics point of view was the big roof for the indoor stadium because it had the longest cantilever length of 39.2 m.

# AESTHETICALLY **ENHANCED VIEW**

One of the main considerations was the behavior of the structure under wind conditions. In order to reduce the uplift due to wind to a tolerable margin under service conditions, tie-down members in the form of steel tubes had to be provided underneath the roof structure. The roof is held in place by the suspension cables, which transfer the loads to the top of the pylon. The back stay cables, which are in balance with the suspension cables, transfer the forces down to the massive counterweight foundations.

The size of the BBR CONA stay cables varies from 0306 to 1906 strands, each with a diameter of 15.2 mm. Great care had to be given to corrosion protection. The tendons consist of individually polyethylene coated strands in high density polyethylene ducts which are cement grouted after final installation.

The anchorages are designed in such a way that the cables can be readjusted or even be replaced at any time. All stay cables are hinge-connected by means of 200 mm diameter steel pins.

The design of the pylon was straight-forward. With a length of 22.77 m and a hinge at the bottom, the pylon is a pure compression member – bending due to wind is negligible. The apex on top of the pylon transfers the forces of the front to the back stay cables. The apex consists of a cast iron cone with radially welded fin plates.

Steel A-frames form the main supports underneath the rear part of the roof. They are hinge-connected to the lower ends of the pylons by a 400 mm diameter stainless steel pin. The pins transfer the large loads on the pylon down to the foundation and provide lateral and longitudinal stability of the structure.

The steel structure was erected on scaffolds in a pre-cambered position so that the correct level was reached upon completing the stressing operations. All cables were precisely pre-adjusted after the installation in such a way that the whole stressing operation could be done at the lower anchorages of the back stay cables only.

## Yishun Stadium roof data

- **Outdoor stadium roof** – 120 x 30 m = 3,600 m$^2$, supported by stay cables from 5 masts
- **Indoor stadium big roof** – 67.5 x 39.2 m = 2,646 m$^2$, supported by stay cables from 4 masts
- **Indoor stadium small roof** – 97.5 x 25 m = 2,438 m$^2$, supported by stay cables from 3 masts

## HEADQUARTERS

**SWITZERLAND**
**BBR VT International Ltd**
Bahnstrasse 23
8603 Schwerzenbach (ZH)
Tel +41 44 806 80 60
Fax +41 44 806 80 50
www.bbrnetwork.com
info@bbrnetwork.com

Additional BBR technology licenses have been granted in Europe, Asia Pacific and America – for more information, please contact the BBR headquarters.

## AMERICA

**EASTERN CANADA**
**Canadian bbr Inc.**
3450 Midland Ave.
Scarborough
Ontario M1V 4V4
Tel +1 416 291 1618
Fax +1 416 291 9960
mducommun@bbrcanada.com

## EUROPE

**AUSTRIA**
**VORSPANN-TECHNIK GmbH & Co. KG**
Schillerstrasse 25
5020 Salzburg
Tel +43 662 45 40 00
Fax +43 662 45 40 00 11
www.vorspanntechnik.com
office@vorspanntechnik.com

**BELGIUM**
see Netherlands

**BULGARIA**
see Spain

**BOSNIA/ HERZEGOVINA**
see Croatia

**CROATIA**
**BBR Adria d.o.o.**
Kalinovica 3
10000 Zagreb
Tel +385 1 3839 220
Fax +385 1 3839 243
www.bbr-adria.com
bbr-adria@bbr-adria.com

**CZECH REPUBLIC**
see Austria

**DENMARK**
see Norway

**ESTONIA**
see Austria

**FINLAND**
see Norway

**FRANCE**
**ETIC S.A.**
48, rue Albert Joly
78 000 Versailles
Tel +33 1 39 50 11 20
Fax +33 1 39 50 11 03
www.etic-international.fr
contact@etic-international.fr

**GERMANY**
**VORSPANN-TECHNIK GmbH**
Fürstenrieder Strasse 275
81377 München
Tel +49 89 724 49 69 0
Fax +49 89 724 49 69 12
www.vorspanntechnik.com
officce@vorspanntechnik.com

**Spankern GmbH (North)**
Lübecker Strasse 53-63
39124 Magdeburg
Tel +49 391 726 56 30
Fax +49 391 726 56 31
www.spankern.de
info@spankern.de

**HUNGARY**
see Austria

**IRELAND**
see United Kingdom

**LATVIA**
see Austria

**LITHUANIA**
see Austria

**LUXEMBOURG**
see Netherlands

**MONTENEGRO**
see Croatia

**NETHERLANDS**
**Spanstaal B.V.**
Koningsweg 28
3762 EC Soest
Post Address:
PO Box 386
3760 AJ Soest
Tel +31 35 603 80 50
Fax +31 35 603 29 02
www.spanstaal.nl
info@spanstaal.nl

**NORWAY**
**KB Spennteknikk AS**
Siva Industrial Estate
N. Strandsveg 19-21
Postboks 1213
2206 Kongsvinger
Tel +47 62 81 00 30
Fax +47 62 81 00 55
www.spennteknikk.no
spennteknikk@spennteknikk.no

**POLAND**
**BBR Polska Sp. z o.o.**
ul. Marywilska 38/40
03-228 Warszawa
Tel +48 22 811 50 53
Fax +48 22 614 57 60
(ext. 108)
www.bbr.pl
bbrpolska@bbr.pl

**BBR Polska Sp. z o.o.**
ul. Tarnogorska 214a
44-105 Gliwice
Tel +48 32 33 02 410
Fax +48 23 33 02 411
www.bbr.pl
bbrpolska.gliwice@bbr.pl

**PORTUGAL**
see Spain

**ROMANIA**
see Spain

**RUSSIA**
see Austria

**SERBIA**
see Croatia

**SLOVAKIA**
see Austria

**SLOVENIA**
see Croatia

**SPAIN**
**BBR Pretensados y Técnicas Especiales, S.L.**
Antigua Carretera N-III
Km. 31, 150
28500 Arganda del Rey, Madrid
Tel +34 91 876 09 00
Fax +34 91 876 09 01
www.bbrpte.com
bbrpte@bbrpte.com

**SWEDEN**
**Spännteknik AB**
Box 158
671 24 Arvika
Tel +46 570 126 60
Fax +46 570 109 50
www.spannteknik.se
info@spannteknik.se

**UKRAINE**
see Poland

**UNITED KINGDOM**
**Structural Systems (UK) Ltd**
12 Collett Way
Great Western Industrial Estate
Southall
Middlesex
UB2 4SE
Tel +44 20 8843 6500
Fax +44 20 8843 6509
www.structuralsystemsuk.com
info@structuralsystemsuk.com

## MIDDLE EAST

### BAHRAIN
see United Arab Emirates

### IRAQ
**Spezialized Prestressing Co**
Karrada, Dist. 901, St. 1, Bldg. 16
Office No. 10
Baghdad

Tel +964 1 718 6333
Fax +964 1 718 1385

www.spc-iraq.com
office@spc-iraq.com

### JORDAN
**Marwan Alkurdi & Partners Co. Ltd**
PO Box 506
Amman 11821

Tel +962 6 581 9489
Fax +962 6 581 9488

www.mkurdi.com
ali@mkurdi.com

### OMAN
see United Arab Emirates

### QATAR
see United Arab Emirates

### KINDGOM OF SAUDI ARABIA
**Huta-Hegerfeld Saudia Ltd**
BBR Prestressing Division
Prince Sultan St. Lotus Building
PO Box 1830
Jeddah 21441

Tel +966 2 662 3205
Fax +966 2 683 1838

www.huta.com.sa
bbr@huta.com.sa

### SYRIA
see Jordan

### UNITED ARAB EMIRATES
**NASA (BBR) Structural Systems LLC**
Head Office, Suite #302
PO Box 28987
Sara Building, Garhoud
Dubai

Tel +971 4 2828 595
Fax +971 4 2828 386

www.bbrstructuralsystems.com
bbr@bbrstructuralsystems.com

## AFRICA

### SOUTH AFRICA
**Structural Systems (Africa)**
Block B, 60 Civin Drive
Pellmeadow Office Park
Bedfordview, Johannesburg 2008
Tel +27 11 409 6700
Fax +27 11 409 6789

www.structuralsystemsafrica.com
info@sslafrica.com

## ASIA PACIFIC

### INDIA
**BBR (India) Pvt Ltd**
No. 318, 15th Cross,
6th Main
Sadashivanagar
Bangalore – 560 080

Tel +91 80 4025 0000
Fax +91 80 4025 0001

www.bbrindia.com
bbrindia@vsnl.in

### JAPAN
**Japan BBR Bureau**
c/o P.S. Mitsubishi Construction Co. Ltd
Harumi Center Bldg. 3F
2-5-24 Chuo-ku
Tokyo

Tel +81 3 6385 8021
Fax +81 3 3536 6937

mail-01@bbr.gr.jp

### MALAYSIA
**BBR Construction Systems (M) Sdn Bhd**
No. 17, Jalan PJS 11/2
Subang Indah
Bandar Sunway
46150 Subang Jaya
Selangor Darul Ehsan

Tel +60 3 5636 3270
Fax +60 3 5636 3285

www.bbr.com.my
bbrm@bbr.com.my

## AUSTRALIA

**Structural Systems (Northern) Pty Ltd**
20 Hilly Street, Mortlake
New South Wales 2137
Tel +61 2 8767 6200
Fax +61 2 8767 6299
www.structuralsystems.com.au
info@nsw.structural.com.au

**Structural Systems (Northern) Pty Ltd**
Unit 1, 12 Commerce Circuit
Yatala, QLD 4207
Tel +61 7 3442 3500
Fax +61 7 3442 3555
www.structuralsystems.com.au

**Structural Systems (Southern) Pty Ltd**
PO Box 1303
112 Munro Street
South Melbourne
Victoria 3205
Tel +61 3 9296 8100
Fax +61 3 9646 7133
www.structuralsystems.com.au
ssl@structural.com.au

**Structural Systems (Western) Pty Ltd**
24 Hines Road, O'Connor
Western Australia 6163
Tel +61 8 9267 5400
Fax +61 8 9331 4511
www.structuralsystems.com.au
structural@wa.structural.com.au

## FIJI

see New Zealand

## NEW ZEALAND

**BBR Contech**
6 Neil Park Drive, East Tamaki
PO Box 51-391
Pakuranga
Auckland 2140
Tel +64 9 274 9259
Fax +64 9 274 5258
www.contech.co.nz
akl@contech.co.nz

**BBR Contech**
38 Waione Street, Petone
PO Box 30-854
Lower Hutt
Wellington 5040
Tel +64 4 569 1167
Fax +64 4 569 4269
www.contech.co.nz
wgn@contech.co.nz

**BBR Contech**
7A Birmingham Drive
Middleton
PO Box 8939
Riccarton
Christchurch 8440
Tel +64 3 339 0426
Fax +64 3 339 0526
www.contech.co.nz
chc@contech.co.nz

## PHILIPPINES

**BBR Philippines Corporation**
Suite 502, 7 East Capitol Building
No.7 East Capitol Drive
Barangay Kapitolyo
Pasig City 1603
Metro Manila
Tel +63 2 638 7261
Fax +63 2 638 7260
bbr_phils@prime.net.ph

## SINGAPORE

**BBR Construction Systems Pte Ltd**
BBR Building
50 Changi South Street 1
Singapore 486126
Republic of Singapore
Tel +65 6546 2280
Fax +65 6546 2268
www.bbr.com.sg
enquiry@bbr.com.sg

## TAIWAN

**Test Posttensioning – ETIC**
05F-2, 95, SEC 3
Roosevelt Road
Taipei
Tel +886 2 2367 6486
Fax +886 2 2367 6487
www.etic-international.fr
test@etic.com.tw

## THAILAND

**Siam-BBR Co Ltd**
942/137.1 5th Floor
Charn Issara Tower
Rama 4 Road
Kwaeng Suriwongse, Bangrak
10500 Bangkok
Tel +66 2 237 6164-6
Fax +66 2 237 6167
www.bbr.com.sg
enquiry@bbr.com.sg

## VIETNAM

see Singapore




A Global Network of Experts
www.bbrnetwork.com