BBR

Innovative Engineering Review

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BBR 60th anniversary

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Imprint

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Foreword

In 1944, three innovative Swiss engineers, Antonio Brandestini, Max Birkenmaier and Mirko Robin Roš established their partnership BBR. Today we are proud to celebrate our 60th anniversary.

The long history of BBR's innovative developments began in 1948 with the patent of the world famous BBRV button head wire post-tensioning system. Since then, BBR has developed a complete range of pre-stressing and post-tensioning systems, ground anchors and stay cable anchorages, covering all applications in structural engineering. Since the rapid development of the pre-stressing technology, mainly from 1950 to 1960, pre-stressed concrete has become the most widely used construction material in today's bridges and increasingly in buildings. BBR has led this development with innovative post-tensioning systems for various structures and executed most prestigious projects world-wide. Today, BBR comprises 12 BBR subsidiaries and 20 BBR licensees in 28 different countries.

This booklet presents an overview of some of the numerous construction works and projects recently undertaken by BBR member firms, including cable stayed bridges, LNG and water tanks, industrial buildings and stadiums applying BBR technology world-wide.

Today's construction markets face very different challenges. BBR's objective is to provide technical solutions of the highest construction standards. BBR's most valuable asset is the professionals at various levels maintaining the three founders' spirit of entrepreneurial and innovative engineering and committed to meeting clients' and partners' highest expectations.

With confidence we are looking forward to meeting your needs in the future through our ability to innovate with our experience and history.

I would like to take this opportunity to thank everyone for their contribution.

Bruno Valsangiacomo
Chairman of
BBR Holding Ltd

Contents

BBR Innovative Engineering Review

For BBR's 60th anniversary, BBR Systems as Technical Headquarters decided to continue a long-standing BBR tradition and present the outstanding achievements within its partner network in this booklet. The last BBR Review was published for the 2002 fib congress in Osaka.

Consistent with our slogan **BBR Innovative Engineering,** this booklet aims to make a wide international structural engineering community aware of work carried out by BBR and to inform on a broad basis about our recent achievements in special product/application- engineering capabilities.

In a world and in a time with information management playing an increasingly important role, this booklet is also to be related to our brand new BBR website, with a special emphasis given to knowing **What-Who-Where** in order to improve our competitiveness.

We are convinced that by making know-how available in a suitable and organized form, we all have a chance to react in time to the permanently changing market expectations, to take the big opportunities, to perform profitably and to tackle different challenges with the most appropriate technology.

After 60 years, BBR is nowadays a loose network of contractors, which is permanently challenged to remain innovative. Many times, I was personally very impressed by the enormous variety of smart skills developed in different regions certainly due to the continually changing market conditions and exigencies, but especially by the different professionals acting in BBR companies – representing our most valuable asset.

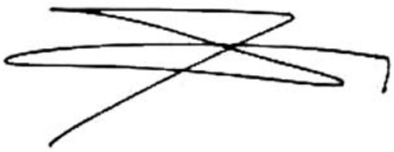
It's time that we understood the power of a well coordinated information platform. Today's communication tools enable an easy and affordable exchange of information. Therefore let's simply **promote, feed** and **make use** of them!

A first step in this direction has been the success in collecting all the various contributions for this booklet. Only the participation of many different authors has made this booklet possible. Thanks a lot!

I also want to thank the staff members of BBR Systems who have assisted in publishing this booklet.

We are proud of our 60 year history and we trust that **together with you,** we can successfully continue to prove our competence in new challenging projects around the world.

Yours faithfully



Dr sc techn Pietro Brenni
CEO
BBR Holding Ltd

About BBR

BBR's Profile

BBR is recognized as a worldwide leading and innovative Specialized Engineering Contractor with total capability in Consulting, Technology and Contracting in the fields of post-tensioning and related construction engineering.

BBR is a total solution provider and offers ideally complete construction solutions, which incorporate all three service elements.

We tailor our services continually to the requirements of our customers and industry. BBR is committed to the highest engineering standards and to developing a close working relationship up and down the supply chain with both clients and suppliers. We achieve this by a close and open co-operation and communication already during tender stage of a project until its final completion. These relationships enable all parties to gain exceptional benefits.

BBR's Background

While BBR's history is 60 years old, BBR is focused on constructing the future. Established traditions are combined with latest thinking and leading technology. Flexibility as an innovative specialist contractor has enabled BBR to maintain a strong global position in a diminishing and increasingly competitive industry.

BBR's Fields of Application

BBR has applied post-tensioning technology in numerous different structures such as bridges, buildings, towers, marine structures, tanks and ground anchors. The scope of work includes stay cables, construction methods, ground engineering, heavy lifting, bearings and services in maintenance, repair and retro-fit. BBR trade marks – BBRV, BBR CONA, BBR FLAT, BBR DINA, BBR HiAm and BBR CONA STAY – are recognized world-wide.

BBR's Technology

All BBR products and equipment are not only the result of years of direct experience but also fulfil the stringent quality standards imposed by different country regulations with codes and specific local regulations.

BBR's Network

BBR operates as a global network with subsidiaries, licensees and suppliers throughout the world. BBR's headquarters are located in Schwerzenbach/Zurich, Switzerland. The global BBR network provides each local BBR member firm access to international in-house know-how and resources and to exchange information on a broad scale and within international partnering alliances. BBR subsidiaries and licensees with strong local roots are all structured differently and offer numerous other construction services in addition to the traditional core business in post-tensioning.

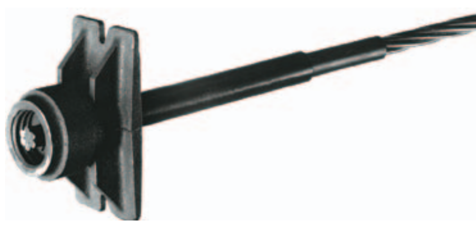
BBR's Track Record

BBR has a proven 60 year track record of excellence and innovation with thousands of structures built with BBR technology throughout the world.

Consulting

Consulting and Design Services in Relation to
- Construction Engineering
- Alternative, Preliminary + Detailed Designs
- Design Checking + Proof Engineering
- Plant Layouts and Manufacturing Processes
- Material Specifications and Quality Control
- Technical Assessment, Inspections
- Technical Assistance
- Site Supervision

BBRV



BBR CONA Single

Contracting

Influencing the important step to success
- Design and Build Contracts
- Complete Post-tensioning Operations
- Prefabrication Plants
- Temporary Works for particular Construction Methods
- Maintenance, Repair and Retrofitting

Technology

Supply and control for quality controlled material and equipment
- Post-tensioning Systems
- Ground Anchors
- Stay Cable Systems
- Bearings and Joints
- Carbon Fiber Reinforced Polymers
- Procedures + Technologies for Testing and Inspection
- Research and Development
- New Technology

Tatara Bridge, Japan

Sunniberg Bridge, Switzerland

BBR CONA

BBR FLAT

BBR History

founded 1944

Author: Hans Rudolf Müller, Dipl. Ing. ETH

Epigraph

Education
Fascination
Realisation

Start

At the beginning of BBR there were three young, technically well educated civil engineers, all graduated at ETH (the Swiss Federal Institute of Technology, Zurich), aged thirty years, already with some practical experience. In 1944, they formed a partnership for the promotion of novel construction elements, especially supporting girders made of concrete and using pretensioned reinforcement. Both Max Birkenmaier and Antonio Brandestini worked since 1941 at Swissboring SA, a specialist firm in the field of geotechnics, when they came to know of the ideas of the French engineer Eugène Freyssinet, who published his ideas in the French journal «Travaux» [1]. The owner of Swissboring, Giovanni Rodio shared the enthusiasm with his collaborators and encouraged them to bring the theoretical studies of the group into a practical undertaking. On the other hand, the third partner of the group, Mirko Roš, was a scientific assistant at EMPA (the Swiss Federal Laboratories of Materials Testing and Research) from 1941 until 1946. He was engaged with compiling all the know-how in materials technology of concrete and steel for the application of prestressing, and starting research for further development. The incentive was that during the Second World War construction material was scarce, especially cement due to reduced availability of energy and because of difficulties in importing steel. Therefore the method of prestressing was a tool for cost savings.
Mirko Roš published the results of his tests in a very important report, the EMPA-Report No.155 [2].

The partnership BBR

The study group was named BBR, according to the alphabetical order of the initials of the partners, and known since 1945 under the name BUREAU BBR:

Birkenmaier Max
1915–2002, Dipl.Ing. ETH 1940, Dr.h.c. 1969

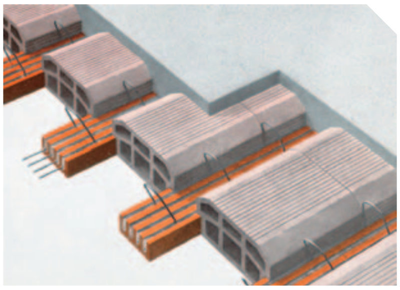
Brandestini Antonio
1915–2003, Dipl.Ing. ETH 1939

Roš Mirko Robin
1912–1968, Dipl.Ing. ETH 1937

From invention to practical application

To get practical experience with the developments of Bureau BBR, and to start production and commercial activities, the firm Stahlton AG was foundet in July 1945. The main shareholder was Giovanni Rodio. Mirko Roš acted as President until his death, and Max Birkenmaier was a full time Managing Director from the start until 1983. Antonio Brandestini was member of the board, but still employed by the contracting firm AG Conrad Zschokke, Zurich up to 1954. Then he formed Proceq SA (processes and equipment). Brandestini recognized the need for the proper design and production of the necessary machines and tools to allow easy handling of post tensioning work and efficient manufacture of prestressing elements, absolute necessities for licensees.
Mirko Roš opened his own design office in 1946. He realised the advantage of adequate design of pre- and

post-tensioned constructions, on the one hand to support licensees and to promote prestressed concrete as such, and on the other hand to demonstrate the benefits of prestressed concrete in winning competitions and awards, especially in bridge design.
The first product was the pretensioned small beam, consisting of burnt clay serving as a mould for mortar. Along the free channels, pretensioned steel wires are arranged and the voids around the wires filled with mortar. After hardening of the mortar, the end blocks holding the stressed wires are released [3].



Stahlton plank

In such a way, the beams are set under longitudinal forces, i.e. prestressed. The combination of steel and burnt clay gave the idea of the trademark «STAHLTON» («Stahl»-steel, «Ton»-clay in German language) for the beam as well as of the manufacturer. The product is the key part of prefabricated slabs and lintels.
In Europe and in Switzerland as well, there was a demand for prestressing concrete with anchored tendons, the so called post-tensioning method. Some methods to anchor prestressing steel (wires, strands or bars) were known, but the accuracy of the anchorages was inadequate, as was soon found out by using firstly the System «Magnel-Blaton». The wedges did not work properly. BBR discussed the matter with a well known wire producer, Dipl. Ing. K. Vogt.
The button heading, to form a safe anchoring of cold drawn high tensile wire was developed and a long lasting collaboration with K. Vogt followed. The anchoring method was named BBRV, adding the V to complete the brand name [4]. The plant, already established in Frick (CH), was frequently enlarged and is now also the fabrication site for the post-tensioning activities.

License package for realisation

Soon after the start of production of STAHLTON planks, entrepreneurs in building construction showed interest in to participating in the success of BBR's designs and products.
The concept not only offered a license to use the designs but also to sell the necessary special equipment or to indicate the best source of supply and additionally to instruct personnel at the licensees' plant and construction sites. Without this combination the transfer of know-how is incomplete. Furthermore, it is important for licensees to get instructors on demand. In this context, licensees often wanted engineering designs from the licensor or through his mediation to support marketing or to have access to specialists in contracting equipment.
BBR was in a position to fulfil the above demands.
Partner Antonio Brandestini's firm PROCEQ SA was responsible for the supply of special equipment, e.g. button heading machines, jacks, mixers as well as testing devices etc. Partner M.R. Roš founded in 1946 his engineering and design office, efficient in the design of prestressed and post-tensioned structures. He designed in 1953 the first post-tensioned bridge for the Swiss Federal Railways, a major line in the city of Zurich (bridge over Thurgauerstrasse). In connection with the licensee in Greece (Domiki Inc. Athens), he designed in 1957 a trunk of 4 km of prestressed pressure pipelines [5], where the pipe winding process BBRV was applied (see also «Technical Milestones» above).
This procedure is very often an effective method to create a winning team in the modern approach in contracting, especially for established licensees. In a similar way, BBR's licensee in India engaged BBR Ltd. for participation in a competition for the design of the superstructure of a 2.8 km long railway bridge over river Godavari near Rajahmundry [6]. The project, designed by CEPAS Plan AG (successors of former design office M.R. Roš) for Hindustan Construction Co. was chosen by South Central Railways, Secunderabad, as the most economic solution (see also «Technical Milestones»).

Adaptation of the Organisation

BBR was founded in 1944 as a partnership of three individuals.
One year later, we find the partnership officially under the label BUREAU BBR, and that lasted up to 1972, when it was transformed to Bureau BBR AG, a limited company, after the decease of Partner M.R. Roš († 1968). Since 1993, Bureau BBR Ltd. changed to BBR Holding Ltd. 1998, acting as licensor with affiliated companies. Licence agreements exist also with independent companies. Today BBR has subsidiaries and licensees in 28 countries.

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[5] Dr.Ing. F.l'Allemand: «Vorgespannte Druckrohre für die Wasserleitung von Athen». «Der Bauingenieur», 35. Jahrgang (1960) Heft 1 pp. 35–37

[6] H.R. Müller, F.E. Speck: «The third Godavari Railway Bridge, India», FIP Notes 1994/2, pp. 15–18, FIP c/o the Institution of Structural Engineers, London

Technical milestones of BBR in prestressed concrete and stay cable technology

BBRV anchor

Schillersteg Stuttgart

Rama VIII Bridge

1944	Setup of partnership BBR
1946	Development of STAHLTON planks and lintels
1947–1949	Development of BBRV post-tensioning system with button headed wires
1952	Development of BBRV ground anchors Development of BBRV tank and pipe winding
1955–1958	Construction of the bridge over the river Thur (CH) (The first application of tendons with a capacity of 1250 kN)
1956	Development of Thosti-BBRV sleepers
1960	Prestressing of large pipes (Athens Aqueduct)
1961	Schillersteg Stuttgart (first cable-stayed bridge with BBRV anchors)
1965	Prestressing of nuclear power vessels and secondary containments starts. Up to 1995 more than 60 units have been equipped with BBRV tendons
1970	Development of BBR HiAm* anchors
1971	Construction of Olympia stadium Munich with BBR HiAm* anchored strands
1972	Development of BBR CONA post tensioning system with strands
1975	Development of BBR DINA anchors
1982–1994	BBR HiAm stays for Second Hooghly river bridge, Calcutta, span 457 m (The longest cable-stayed bridge in Asia at that time)
1992	Development of BBR-CONA STAYS
1991–1997	Godavari Railway Bridge (India), 2.8 km long, with DINA hangers (The longest railway bridge in India)
1996	Development of stays with carbon wires (Bridge «Storchen», Winterthur CH)
1998	«Sunniberg» bridge with BBR HiAm stays near Klosters (CH)
1999–2002	«Rama VIII», cable-stayed bridge (Thailand), with BBR CONA STAY
2000	Development of complete package of BBR-FRP Strengthening Systems
1961–2004	Stays supplied for more than 200 cable-stayed bridges

BBR HiAm in collaboration with Leonhardt & Andrä, Stuttgart

Segmental Bridge in Kitchener, Ontario

Highway 8/7 Interchange, East-South Ramp Flyover 4

Author: Tim Pahapill

Reinforcement of the Segmental Bridge

View into the Bridge Deck Section with PT ducts

Overview and Location

The tri-cities of Kitchener-Waterloo-Cambridge in southern Ontario are located 100 km southeast of Toronto. The region has benefited from continuing expansion, but now faces a problem of traffic gridlock that is threatening economic growth. Several major capital improvements have been made to improve traffic flow through the existing regional highway 8/7 interchange.

Scope

In the final phase of a long-term project started in 1999 by the Ministry of Transportation of Ontario, a two-lane flyover was built to off-ramp Highway 8 east to Highway 7 south. In spring 2003, construction began on a seven-span, prestressed concrete trapezoid-section, segmental bridge on conventional falsework.

Project description

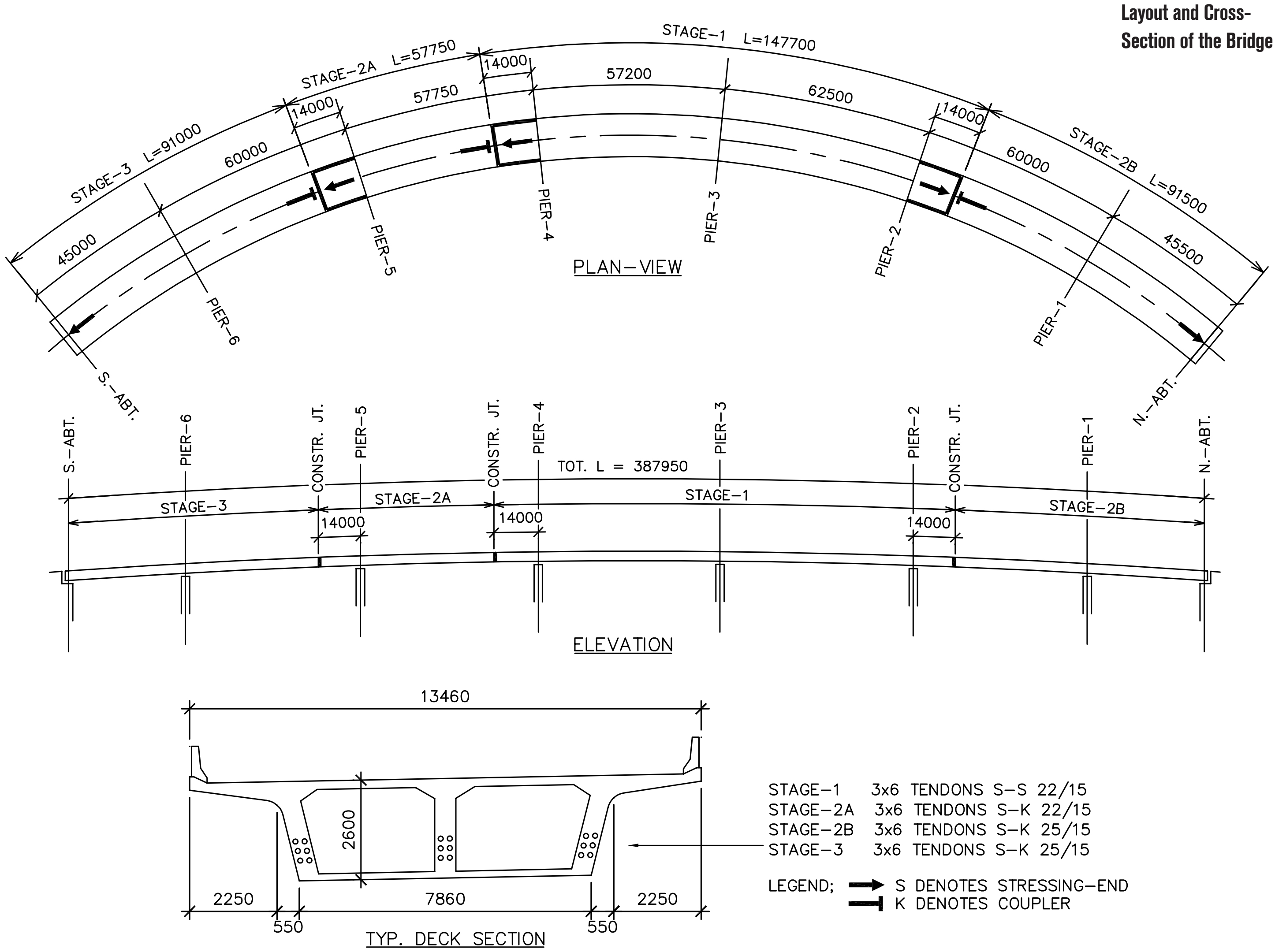
The superstructure was cast in four stages. The longitudinal tendons were coupled at the construction joints with BBR K-couplers for the BBR Cona 2506 and 2206 post-tensioning system. There were six longitudinal tendons in each web. Stages 2A and 2B were cast on either end of Stage 1, which was stressed from both ends. The dual- purpose BBR K-couplers then acted as dead-end anchors for the remaining segments that were stressed against the previous stage. The transverse tendons in the pier diaphragms were BBR Cona 1906, and the abutment and stage diaphragms utilized BBR Cona 706 and 406 respectively.

Region/Location	Kitchener-Waterloo Region, 100 km southeast of Toronto, Canada
Purpose/Usage of the structure	Highway 8/7 Interchange Improvements, New East-South Ramp Flyover
Owner	Ministry of Transportation of Ontario
Designer/Supervisor Engineer	Morrison Hershfield Group Inc.
Main Contractor	Dufferin Construction, a division of St. Lawrence Cement
Specialist Contractor	Canadian BBR
BBR Scope of work	Supply and installation of BBR CONA PT
Key Data	Type of construction: 7 spans, span length 45.0 m to 62.5 m, overall length 388 m. Cast in place segmental construction on conventional falsework. Construction time: March 2003 to December 2003
BBR Product/Technology/System used	187 t longitudinal tendons BBR Cona 2506 & 2206 w/K-Couplers, 22 t transverse tendons BBR Cona 1906, 706 & 406
Contact	Tim Pahapill, E-Mail: tj918@cogeco.ca

Construction product, BBR applications

The BBR K-couplers performed admirably. The tendons in the previous stage were grouted before the tendons in the ensuing stage were coupled. Therefore, special attention was required to avoid any grout contamination of the integrated spring-loaded grips in the dead-end side of the K-coupler. Temporary grout caps were required to seal the BBR Cona wedges in the stressing side of the K-coupler prior to grouting each stage. This was highly successful because the dead-end side of the BBR K-couplers are filled with grease and sealed on both ends during manufacturing. The temporary seals on the front end of the K-couplers were left in place until immediately prior to coupling of the individual strands. As well, we followed the advisable practise of de-burring and cleaning the end of each strand before insertion into the BBR Cona K-coupler. We believe that this additional procedural step improves the level of quality control by ensuring the tendon coupling mechanism is not fouled by small metal shavings that may break off from the sharp edges of a freshly cut strand.

Layout and Cross-Section of the Bridge



Bauxite Bulk Storage Silos in Sept-Iles, Quebec

Project Alouette Phase II, Silos d'Alumine Nos. 3 and 4

Author: Tim Pahapill

View of the four Alouette Silos

Overview and Location

The Alouette aluminum smelting facility in Sept-Îles, Quebec's north shore region, is located 850 km northeast of Montreal. Construction of the Project Alouette Phase I, Silos d'Alumine Nos. 1 and 2 was completed in 1993 with prestressing works by Canadian BBR. To meet increasing worldwide demand for aluminum products, SNC-Lavalin/Hatch are overseeing a major plant expansion that will double current production capacity by 2005.

Detail of the anchorage zone

Scope

As part of this ambitious project, two additional bulk storage silos were built to each hold a volume of 60,000 mt of refined Bauxite (Alumine). In spring 2003, construction began on two 33 m diameter, 65 m tall, prestressed concrete silos.

Construction method

The walls for both silos were slipformed simultaneously in fall 2003. The conventionally reinforced roof was cast in spring 2004, using an innovative falsework system that initially served as a main structural element in the slipform scheme. These 33 m long joists also served as anchorages for the outrigger tie-downs required for the swing stage work platforms used for accessing the circumferential prestressing works.

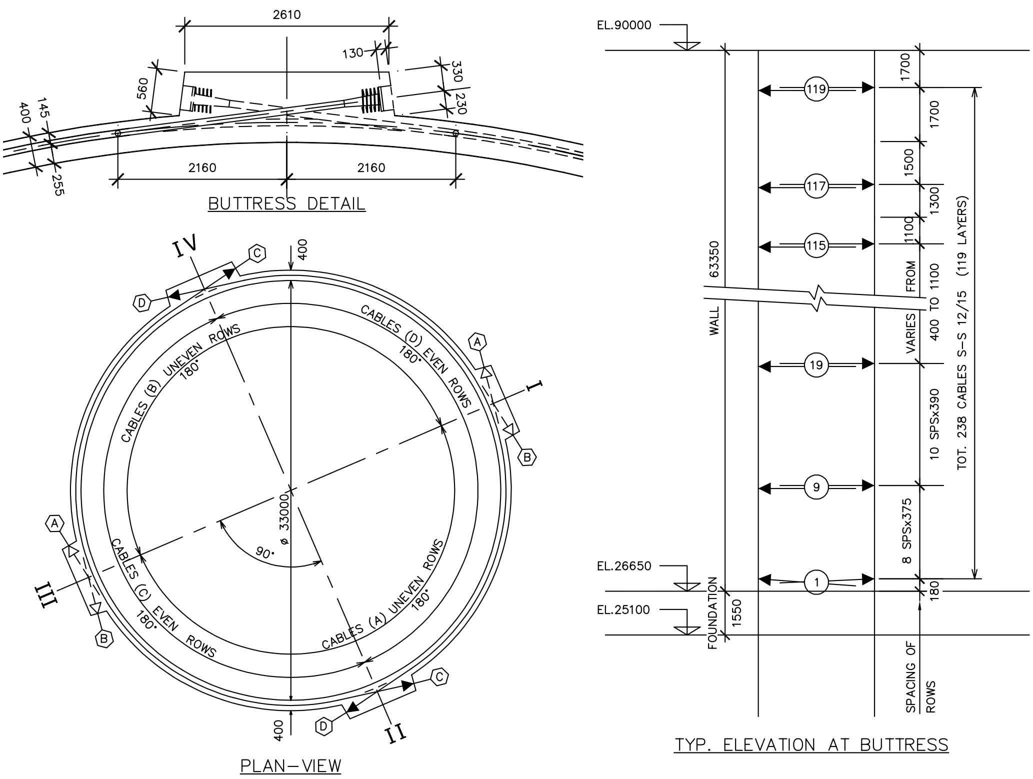
Construction product, BBR applications

There are four buttresses on each silo. Two BBR Cona 1206 tendons anchored on both sides of opposite buttresses formed one tendon layer in elevation. Silo No. 3 required 111 layers. Silo No. 4 required 119 layers. In addition, 2–3 13 mm strands were installed in each duct to serve as passive mild steel reinforcing rods.

The BBR Cona 1206 post-tensioning system installations were simple and trouble free. The stressing was carried out with two 350-ton jacks in four distinct sequences. Both tendons in every fourth layer were stressed simultaneously. The layers were alternated between buttresses after each sequence was completed. All the tendons were stressed from both ends, one end at a time. The maximum observed discrepancy between theoretical and actual tendon elongation was less than 3 %.

After the tendons were cropped, the recesses were reinforced with a prefabricated wire mesh that was tied to threaded inserts in the BBR Cona 1206 bearing plate. The recesses were filled with Sika 212 sanded grout by gravity feeding from a rooftop mixing station. The tendons were grouted with type 10 Portland cement, w/c ratio 0.45, and 750 mg Sika Intrusion Aid per 120 kg batch.

Region/Location	**Sept-Îles, Quebec north shore region, 850 km northeast of Montreal, Canada**
Purpose/Usage of the structure	**Two new Bauxite Bulk Storage Silos**
Client	**Groupe C.R.T. Inc.**
Designer/Supervisor Engineer	**Groupe-Conseil BPR Consultants/SNC-Lavalin/Hatch**
Main Contractor	**Alcan-Alesa Technologies Inc.**
Specialist Contractor	**Canadian BBR**
BBR Scope of work	**Supply and installation of BBR CONA PT**
Key Data	**Type of construction: 2 silo structures, 400 mm wall thickness, 33 m diameter, 65 m tall. Slipformed construction Construction time: March 2003 to September 2004**
BBR Product/Technology/System used	**Silo No. 3: 171 t stressed tendons BBR Cona 1206 + 23 mt mild steel rods Silo No. 4: 183 t stressed tendons BBR Cona 1206 + 25 mt mild steel rods**
Contact	**Tim Pahapill, E-Mail: tj918@cogeco.ca**



Silos Layout

The World's Largest Prestressed Concrete Tank

World Record Holder: 35.0 MG Earl Thomas Reservoir

Author: Max J. Dykmans

Overview and Location

The completion of the reservoir will increase the storage capacity of the plant to total 77-million gallons of drinking water. The world's largest prestressed concrete tank will ensure that the City of San Diego continues to meet the rapidly increasing demand for clean, safe drinking water.

Roof slab pouring sequence

Scope

For over 40 years, DYK and its predecessor companies have made numerous noteworthy improvements in the design, construction and prestressing of concrete storage tanks. In the late 1960's, as water tanks increased in both size and demand, DYK Incorporated introduced the first strand wrapping machine. Since then, DYK has prestressed, built or designed nearly 800 low maintenance tanks in some of the world's most diverse climates, with capacities ranging from 80,000 gallons to 35 million gallons for a total capacity of more than three billion gallons making DYK the undisputed leader in prestressed concrete storage tank research and development. Proven DYK planning, engineering, and technology has led to stronger, more attractive tanks with greater seismic reliability, less leakage, low maintenance and longer life spans for municipal industrial and commercial users.

Award winning DYK tanks have been commissioned by those interested in long lasting, seismically reliable liquid storage tanks enabling higher quality of life and multi-land use. Playgrounds, tennis courts, cul-de-sacs, native habitats, and gardens have all been installed on top of fully buried flat roof tanks. Other DYK tanks have been completely disguised with architectural details for seamless integration into neighborhoods and office parks. DYK designs tanks to optimally fit the landscape and community needs. Included in our experience record are many tanks in California, Arizona, Nevada, Oregon, Washington, Utah, Montana, Hawaii, Alaska, Wyoming, New Mexico, Idaho, Singapore and Egypt. A 35 million gallon strand-wrapped prestressed concrete tank is currently under construction in San Diego, California, as part of the Alvarado Water Treatment Plant upgrade and expansion project. Since the Alvarado WTP is San Diego's oldest existing water treatment plant, these improvements will ensure that the City's increased capacity of water will meet all current and future drinking water standards and provide maximum protection of public health.

Model view of the Artwork with cypress trees

Project description

Upon completion in the summer of 2005, the structure will be the largest circular, prestressed concrete tank in the world. The new Earl Thomas Reservoir will store 35 million gallons of treated water to serve 500,000 people. The reservoir replaces the old Earl Thomas Reservoir, a 50-year old rectangular structure which was deteriorating. In addition to the reservoir replacement, the Plant will also see numerous aesthetic enhancements and landscaping. A road will run across the top that will direct all plant traffic over the roof of the new reservoir. The design of the new reservoir will require less maintenance than other types of reservoirs. It is an important addition to the City's water system because it will provide extra water storage to meet peak demands as well as for fighting fires.

Construction method

The reservoir has an inside diameter of 406 feet and a water depth of 39 feet. The reservoir corewall tapers from 38-inches thick at the base to 12-inches at the top. The wall was vertically post-tensioned with nearly 600–1 ⅜-inch diameter high-strength threadbars and circumferentially prestressed with over 200 miles of ⅜-inch diameter, seven-wire galvanized strand. The circumferential prestressing is protected with several layers of automatically applied alkaline rich shotcrete. The entire prestressing and shotcreting operation was completed using one of the world's most technologically advanced, fully automated, state-of-the-art machines to ensure that the necessary quality control was consistently maintained. This machine continuously and electronically monitored the applied stressing force on the strand as it was applied. To meet the high seismic performance criteria established in the Southern California area, the reservoir incorporates flexible connections at the wall base and wall top. While movement of the wall will be allowed, watertightness will not be compromised. The design incorporates a PVC waterstop at all construction joints to ensure watertightness for the structure. Two hundred and forty one 30-inch diameter concrete columns will support the 18-inch thick two-way flat slab cast-in-place concrete roof. The roof is designed for 30.0 psf live load, H20 truck and 2 feet of soil.


Winding operation


Erection of columns

BBR automated strand winding machine

The project's landscape, which will encompass the facility's perimeter, will consist of sycamore trees and coast live oaks. In addition, the roof, considered environmental artwork, will be ringed with hundreds of Italian cypress trees to help all who enter to visualize the enormous scale of the underground reservoir. The treatment plant will remain in operation during the upgrades and expansions, keeping with the plant's 53 year history that it has never been off-line for more than 24 hours.

Region/Location	San Diego, California, USA
Purpose/Usage of the structure	Prestressed Concrete Tank
Designer/Supervisor Engineer	DYK Incorporated
Specialist Contractor	DYK Incorporated
BBR Scope of work	Design Supply and installation of BBR CONA Prestressing with BBR winding machine
Key Data	Inside diameter: 125 m, water depth: 12 m Construction time: 2004–Summer 2005
BBR Product/Technology/System used	BBR automated electronically monitored winding machine
Contact	Max J. Dykmans, E-Mail: dykinc@dyk.com

Krishnarajapuram Bridge, Bangalore

Cable Stayed Bridge

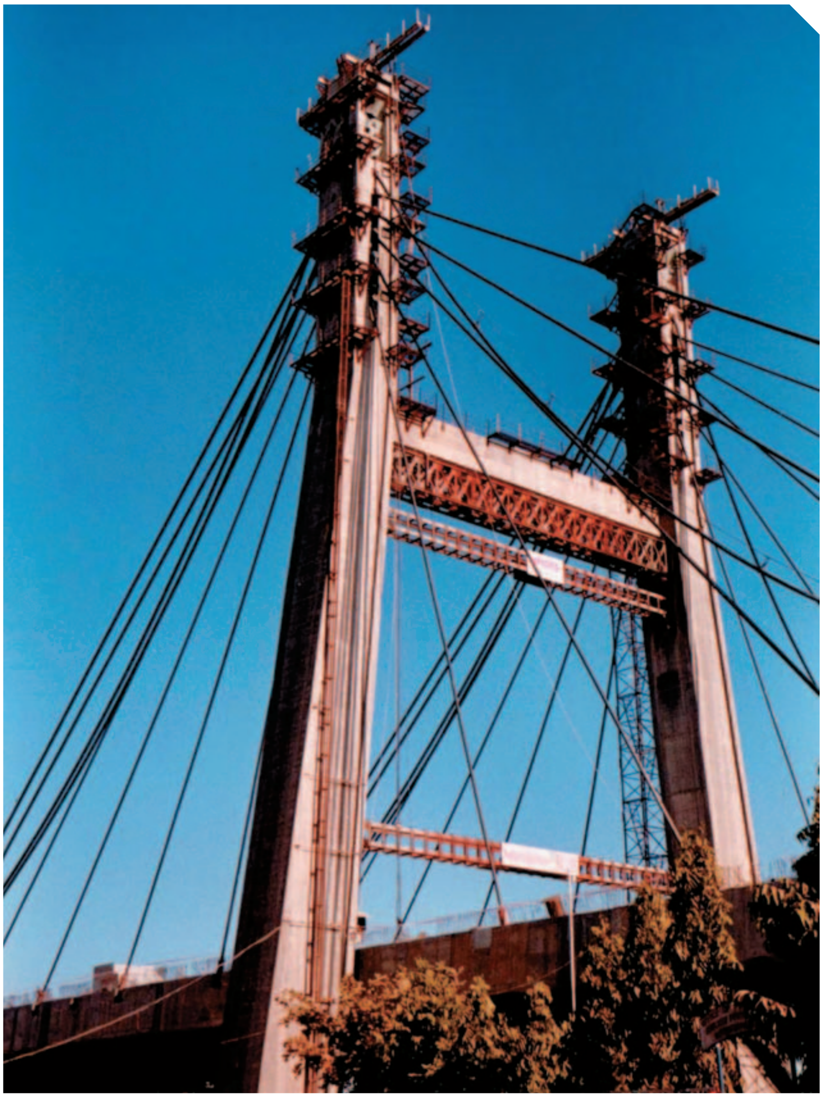
Author: S. K. Agrawal

Overview and Location

The Krishnarajapuram cable-stayed bridge is a tribute to Indian bridge engineering, bringing the state-of-the-art in bridge design and construction technology to the paradigms of Indian bridge building know-how. The Indian Railways, for the first time in the country, considered a cable-stayed bridge concept of this kind to cross the busy railway tracks at Krishnarajapuram, replacing an old road over a bridge which had become redundant in view of ever increasing road traffic in the busy Bangalore–Kolar–Chennai road on National Highway No. 4.

Scope

Preliminary studies were carried out by the Railways in the mid 90's, based on a presentation on the latest trends and concepts in bridge engineering by BBR (India) Ltd, Bangalore, with their principals, BBR Systems Ltd of Switzerland. After carrying out further detailed studies with various alternative bridge systems, to compare the technical and economic merits and de-merits, the proposal of the cable-stayed bridge was decided upon, in view of the following merits.



Pylon view during construction

Project description

The 106 m main span of the bridge with open deck, supported on an array of stay cables, crossed over all the busy railway tracks underneath without any ground supports in the railway zone, also facilitating future expansion of the yard at Krishnarajapuram railway station. The main support of the bridge, the pylon, could be positioned completely outside the railway track zone.

The 45 m cable supported open deck side span on the Madras side, and a 50 m continuous box girder span on the Bangalore side, caters for a clear road traffic way under the bridge, without obstructions.

The bridge, spanning over the live and busy railway tracks could be constructed without disrupting train movements, using a sophisticated traveling form carrier, specially built for the purpose, thus avoiding any ground support during the construction of the bridge deck. This also helped to reduce the overall construction time required for the cable supported span.

The 230 m long, 23.4 m wide, four lane bridge structure, with the 180 m stay cable supported spans built monolithically with a 50 m span continuous box girder, eliminated any expansion joints inbetween the end abutments, thus ensuring a better and smooth riding quality for motorists.

The wide open space below the bridge with only a few pier supports, facilitates commercial exploitation of the space.

The cable-stayed bridge, with an array of the stay cables fanning from the concrete pylon, long, wide clear spans underneath with minimal obstruction to the landscape and thus to the rail traffic, result in a extremely aesthetic and elegant structure, destined to be a landmark not only for the city of Bangalore, but for the whole country.

Construction product, BBR applications

The BBR DINA stay cables supporting the bridge deck, comprising high strength, high fatigue-resistant steel wires, have been manufactured completely indigenously, except for the raw material billets for the steel wires, which were imported from Japan. These steel wires were manufactured in Calcutta and were road transported to the stay cable fabrication facility of BBR (India) Ltd at their factory in Yeshwanthpur, Bangalore, where the entire stay cable manufacture has been carried out indigenously, for the first time in the country.

Cantilever Form Traveller suspended from BBR Dina Cables

Krishnarajapuram Bridge

▲Bridge under construction

Transforming these bare wires into complete units of bridge stay cables was carried out by BBR (India) Ltd at Bangalore. World-renowned BBR Dina parallel wire stay cable technology, which has been adopted for numerous stay cable bridges around the world, has been used for the stay cables of Krishnarajapuram bridge also. The entire manufacture of the components and accessories required for the stay cables, including the high strength, high fatigue-resistant BBR Dina anchorages, were manufactured by BBR(India) at their stay cable manufacturing facility at Yeshwnthpur, Bangalore. A total of 160 tons of high strength steel wires, amounting to an equivalent wire length of 530 kilometers, was used for the entire stay cable system of the bridge.

The steel POT cum PTFE bridge bearings, supporting the bridge structure at the abutments, piers and the pylons, were manufactured and installed by BBR (India). The high capacity bearings, with a capacity up to 1610 tons, were manufactured using high strength steel, at the bearing manufacture unit of BBR (India).

The concrete edge beam and diaphragm components of the bridge deck are prestressed using the BBRV system. The prestressing system, using high strength steel wires, was prefabricated with BBRV high strength steel anchorage units, transported to the bridge site, installed and stressed by BBR (India). A total of 140 tons of high strength steel wire, amounting to an equivalent wire length of 460 kilometers has been used in this project. A similar system was also used for the BBRV ground anchors to anchor the short back span abutment of the bridge to the ground.

Construction method

The fabrication, erection and operation of the steel BBR Cantilever Form Traveler (CFT) weighing more than 160 tons, used for concreting the bridge deck segments over the live railway tracks, called for the most critical and demanding work involvement by all parties concerned, right from the designer to the skilled laborer operating the winches. Operations with the BBR CFT, which was fully suspended from the bridge deck, with live high voltage railway traction wires just below it, required careful planning and checking down to the last detail during execution of all operations using the BBR CFT. This was a challenging feat and was carried out successfully throughout the entire project. The coordinated efforts by all the agencies played a vital role in the success of operations with the BBR CFT, realizing a safe and on timely completion of the total project.

The geometry control of the bridge during construction, with its relatively flexible deck, suspended from the stay cables, was also an entirely new and challenging experience. The geometry of the cable-stayed main span, which was constructed in several sequential stages using the traveling form carrier suspended from the bridge deck itself, was to be controlled within satisfactory limits to the theoretically predicted values established by a computer run construction stage analysis.

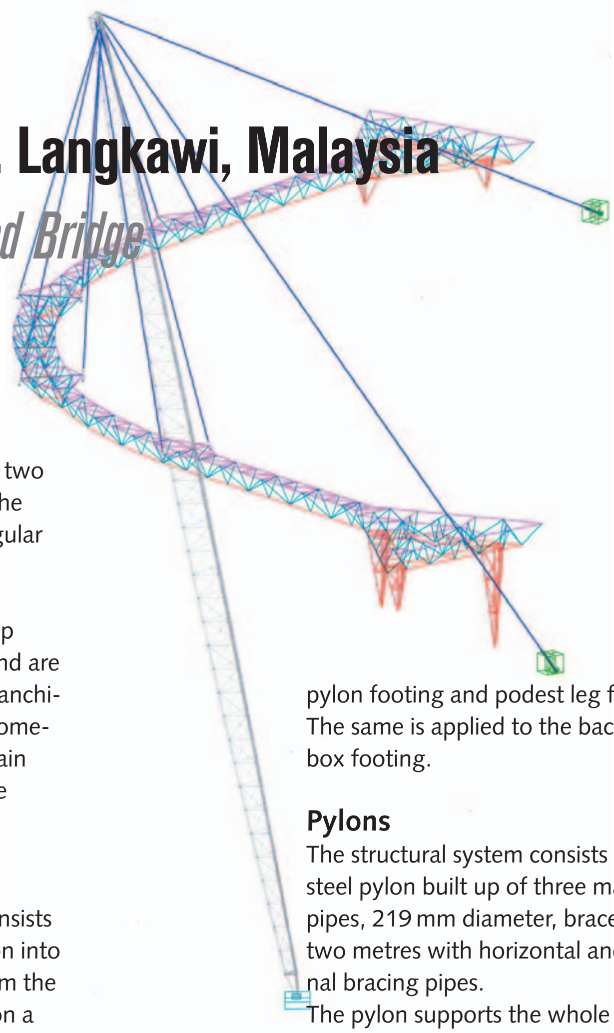
This bridge geometry control process required immediate and accurate computations and decisions for the site engineers during construction, which was successfully carried out by BBR (India) through all stages of construction, resulting in a finished bridge deck geometry well within the construction tolerances, completed within the scheduled time.

The corrosion protection grouting operations, with in-situ cement grout for the stay cables and special grease in the tie-down cables of the bridge, was also an equally challenging task, executed by BBR (India). The grouting operations, which were to be carried out up to a height of 40 meters from the bridge deck and the atypical problems faced during the operations called for ingenious and innovative solutions during execution, culminating in a successful and on time completion of the grouting operations. Apart from the above, systematic procedures and control measures were established at the factory during manufacturing and also on site during installation, for ensuring a high quality of the end products.

Region/Location	**Bangalore, India**
Client	**Southern Railways**
Consultant	**BBR Systems, Switzerland**
Main Contractor	**IRCON International**
Subcontractors	**AFCONS, BBR (India) Ltd.**
BBR Scope of work	**Design Supply and installation of BBR Dina Stay Cables, Construction Methods**
Key Data	**Total length: 230 m with 180 m span asymmetric cable stayed portion with single Pylon of 58 m height. Construction time: February 1998 to December 2002**
BBR Product/Technology/System used	**BBR Dina 96 7 – 264 7, total stay cable steel 162 t. BBR V PT, total steel 140 t.**
Contact	**S. K. Agrawal, E-Mail: bbrindia@bbrindia.com**

G. Machincang Bridge, P. Langkawi, Malaysia

Cable Stayed Curved Bridge



Author: Y. L. Voon

Overview and Location
Built on top of the Gunung Machincang Cable Car Top Station, this curved bridge will connect two protruding hill tops, separated by a deep valley. This is to be part of the jungle trail/nature walk feature for the G. Machincang cable car attraction.

The pylon foundation is at level 604.5 m while the deck of the bridge is at level 660 m. The top of the pylon extends to level 686 m. The pylon inclines in two dimensions at angles of 78° in one plane and 2° in the other.

The deck structure is curved in plan for a curved length of 125 m.

Project description
The 81.5 m pylon is founded an a concrete pad.

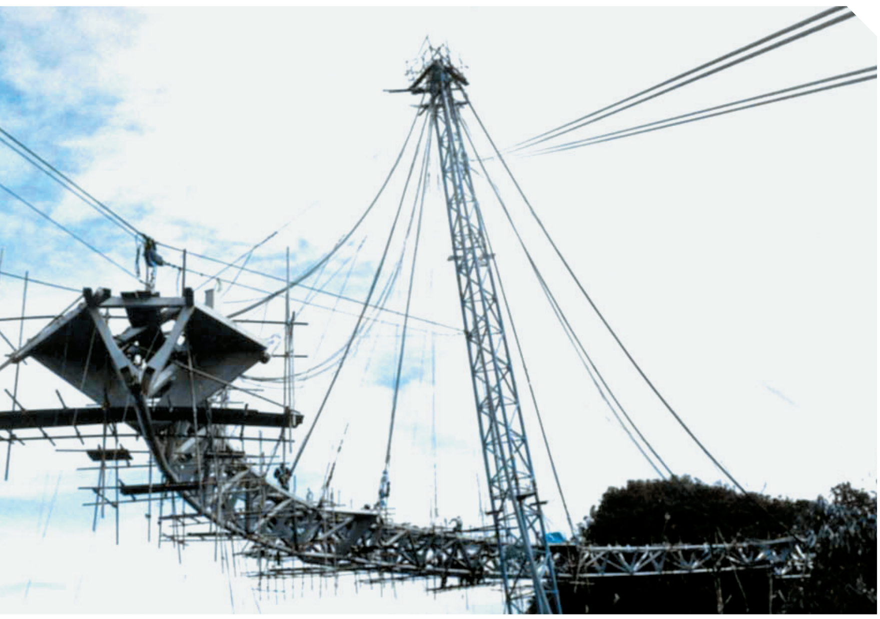
The deck structure protrudes from two platforms (podests 1 and 2), separated by a straight line distance of 110 m. The first 25 m portion of the deck is straight, followed by another three curved lengths of 25 m and ending with another 25 m of straight portion.

The deck structure is built-up of sectional hollow sections for the two top chords and a single pipe at the bottom chord, making it a triangular truss section.

The podest platforms are built-up using similar triangular trusses and are supported on three steel truss stanchions. The legs conform to the geometry profile of the existing mountain ground, making them of variable heights up to 10 m high.

Foundation
The foundation for the pylon consists of a «hand dug» concrete caisson into sound rock to a depth of 6m from the existing ground. The pylon sits on a pin in a slot in the foundation concrete, enabling this connection to be a pin connection during the construction stage.

All other foundations for the podest legs are of concrete pads, tied together by prestressed cables into a rigid triangle format. In order to maintain integrity with the slope of the ground, ground anchors are drilled into the lower slope of the ground around the pylon footing and podest leg footings. The same is applied to the back stay box footing.



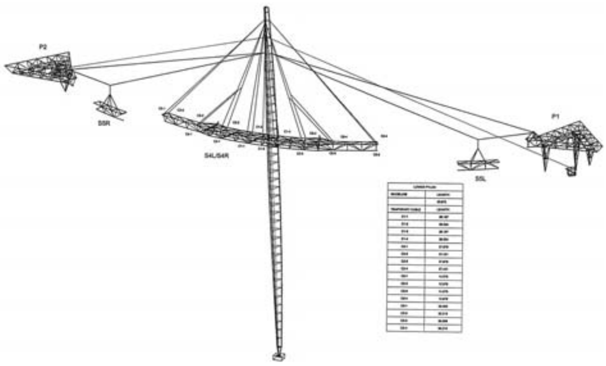
Pylons
The structural system consists of a steel pylon built up of three main pipes, 219 mm diameter, braced every two metres with horizontal and diagonal bracing pipes.
The pylon supports the whole structural system of the deck by means of stay cables connected to eight points on the deck structure. The pylon is balanced by two main back stay cables connected to concrete back stay boxes.

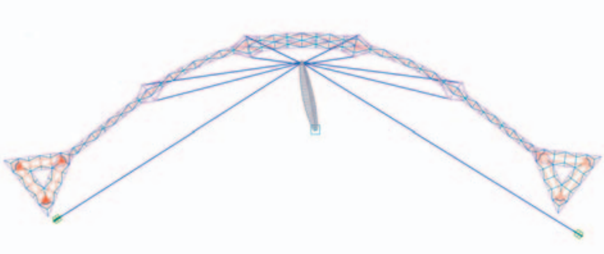
During construction, the pylon has a pin connection at the base to allow rotation into its final position. After final positioning and fine tuning of the deck, the base will be grouted.

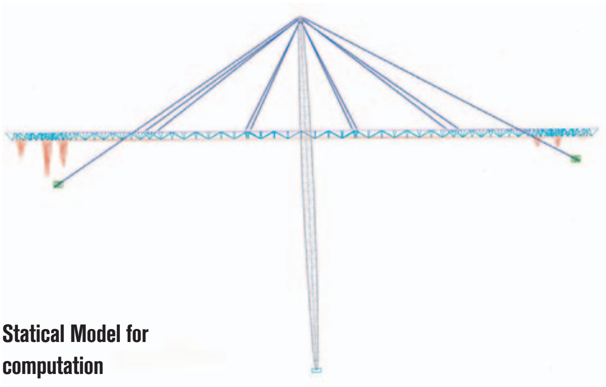
Stay Cables
The cable system selected for this project is the BBR CONA STAY system. The front eight stays are made up of seven No. 0.6" strands, encased in polyethylene. The two back stays are of 12 No. 0.6" strands encased in polyethylene.

The anchorage system is the BBR CONA STAY System, consisting of adjustable anchor heads, held back by high fatigue BBR wedges. The forces in the front and back stays are not expected to exceed 0.45 of the ultimate strength of the cables.

Construction product, BBR applications
BBR Construction Systems (M) Sdn Bhd was awarded the contract to







Statical Model for computation

View of the pylon and deck steel truss structure with temporary stays

Abutment during construction

fabricate the steel pylon, podest & deck and erecting the structure inclusive all stay cables.

The construction of the whole structure is very challenging as there is no access other than by cable car to the peak. The maximum load the gondolas can carry is less than 0.5 tons.

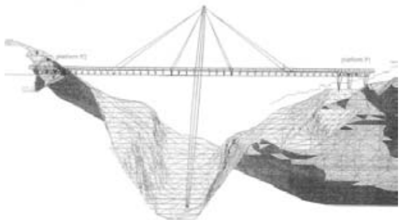
With this restriction, the only way to transport the construction equipment and steel segments to the site is by helicopter. A helicopter capable of carrying 4.5 tons load was employed for this purpose.

Important experience made with system/product application

The pylons were split into seven segments to be within the carrying capacity of the helicopter and were transported and erected in a vertical position by helicopter. The helicopter hovering position must not exceed 30 minutes for fear of over heating. This limits the maximum time to fix the segments to less than 30 minutes. This feat was achieved for the seven segments.

Another constraint was that the weather tends to get very foggy in the afternoons and the helicopter can only fly in the morning and occasionally in the afternoon when visibility is good.

Originally the deck segments were to be erected by helicopter, but evaluation of the method and safety, rules this method out. Instead the contractor opts for a working cable line system connected to the podest platforms and the pylon to lift the deck segments into position. The joints are pinned temporarily and then due to aesthetic requirements, all joints were fully welded.



Preliminary Layout of the Bridge

Region/Location	Malaysia
Owner	Langkawi Development Authority (LADA)
Designer/Supervisor Engineer	M/S Cepas Plan, Zurich Angkasa Jurutera Perunding Sdn Bhd
Main Contractor	Alam Langkawi Sdn Bhd
Specialist Contractor	BBR Construction Systems (M) Sdn Bhd
BBR Scope of work	Design Supply and installation of BBR CONA Stay Cables, Construction Methods
Key Data	Main span: Curved Length 125 m Construction time: February 2004 – August 2004
BBR Product/Technology/ System used	BBR CONA Stay 706 – 1206
Contact	Y. L. Voon, E-Mail: ylvoon@pc.jaring.my

BR8 Bridge, Putrajaya, Malaysia

300 m Stayed Cable Arch Bridge, Jambatan Seri Saujana

Author: Chin Beng Lim

Overview and Location

Bridge BR8 is located in Putrajaya, the new Administrative Centre of Federal Government of Malaysia. This bridge is the world's first cable-stayed arch bridge spanning across an artifical lake. It is unique because the deck is supported by a hybrid system of arch and stay cables. It is aesthetically very pleasing.

Project description

The bridge has two pylons with a span of 300 m. The two inclined pylons rise to a height of 73 m. The bridge deck is a 32 m wide multi-cell curve post-tensioned concrete box girder. A single plane of 22 front stay cables support the middle of the deck at 5 m spacing. The pylon is stabilized by two planes of 20 backstay cables, anchored into counterweight earth filled boxes. The wings of the deck are supported by hangers from the inclined arch. The two arches are made up of 2.1m diameter rolled steel pipes. They are anchored into concrete buttresses at the abutments. The top of the arch rises 34 m from the deck and is stabilized by K-bracings.

Construction method

As the artificial lake was not filled with water during construction, the deck was constructed on temporary falsework from each pylon. The deck was cast in 10 m length segments. The BBR CONA 1906 system was used for the longitudinal and transverse tendons.

The 42 m height of the pylon was constructed using a jump form. The upper 31m consisted of steel box modules. Due to the complex 3D geometry, the whole steel pylon head was fabricated in one piece to house the stay cable anchorages accurately. It was then divided into nine pieces for delivery and erection using two 150 ton cranes. The steel pylon box was filled with concrete and strengthened with prestressed bars.

Due to crowded working conditions on the constructed deck, the assembly and welding of arch segments was done on the north side, while the cable fabrication and installation was carried out on the south side.

Hangers

Each hanger consists of four to six 36 mm diameter prestressing bars. Bar couplers are staggered inside the steel pipe. Once the closure strip is completed, stressing was done from the access in the steel arch using four jacks simultaneously. The hangers are stressed in a symmetric and distributed way along the two arches to load the arches evenly.

Stay Cables

The stay cables consist of Malaysian made 15.24 mm diameter PE sheathed greased ungalvanized strands. The strands are further protected by an external HDPE and cement grouted after completion. Stay cable sizes range from 53 to 91 strands. The strands are anchored using wedges in the anchor head which allows some adjustment by a threaded lock ring which sits on the bearing plate. Full scale fatigue tests were successfully carried out using these locally made strands in Chicago on 9106 BBR CONA Stay.

Bridge after the installation of Hangers and Stays

Due to the availability of the completed deck space, all stayed cables were preassembled on site, and lifted into the respective location using two cranes. The upper cable end is secured to a launching «banana», which could rotate to the correct angle so that it could be inserted into the steel tube in the pylon. Once the top is secured, the lower end is lifted and lowered into the trumpet tube of the lower anchorage using a winch.

Important experience made with system/product application

Stressing was done using two 1200 ton jacks from inside the counterweight boxes on two backstays simultaneously and one jack under the bridge deck on the main stay. The jack was mounted on a steel sliding platform to enable stressing of each anchor. The stays are stressed while maintaining the zero position at top of pylon. The deck was stressed to the point at which the deck is just about to lift off from the falsework.

The stay cables and hangers were stressed to counter the deflections due to the concrete self weight. After removal of temporary falsework and superimposed dead loads, the bridge deflections are monitored. Lift off forces on the stays and hangers were tested to check the existing force against estimated forces and found acceptable.

Region/Location	**Putrajaya, Malaysia**
Designer/Supervisor Engineer	**Perunding Jurutera Satu (INT) Sdn Bhd**
Main Contractor	**Road Builder (M) Sdn Bhd**
Specialist Contractor	**BBR Systems Ltd/BBR Construction Systems (M) Sdn Bhd**
BBR Scope of work	**Supply and installation of post-tensioned cables, stayed cables and bar hangers**
Key Data	**Main span: 300 m Construction time: February 1998 – August 2000**
BBR Product/Technology/System used	**BBR CONA Stay 9106, BBR CONA 1906**
Contact	**Chin Beng Lim, E-Mail: chinbng@pc.jaring.my**

Ninoy Aquino International Airport, Manila

Flat Slabs at International Passenger Terminal 3

Author: Rey C. D. Singh

Overview and Location

BBR Philippines Corporation was part of the planning process prior to the construction of the Ninoy Aquino International Airport – International Passenger Terminal 3. The new airport is located in Pasay City, Metro Manila, Philippines, and will be the most modern terminal in the country. Its systems for aircraft guidance, passenger management, baggage handling, and security control are on par with the world's best. Truly, this is an international airport of the highest standards.

The completed Main Buildings

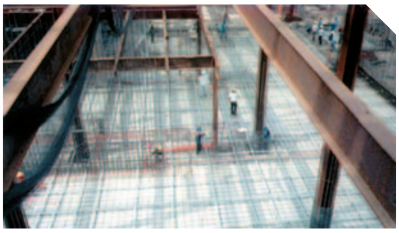
Project description

The airport is located on a soft soil area, which required bored pile foundations. The solution for the main building (Head House 01A, 01B, and 02A) called for a two-way flat slab system.

Construction product, BBR applications

The use of BBR CONA Flat Prestressing Systems was required even for the ground floor because of the soil's expansive properties. Hence, a suspended slab was designed for the first floor since the soil contracts during the dry season and expands during the rainy season.

The column to column distance for the main building is nine meters, which results in a flat slab floor system of 9 x 9 meters with a drop panel of 3 x 3 meters. The construction process required table forms and within an average of three days, these table forms were moved to other areas after stressing the tendons.



Tendon Layout at the Head House 01A

View of the Project Site during Construction

View inside the Main Building (Head House 01B)

Region/Location	Pasay City, Metro Manila, Philippines
Purpose/Usage of the structure	International Airport Terminal
Client/Owner	Philippine International Air Terminal Co., Inc.
Designer/Supervisor Engineer	Meinhardt Philippines, Inc.
Main Contractor	Takenaka Corporation (Philippines Branch)
BBR Subcontractor	BBR Philippines Corporation
Key Data	Area: 92,492 square meters Type of Construction: Two-way Flat Slab System Construction time: September 2000 to March 2001
BBR Product/Technology/ System used	Main quantities: BBR Flat 406: 5,500 pcs
Contact	Rey C. D. Singh, E-Mail: bbr_phils@pacific.net.ph

New Badiwan Bridge, Phillipines

Autor: Rey C. D. Singh

Overview and Location

The bridge was constructed along the slopes of the Rosario-Baguio Section of the Marcos Highway located in La Union and Benguet Provinces of the Republic of the Philippines, which experienced difficulty in maintaining a highway because of erosion and intermittent landslides.

Project description

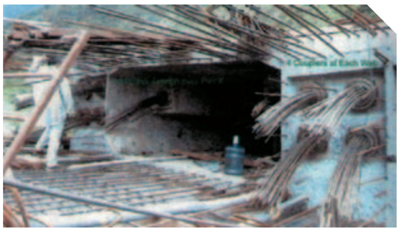
The 519-meter concrete Box-Girder bridge was constructed on concrete piers on a caisson foundation. The superstructure for this bridge is a single cell prestressed box girder. The girders are supported on 12 piers and an abutment at each end. The lengths of the 13 span superstructure starting from Abutment A (Manila end) are : 32-40-40-40-40-50-40-40-40-40-40-40-32 m.

Construction method

The 50 meter main span is constructed monolithically with Piers 5 and 6. The box girder is continuous over all the other piers. Due to the requirement that the tendons be made continuous, the superstructure construction started from Abutment A and proceeded «span by span» until Abutment B.

Construction product, BBR applications

BBR Philippines Corporation carried out the prestressing works for the New Badiwan Bridge. Eight Main Tendons of 2706 Strands each were installed extending from Span 1 to 13. Additionally two 2706 Strand Tendons were installed at Span 5 and 2706 Strands and four 19 Strand Tendons at Span 6. To accomplish the required continuity of the tendons, BBR CONA Coupling 3105 Type K were used.



Couplers at Span 5, showing the eight Main Tendons and the two dditional Tendons of 27 strands each

▲Aerial View of the Bridge from Baguio Side (Abutment B)

▲Approaching the Bridge from the Manila Side (Abutment A)

Region/Location	Baguio City, Benguet Province, Philippines
Purpose/Usage of the structure	Viaduct
Client/Owner	Department of Public Works and Highways (DPWH)
Designer/Supervisor Engineer	Pacific Consultants International (PCI)
Main Contractor	E. Ramos Construction
BBR Subcontractor	BBR Philippines Corporation
Key Data	No. of Spans/Length/Width: 13 spans/519 meters/11.25 m (carriageway = 7.32 m) Type of Construction: Post-Tensioned Box Girders; 31 Anchors and Couplers Construction time: July 2000 to November 2001
BBR Product/Technology/System used	Main quantities in BBR product involvement BBR 3105 Anchors & Couplers: 104 pcs Wedges (0.5"): 2,808 pcs 3105 Round Ducts: 708 pcs (5.80 meter-length) 1905 Round Ducts: 35 pcs (5.80 meter-length)
Contact	Rey C. D. Singh, E-Mail: bbr_phils@pacific.net.ph

MRT C704, Singapore

Upper Serangoon Road Viaduct

Authors: Chan Tuck Meng/Andrew Tan

View of Middle Stretch of the Viaduct

▲ View of Viaduct from Boundary Rd/ Upper Paya Lebar Road

Overview and Location

The viaduct is a 1.5 km long dual four-lane elevated carriageway running in parallel above the existing Upper Serangoon Road and crossing two major road junctions at Braddell Road/Bartley Road and Boundary Road/Upper Paya Lebar Road.

This project was the first of its kind in Singapore where there are four vertical levels of traffic flow in one location: – a viaduct at level 1, – Upper Serangoon Road at level 2; – Braddell Road underpass at level 3; and – NE MRT Line at level 4.

This has maximized the use of land, while expanding road capacity, to accommodate both public and private transportation needs.

The traffic capacity is doubled along the Upper Serangoon Road. This will bring benefits to road users, especially those living in Hougang, Punggol and Sengkang. Motorists from the north-eastern part of Singapore will now be able to make an uninterrupted journey into the city, bypassing several road junctions. This will cut down their traveling time.

◄ Balanced Cantilever Method

Scope

The scope of the works consisted of design and construction of the viaduct beginning from Upper Aljunied Road and ending at Yio Chu Kang Road including piles, pile caps, piers, cross-heads, box girders, abutments, retaining walls, approach structures and slabs, drainage system and temporary shoring and falsework.

Project description

The design concept of the viaduct consists of post-tensioned, cast-in-situ twin-cell box girders supported on a single central pier in the transverse direction. The viaduct comprises 40 spans and is divided into four sections, with each section acting as a continuous frame structure over 8 or 12 spans. The length of a typical span is between 34.2 m and 36.5 m. The depth of the concrete box girder in a typical span is 2.2 m. The spans at the two crossings, Braddell Rd/Bartley Rd and Boundary Rd/Upper Paya Lebar Rd, are 70 m and 50 m respectively where the maximum depth of the concrete box girders is 3.0 m at the pier.

Construction method

The construction method consisted of constructing the typical spans on an Advanced Launching Girder (ALG) with system formwork for span-by-span cast-in-situ construction; and constructing the two crossings using the cast-in-situ segmental balanced cantilever construction method. This was the first time ALG with system formwork was used in Singapore and it has demonstrated the effective use of this construction method in the viaduct construction to achieve quality finishes.

The Advanced Launching Girder was a 850 ton steel structure specially designed and fabricated for the cast-in-situ construction of 33 of the 39 spans of the viaduct. Firstly, the piers and the cross heads were constructed in advance of the ALG. For the construction of every span, four formwork units were adjusted, raised and suspended on the transverse trusses using Maccalloy bars (high tensile bars) in conjunction with the hollow ram jacks. After the formwork units were in place, fixing of reinforcement, placing of ducts and concreting followed. The concreting of the north-bound and south-bound viaducts had to be done simultaneously. When the structure achieved a concrete strength of 30MPa, the stressing of the tendons began. Upon complete transfer of load to the starting elements and piers, the formwork units were dismantled and placed on the working platform. The entire ALG was then jacked to the next span. This cycle was then repeated.

The Segmental Balanced Cantilever Method was used to construct the spans over the Braddell Road/Bartley Road and Boundary Road/Upper Paya Lebar Road underpasses. The spans of the viaduct in these areas are 70 m and 50 m respectively.

The method features segmental construction of 3.4 m long segments. One segment to the left of the pier was first constructed and then stressed against the crosshead, followed by the corresponding unit on the right, which was also to be stressed against the crosshead. The sequence was then repeated. Finally, there was additional prestressing to provide continuity to the overall frame structure.

Advanced Launching Girder method

Construction product, BBR applications

The PT system used consisted of BBR CONA. 1205 was used for the balanced cantilever segments, 1905 for the main superstructure built by ALG and 3105 for the diaphragms. The lengths of the cables vary from approximately 8 m to 42 m. In total, approximately 600 tons of PT strands was used.

Important experience made with system/product application

The in-house design of both the permanent structure as well as the specialist temporary works was the cornerstone of the project. The design and build form of contract provided the flexibility necessary in completing complex projects of this nature. Furthermore, during the design stage, much consideration was given to the safety aspects of the various temporary structures.

Region/Location	Upper Serangoon Road, Singapore
Purpose/Usage of the structure	Vehicular viaduct
Client	Land Transport Authority
Designer/Supervisor Engineer	BBR Systems Ltd/Engineering 2000
Main Contractor	Wayss&Freytag-Econ-Chew Eu Hock J.V.
BBR Scope of work	Design and build of viaduct including pier, crosshead, diaphragm, superstructure, approach structure
Key Data	4-lane carriagewa<, 40 spans, typical span: 34.2 m to 36.5 m, road crossing span: 70 m and 50 m, total length: 1.5 km. type of construction: Advanced Launching Girder; and Segmental Balanced Cantilever methods Construction time: 1997 to 2001
BBR Product/Technology/System used	BBR CONA 1205, 1905 and 3105 PT quantity: 600 tons
Contact	Chan Tuck Meng/Andrew Tan, E-Mail: tanandrew@bbr-singapore.com.sg

PSA Container Terminal, Singapore

Phases 1A and 1B

Authors: Chan Tuck Meng/Andrew Tan

Erection of the beams

Overview and Location

The Port of Singapore Authority developed the container terminal on reclaimed land located at Pasir Panjang in the south-west of Singapore island. The overhead beam structures are used to support cranes operated by fully-automatic computer control.

Scope

The scope of the works consists of the construction of precast beams at ground level and hoisting them up into position on top of the columns. The columns were not constructed by BBR.

Project description

The project was divided into two phases, Phase 1A and 1B, with each phase under a different contractor. BBR was engaged by the contractors of both phases to undertake the construction of the PT precast beams and lifting them to the top of the columns constructed by others. For Phase 1A, there were a total of 220 beams. The dimensions of a typical beam are 30.765 m (length) x 2.5 m (width) and 3.5 m (depth). The average weight of a beam is 560 tons. The beams are supported by columns and the structure height is about 28m. For Phase 1B, there were 102 beams with typical dimensions of 32.565 m (length) x 2.5 m (width) and 4.25 m (depth).

Heavy Lifting set up

Construction method

The lifting equipment consisted of four centre-hole jacks of 260 tons capacity each with a maximum working pressure of 10,000 psi. The stroke of the jacks were initially 250 mm, but later replaced with jacks of longer strokes (480 mm) to reduce the duration of lifting operation of the beams which was critical in terms of production as well as safety.

Initially it took about eight to ten hours to complete a lift of about 24 m. However, with the change to the longer stroke jacks, the lifting operations could be reduced to just four hours. The reduction in the duration of the lifting time was critical because a lifting operation carried out at night was a safety concern. With a duration of eight to ten hours, it meant that lifting operations must start in the morning before 10 am at the latest. All requests to proceed with lifting after that were rejected by the clients.

However with the longer stroke jacks, the operation was cut down to four hours. This meant that lifting operation could commence even after lunch (about 1 pm) and be completed before it gets dark (approx. 7 pm).

Using the Short Stroke (250 mm) Jack, the lifting operation took about eight to ten hours for a height of about 24 m. With the Long Stroke (480 mm) Jack, the lifting operation took about four hours for a height of about 24 m.

Construction product, BBR applications

The PT system used was BBR CONA 1906 and 1206. A total of 1,053 tons were used for Phase 1A and 434 tons for Phase 1B. The lifting equipment consisted of BBR CONA 1206 lifting units.

Important experience made with system/product application

The use of the lifting equipment to hoist PT beams precast on the ground to a height of 24 m represented a considerable savings of time and money as compared to the conventional method of using mobile or crawler cranes for such lifting purposes. The extensive experience of BBR in the field of load handling has well-positioned us to provide the services for the design, supply and operation of such equipment.

Region/Location	**Pasir Panjang, Singapore**
Purpose/Usage of the structure	**Overhead beam crane superstructure at container terminal, PT precast beam and heavy lifting**
Client	**Port of Singapore Authority**
Designer/Supervisor Engineer	**BBR Construction Systems Pte Ltd (for lifting arrangement and execution)**
Main Contractor	**Phase 1A – Hock Lian Seng – Mitsui JV** **Phase 1B – Koh Brothers Building & Civil Engineering Contractor (Pte) Ltd**
BBR Scope of work	**Construction and installation of PT precast beams by heavy lifting**
Key Data	**Phase 1A: 220 beams, length: from 18.0 to 35 m, average beam weight: 560 tons.** **Phase 1B: 102 beams, length: from 14.7 to 35 m, average beam weight: 428 tons, structure height: 28 m** **Construction time: 1996 to 1998**
BBR Product/Technology/System used	**BBR Cona 1906 and 1206** **PT quantity: 1,500 tons** **BBR Heavy Lifting Equipment: 2 No. 1206 lifting units**
Contact	**Chan Tuck Meng/Andrew Tan,** **E-Mail: tanandrew@bbr-singapore.com.sg**

Cantilever segmental bridges built using Formtravellers

Construction of Bridges with Balanced Cantilever Method in Taiwan High Speed Rail Project C291, Tainan, Taiwan

Author: Jeff Liaw

Overview and Location

Taiwan's largest infrastructure project ever, the on-going Taiwan High Speed Rail Project surpasses all Build-Operate-Transfer (BOT) construction projects worldwide in terms of its cost US $15 billion. The north-south THSR line runs approximately 345 km from Taipei to Kaohsiung, passing through 14 major cities and counties as well as 77 townships and regions. The civil works, divided into 12 separate contracts, comprise some 63 km of tunnels, 252 km of viaducts and bridges and 30 km cut and fill. The high-speed train, manufactured by the Japanese Shinkansen System, will travel at a speed of 250–300 km/h in 90 minutes the distance that now takes up to ten hours to drive on the freeway.

Taiwan is a small island with 35'980 km² and a population of more than twenty-three million. In such conditions where space is limited and the terrain is difficult, bridge and viaduct type projects are often the preferred choice by infrastructure planners. During the course of the Second Freeway Program (1990–2002), Taiwan's construction industry has seen a maturing development of many special bridge construction methods – from movable scaffolding systems to precast segmental systems. Special construction methods such as the cast-in-place free cantilever method are now not so «special» in Taiwan.

Scope

Construction works for Section C291 are being executed by a joint venture between Evergreen Construction Corporation and Shimizu Corporation (ESJV) and began in April 2000. This section is 28.5 km long and is located approximately parallel to the existing railway and Freeway No. 1 in Tainan County of southern Taiwan.

Project description and construction method

As C291 consists entirely of viaducts, ESJV selected a mix of movable scaffolding system (MSS), cast-in-place (CIP) and free cantilever method (FCM) for the execution of its superstructures. Since Section C291 is part of the test track, the owner required that it shall be completed well ahead of all other HSR civil contracts. Hence, appropriate planning and accurate execution were critical in meeting C291's extremely tight construction schedule. This is of paramount importance since the free cantilever bridges are usually the critical element in the construction progress.

Construction product, BBR application

A JV between BBR Systems and DSI Taiwan was awarded the subcontract to build the superstructure of all nine cantilever bridges on Contract C291. Seven of them cross existing freeways and highways but two cross over the Er-chia River and Tzeng-wen River, respectively. The scope of the work includes construction of cast-in-place segments by employing nine sets of formtravellers and supplying post-tensioning systems. A total of 1,476 sets of anchorages type MA, 15,400 m³ of concrete and 3,100 t of steel reinforcement has been used for the entire work. The subcontracted works were completed at the beginning of 2004.

Important experience made

One of the best experiences made for this particular contract was the capability to create a successful team between DSI and BBR in a proper JV form in order to manage successfully the various challenges in the planning stage but also during execution, benefiting from all possible synergies.

Region/Location	Tainan, Taiwan
Client	Taiwan High Speed Rail Corporation, Taiwan
Designer/Supervisor Engineer	Moh and Associates, Taiwan
BBR Subcontractor	BBR Systems and DSI Taiwan JV
General Contractor	JV of Shimizu, Japan/Evergreen, Taiwan
Checking Engineer	T.Y. Lin, Taiwan
BBR Product/Technology/System used	Supply of 9 sets of Formtravellers; Supply and installation of 1,476 sets Anchorages type MA 0.6” with accessories; Technical assistance
Contact	Jeff Liaw, E-Mail: jeff.liaw@dywidag-systems.com.tw

Rama VIII Bridge, Bangkok

Cable Stayed Bridge

Author: Peter Ekberg

Overview and Location

Rama VIII Bridge, 475 m long and located in Central Bangkok, is an asymmetrical cable-stayed bridge with a 165 m high single pylon. Construction work started in 1998 and was completed by early 2002 with an overall budget of THB 2.7 billion, including 2 km long approaches on both sides of the Chao Praya River. The bridge was opened to traffic on 7 May 2002.

Scope

BMA awarded the design and build contract to the Thai-Chinese-Swiss construction consortium with PPD Construction Co. Ltd. from Bangkok, China State Construction from Beijing and BBR Systems Ltd. from Switzerland.

BBR fabricated and installed the stay cables, executed all post-tensioning work on the concrete structure (pylon, deck structure and viaducts) and installed all expansion joints. BBR Systems was in charge of the technical and operational preparation and site management with the assistance of local Thai engineers, supervisors and working force.

The objective for the design and construction method was to minimise impact on people and the environment, but to maximise reduction in

Visit of the King during construction

traffic problems. Historic buildings on the Bangkok side also limited design options.

An asymmetrical cable-stayed bridge was the optimal choice. The bridge has no foundation piers itself, reducing construction time and maintaining the ecology with no interruption to river transportation. Finally, the bridge provides spectacular scenic views and a unique driving experience «through» the stay cables.

Installation of BBR CONA STAY Cables

The bridge and its related structure use shapes and colours occurring in traditional Thai art and buildings. Motifs are based on King Rama VIII's Royal Seal. The inverted Y-shaped pylon is fashioned after the Crystal Palace and from Phra Bodhinsattava motifs. The observation deck on the top of the pylon is designed in the shape of an ornamental lotus.

Construction method

The bridge's construction started with the pylon in order to facilitate the later cable installation. In sequence, the back and anchor spans were constructed, which served as areas for cable assembling. Finally, the bridge's 300 m main span was built in only six months with cantilevered erection and simultaneous installation of the total 56 stay cables in the front, balanced with 28 back stay cables.

Construction product, BBR applications

BBR offers four different stay cable systems with individual benefits. For Rama VIII Bridge the BBR CONA STAY was selected for its site assembly capability.
The 56 Main Stay Cables are from 65 m to 325 m long and are arranged in 28 pairs in a half fan shape. Each stay cable is manufactured out of 15 to 29 high tensile 7-wire strands with a diameter of 15 mm each. The high tensile super strands are waxed and PE coated. Each strand is individually secured in the anchor head by means of three part wedges.

Visit of the King

Besides the Grand Opening Ceremony on 20 September 2002, H.M. the King visited the bridge during construction and showed a very detailed interest in construction technology and working methods applied. H.M. the King pressed the power switch to stress one BBR stay cable strand (A-15) on His visit on 20th September 2001.

Bridge at Night

Bridge during construction

Region/Location	Bangkok, Thailand
Purpose/Usage of the structure	Stay Cable Bridge
Client	Bangkok Metropolitan Administration
Consultants	Mott Macdonald; Epilson; Buckland & Taylor Ltd.
Main Contractor	JV China State Construction and Engineering Co. Ltd; PPD Construction Co. Ltd; BBR Systems Ltd
BBR Scope of work	Supply and installation of BBR CONA STAYS and BBR CONA prestressing system
Key Data	Total length 475 m; stay cable main span 300 m from 1 pylon; composite deck 29 m wide 84 BBR CONA STAYS types 1106 to 6506; lengths 69m to 325m, total stay steel 670 tons; BBR CONA types 1205 to 3105, 270 tons of PT strands Construction time: 1998-2002
Contact	Peter Ekberg, E-Mail: pekberg@bbrsystems.ch

West Gate Bridge, Melbourne

Authors: Dr. Pietro Brenni/Marcel Poser

Overview and Location

The use of fibre reinforced polymers (FRP) as reinforcement for civil engineering structures has rapidly gained appeal in recent years. This is due to the many advantages which these types of materials have over conventional steel reinforcement for certain types of application. While no national design codes exist to date, several national guidelines offer the state-of-the-art in the selection of FRP systems and design of civil engineering structures incorporating FRP reinforcement. This paper outlines what, to the authors' knowledge, is the world's largest application of FRP reinforcement in the strength enhancement of a prestressed concrete bridge to date.

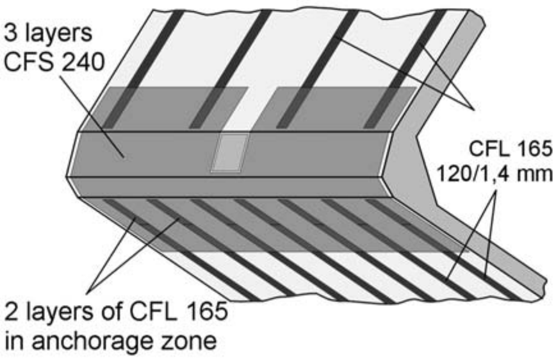
Designed in the 1960's, construction of the West Gate Bridge in Melbourne, Australia, was completed in 1978. Due to a more than seven-fold increase in daily vehicle usage since its opening, the owner, State of Victoria Road Authority VicRoads, decided to increase the number of lanes over a 670 m length of one of the concrete approach viaducts. A Design and Construction approach was chosen and the successful bid team provided a solution which incorporated external post-tensioning located within the box girder cells, together with carbon fibre reinforced polymer sheets and laminates.

Project description

Designed in the 1960s in accordance to the loading requirements in effect at the time, West Gate Bridge was finally opened to traffic in 1978. The bridge plays an important role in linking the industrial and residential areas west of the Yarra River with Melbourne and the port areas. It has been estimated that West Gate Bridge has provided savings of up to AUD 3 million per day in the form of reduced transport costs and travel time.

The bridge consists of continuous curved approach viaducts, constructed from precast concrete segments post-tensioned together, and a steel stay cable bridge with a multi-cell deck cross-section. The curved approach viaducts have lengths of 670 m and 871 m for the west and east viaducts, respectively.The deck is 35.62 m in width with a depth of 3.9 m and spans approximately 67 m between piers. The centre-to-centre distance between consecutive cantilever segments is approximately 3.7 m.

The bridge was originally designed to carry four lanes in either direction in addition to two emergency service lanes. In order to accommodate increased traffic during peak hours, VicRoads decided to increase the number of lanes in one direction of the western approach viaduct by utilizing an existing service lane over the 670 m length. Thus, no superstructure expansion was necessary.



Strengthening Schema

Construction method

The concept developed and offered by the tender team proposed enhancement of the box girder flexural capacity by means of conventional externally post-tensioned tendons. Other areas of concern were addressed by means of externally bonded reinforcement in the form of BBR carbon fibre reinforced polymer BBR (CFRP) using both unidirectional sheets and laminates.

The arrangement of the FRP reinforcement is as follows:

1. Torsional strengthening of the box girder entailed the use of BBR CFRP laminates around the external circumference of the box girder elements near the piers. In the adjacent segments only the soffit was strengthened due to lower torsional demands and adequate internal steel reinforcement in the web and top slab. Continuity of the shear reinforcement was achieved by slotting the laminates into the underside of the box girder top deck slab. At the lower corner of the box girder, the web and soffit slab laminates were spliced by means of BBR CFRP sheets wrapped around the bottom corner of the box girder with the necessary overlap length provided.
2. Flexural capacity enhancement of the precast deck slab elements spanning the cantilever frames was provided by BBR CFRP laminates. In the negative moment regions, i.e. above the piers, the laminates were bonded into slots cut into the deck. Positive moment capacity was enhanced by means of laminates bonded to the soffit of the slabs in the span direction.
3. The flexural capacity of the cantilever frame elements was increased by means of steel plates glued and bolted to the compression strut. In addition, BBR CFRP laminates were bonded to that portion of the deck slab soffit which acts with the frame as a composite element.

Although no design codes dedicated to the use of FRP reinforcement in civil engineering structures existed at the time detailed design was carried out, a number of national guidelines have recently been published summarising the state-of-the-art in the design of structures using FRP reinforcement. Technical Report 55 (TR-55), published by the UK Concrete Society, was selected by URS as the guiding document for the design and detailing of the FRP system. As some design aspects were not adequately covered in TR 55, German guidelines were used in some situations. The assumptions applied in the design of reinforced concrete elements using conventional materials, i.e. plane sections remain plane, strain compatibility, equilibrium of forces acting at a cross section, constitutive (stress/strain) behaviour, are also applicable when strengthening with FRP reinforcement. The potential for sudden brittle failure is reduced by relying on safety factors which take the linear stress/strain behaviour of the FRP reinforcement into consideration.

Construction product, BBR applications

Mass production has led to the affordability of FRP materials and the extension of their application from such industries as aviation, electronics and the automobile industry to the construction industry. Several factors make the use of FRP reinforcement more appealing than conventional solutions, such as externally bonded steel plates. Some of these factors may be enumerated as follows:

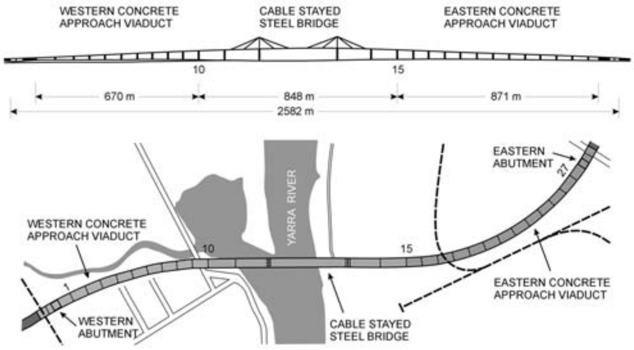
1. The light weight of FRP composites lends itself to ease of handling and installation resulting in lower costs in labour, equipment and transportation. As previously indicated, there is no need for heavy lifting, drilling, cutting and welding equipment as would be required for steel plates.
2. Installation of FRP reinforcement can usually be executed without disruption to normal operation of the structure.
3. Exceptional mechanical properties as exemplified by high tensile strength and high E-modulus. The stress-strain behaviour of FRP composite reinforcement is linear up to failure and is an important consideration for design.
4. The alleviation of durability problems normally associated with structural steel.
5. Low profile thickness.
6. Resistance against tension fatigue, corrosion and chemical attack.

Fibre reinforced polymer reinforcement used in civil engineering applications typically comprises sheets of continuous carbon, aramid or glass fibres embedded in a thermoset resin. The resin can be factory-applied and cured (prepeg), in which case the FRP reinforcement is delivered as strips (laminates) and installed on the structural element with an adhesive. Alternatively, the sheets (in fabric form) are delivered to the site in rolls where the saturant is applied on-site either before (wet lay-up) or after (dry lay-up) installing the sheets on the structural element. Choice of method is usually dependent on the weight of the FRP sheet. The saturant functions both as a matrix in which the fibres are embedded and as an adhesive. The choice of sheets or laminates is dictated by the intended use of the FRP reinforcement; laminates are preferred for flexural enhancement while sheets are wrapped around structural elements in order to increase their shear strength, confinement and/or compressive strength. Sheets can also be used to increase ductility through increasing the axial load carrying capacity of structural elements. The mechanical properties of the FRP reinforcement are determined not only by the type of fibres but also by the fibre volume fraction and orientation of the fibres.

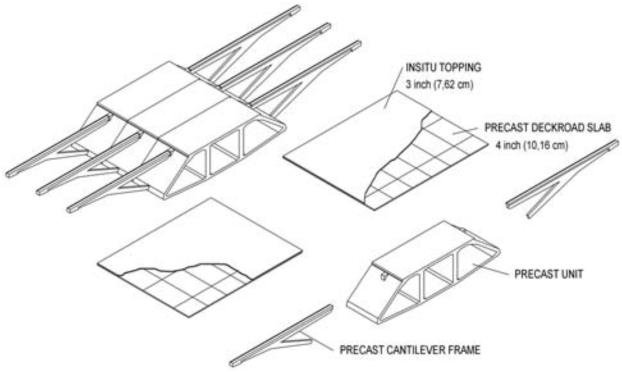
Installation of the FRP reinforcement was carried out in accordance with the detailing prescribed by URS/bow engineer. In order to guarantee optimal utilization of the unique strength characteristics of FRP reinforcement, proper application procedures must be outlined and followed. To this end, a detailed quality assurance document was drafted by Abigroup with the assistance of BBR Systems, outlining not only the proper installation procedure but also a quality control programme that guaranteed the designated performance levels. It is to be noted that traffic flow was not disrupted during the FRP installation and the bridge was operational to its full capacity.

Important experience made with system/product application

Durability, corrosion resistance, low weight, high strength and ease of installation are some of the factors which favour the use of FRP reinforcement over bonded steel plates in rehabilitation, retrofit and/or strengthening of structures. What can be considered to be the world's largest application of FRP reinforcement in the strengthening of a reinforced concrete bridge was executed in Melbourne, Australia. Approximately 40 km of BBR CFRP sheets and laminates have been used to upgrade the strength capacity of this economically important bridge. The advanced composite material was used in flexure, shear and torsion applications in combination with conventional steel prestressing tendons as external post-tensioning.



Situation



Structural Elements

Region/Location	**Melbourne, Australia**
Client	**VicRoads**
Consultants	**URS Pty Ltd (Melbourne)**
Main Contractor	**Abigroup Pty Ltd (Melbourne)**
BBR Scope of work	**Supply of BBR FRP products, testing and technical support. 40 km of BBR CFRP sheets and laminates installed.**
Key Data	**Total length of strengthened viaduct = 670 m; span = 67 m; deck width = 35.6 m Years of Execution: 2001 to 2002**
Contact	**Dr. Pietro Brenni, E-Mail: pbrenni@bbrsystems.ch**

Narrows Bridge Duplication, Perth

Author: Hudson Lun

Overview and Location

The incremental launching system was adopted to reduce disruption to both road and river traffic in the area. The location is in Perth, Western Australia.

Scope

Construction of a duplicate bridge alongside the existing Narrows Bridge required to match the profile of the existing structure. The section depth varies from 1.6 m at the abutments to 2.3 m mid-span to 4.2 m over the piers.

Stressing Jack in operation

Project description

The structure is comprised of four «I» beams wide and was constructed in two halves (i.e. two «I» beams per half). Both halves were concurrently incrementally launched from the south abutment and then an in-fill strip was poured between the two halves to form one bridge.

Construction method

The incremental launching system was adopted to reduce disruption to both road and river traffic in the area. The varying cross-section resulted in a very complex launching system, which supports the bridge on corbels cast onto the inside face of the webs. The structure was supported by a series of trolleys in the casting area, which were set at various heights to coincide with the profile of the bridge. The structure was launched across twelve temporary piers and then lowered onto four permanent piers following completion of the launching process. The launching equipment was designed to allow for lifting and pushing the bridge, then raising hydraulic rams to serve as a braking system to prevent the bridge from sliding backwards between launching cycles.

Construction product, BBR applications

The concentric post-tensioning system comprised 14 BBRV tendons ranging from 19ϕ7 mm wires to 42ϕ7 mm wires per segment. The continuity post-tensioning system comprised 64

View of the bridge over the temporary piers

Launching truss

Bridge after
finishing works

BBR Cona 1905 mm strand tendons, 80 BBR Cona 1906 strand tendons, 48 BBR Cona 2206 strand tendons and 56 BBR Cona 2706 strand tendons.

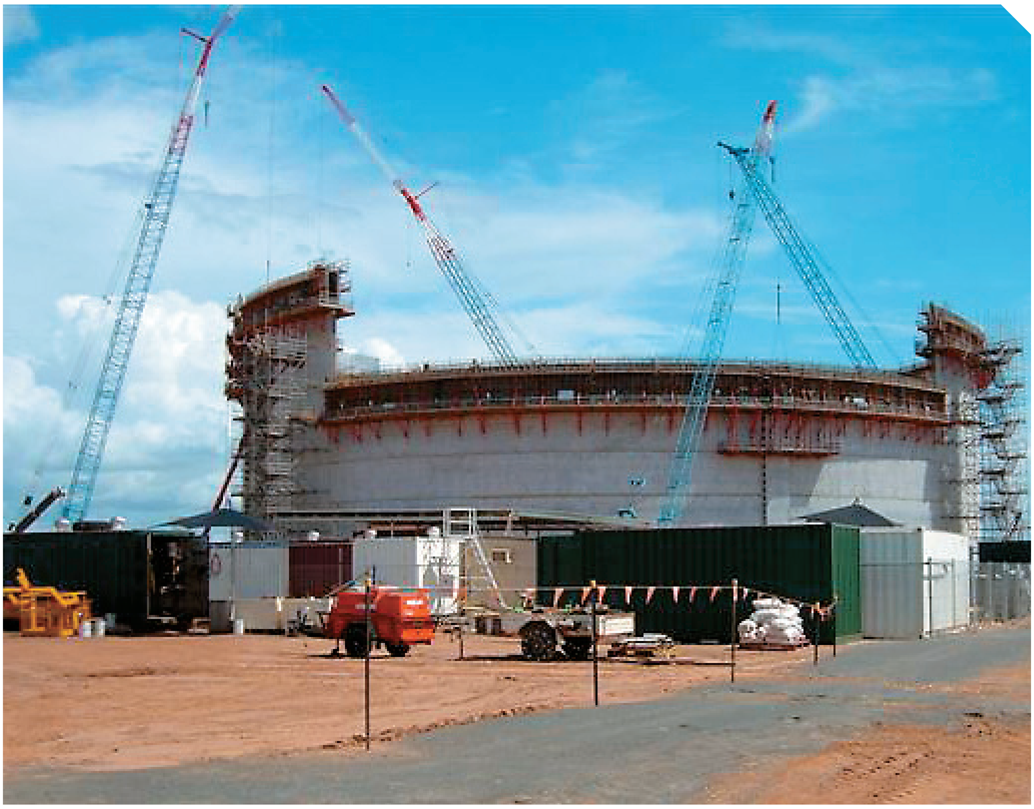
Important experience made with system/product application

The continuity cables were terminated by casting anchorages into ‘blisters’ cast onto the top and bottom flanges at various locations along the structure. Access for stressing the continuity cables was very restrictive and made it difficult to use multi-strand stressing jacks. Hence, many of the cables were successfully tensioned using mono-strand jacks.

Region/Location	Perth, Western Australia, Australia
Purpose/Usage of the structure	Narrows Bridge Duplication
Client	Main Roads Western Australia
Designer/Supervisor Engineer	Structural Systems Western Ltd
Main Contractor	Leighton Contractors
BBR Scope of work	Design, Incremental launching, Installation BBR PT
Key Data	Type of construction: Construction time: October 1999 – January 2001
BBR Product/Technology/System used	BBRV 19φ7 and 42φ7, BBR Cona 1905, 1906, 2206 and 2706
Contact	Hudson Lun, E-Mail: hlun@wa.structural.com.au

LNG Tank, Darwin

Author: Hudson Lun



Tank under construction

Overview and Location

Northern Territory, City of Darwin, Australia.
The 188,000m³ LNG Tank, located near the City of Darwin in the northern most part of Australia, is part of a major infrastructure project linking the far north with the southern cities of the continent.

Project description

The tank was designed by Breuchle Gilchrist and Evans and the main contractor awarded the contract to build the LNG Tank was Thiess Contractors. Thiess subsequently sub-contracted the post-tensioning work to Structural Systems (Western) Ltd based out of Perth, Western Australia more than 3000km from the project site.

The basis of the award of this work was the superior bid, experience and expertise that Structural Systems brought to the project.

Work commenced on the construction of the tank in August 2003 and is scheduled to be completed August 2005. The post-tensioning works commenced in June 2004 and will largely be complete by November 2004.

Structural Systems based a full-time project team at the site to meet the demanding construction schedule and rigorous safety regime. Project Manager, Tony Cotham with over ten years of post-tensioning experience heads the team with supervisors Bryce Gooding and Glenn Adams leading the way.

Construction method

A special access system to climb all four of the buttresses of the tank needed to be installed, including a special access for the tip ring beam to allow movement of the multistrand jack from vertical anchorage to vertical anchorage. Special access holes were constructed at the base of the tank to allow the installation of the bottom anchorages.

Special Construction holes (3 m x 3 m) are being left open for construction access to the interior of the tank and be filled and post-tensioned on the completion of the works.

Construction product, BBR applications

The project includes the installation of over 22,600 m of ducting for the 286 No Tendons BBR CONA 1906 to be installed. All of the tendons are 19/15.2 mm strand tendons either 36 m long for the vertical tendons or 148m for the «half hoop» horizontal tendons.

Detailed view of the bottom slab with the special accesses for BBR anchors

Strand lifting operation

Region/Location	Northern Territory, City of Darwin, Australia
Purpose/Usage of the structure	LNG Storage Tank
Client	Bechtel
Designer/Supervisor Engineer	Bruechle Gilchrist & Evans
Main Contractor	Thiess Contractors
BBR Subcontractor	Structural Systems Ltd (Western)
Key Data	No. of spans: 1 No. Concrete Tank Volume: Internal volume capacity of 188,000 m^3, span height: 35.2 m Diameter: 92 m, wall thickness: 550 mm Type of construction: Concrete construction with horizontal and vertical post-tensioned reinforcement
BBR Product/Technology/System used	Main Quantities in BBR product involvement: 114 No. 148 m long BBR Cona 1906 Tendons horizontally, 172 No. 36 m long BBR Cona 1906 Tendons vertically. Total of 550 tonnes of 15.2 mm strand.
Contact	Hudson Lun, E-Mail: hlun@wa.structural.com.au

Canning Dam, Perth

Strengthening of Concrete Dam Wall

Author: Hudson Lun

Overview and Location

Western Australia, City of Perth
Canning Dam is one of the key water sources for Perth. The dam is 467 m long and approximately 70 m high.

Scope

Canning Dam is one of the key water sources for Perth. The dam is 467 m long and approximately 70 m high. Upon checking the safety of the dam, problems identified included:

- Inadequate earthquake resistance.
- Insufficient spillway capacity to cater for the current design maximum rainfall data, which would cause crest overtopping and subsequent loss of the dam.
- Structurally significant cracking existed throughout the dam, especially at the lift joints and at the level of the upper gallery.
- The buoyancy effect from uplift pore pressures under the dam also reduced the current structure's safety, although these had been greatly decreased by earlier works.

Stressing Jack under operation

The dam was originally built during the 1930's and was the most important project in Western Australia at that time. As such, the structure has heritage significance. Other options of repairing or replacing the dam required that the dam be taken out of service, which made such choices unacceptable. All of these criteria were considered in determining the final solution.

When all the calculations were completed the level of force required to stabilize the dam was enormous. The bedrock below the dam is very hard granite, which lead to the possibility of using anchors larger than those previously used anywhere in the world. Burrinjuck Dam in NSW was the world's first dam to use permanent anchors of 65 strands x 250 kN. There had been interest after the success of that project in looking at larger anchors if the geotechnical conditions suited and that the force required may justify such consideration. If larger anchors were feasible, there may be savings in several areas, such as reduced stressing pits and increased anchor spacing. Less anchors to drill, install and stress may provide some time saving to the project duration.

Project description

During the early design development phase of Canning's Remedial Works, serious interest existed in investigating the possibility of 91 strand x 261 kN anchors. This would deliver a 47 % increase in capacity over the 65 strand anchors. As this has never been undertaken in the world, a full scale test would be required to provide any confidence of success.
AUD $28 million contract for upgrading the safety of Canning Dam was awarded by Water Corporation to Walter Construction Group, to remove and replace the top 3.5 m of the crest and then install 166 No. Permanent Rock Anchors to tie the dam down to its foundation. The post-tensioning would increase the structure's ability to withstand earthquake and increased flood flows. Prior to upgrading, the dam was well below accepted safety standards. Design of the works was by Geo-Eng, and the project managed by Brown and Root.

The AUD $12 million anchoring component of the project was subcontracted to Structural Systems Limited. Although permanent anchors have been widely used, the anchors required to stabilise Canning Dam are 48 % larger in capacity and 11 m longer than those used only once before anywhere in the world. The largest 91 strand anchors have a breaking load of over 23,750 kN (2,400 t) and lengths of up to 142 m, setting two world records. These were generally installed in pairs, as close as 1.9 m apart. Overall, some 210,000 tonnes of force was applied to the dam crest. All of the detailed anchor and, equipment design and site works was completed by Structural Systems Limited. Considerable specialist infrastructure was developed from scratch to undertake the works. The worlds largest stressing jack was manufactured (2,000 t capacity) specifically for this project. Approximately 13 km of anchors were fabricated, installed and stressed to complete the anchoring works. The application of anchors on a scale once only dreamed of has been successfully undertaken by Structural Systems Limited.

The anchoring works at Canning Dam are significant for numerous reasons, and confirm the excellence of Australian engineering, being not just to borrow from overseas accomplishments, but to understand and further develop technologies to a level of leading such achievements.

Canning Dam suffered from low factors of safety and Alkali Aggregate Reaction (AAR), which will require monitoring as the age of the dam increases. After realizing the significant problems in regard to the dam's overall safety and the serious risk of the loss of water supply from dam failure and subsequent potential loss of life (up to 100,000 people), Water Corporation of WA engaged Brown & Root (previously Kinhill) to manage the upgrading works, who contracted Geo-Eng to undertake the detailed design. Numerous possible solutions to upgrade the dam were considered, including adding mass, but the chosen solution involved the removal of the heavily cracked upper 3.5 m and replacement with a new reinforced

BBR Cona Sol preparation

Canning Dam

concrete «capping» beam to distribute the anchoring point loads into the existing structure.

Canning Dam was originally built during the 1930's, and has significant heritage value to Western Australia. The anchored option was favored not only from a cost effectiveness and timing point of view, but also that the visual appearance of the dam would remain as originally constructed.

During the design period, Geo-Eng determined the required forces to stabilize the dam and bring the dam to accepted standards. These forces were such that the existing anchoring technology, that had only just completed the world's first 65 strand anchors, Minimum Breaking Load (M.B.L.) of 16,250 kN, was underdone and difficult to accommodate from a spacing point of view due to the magnitude of total load required.

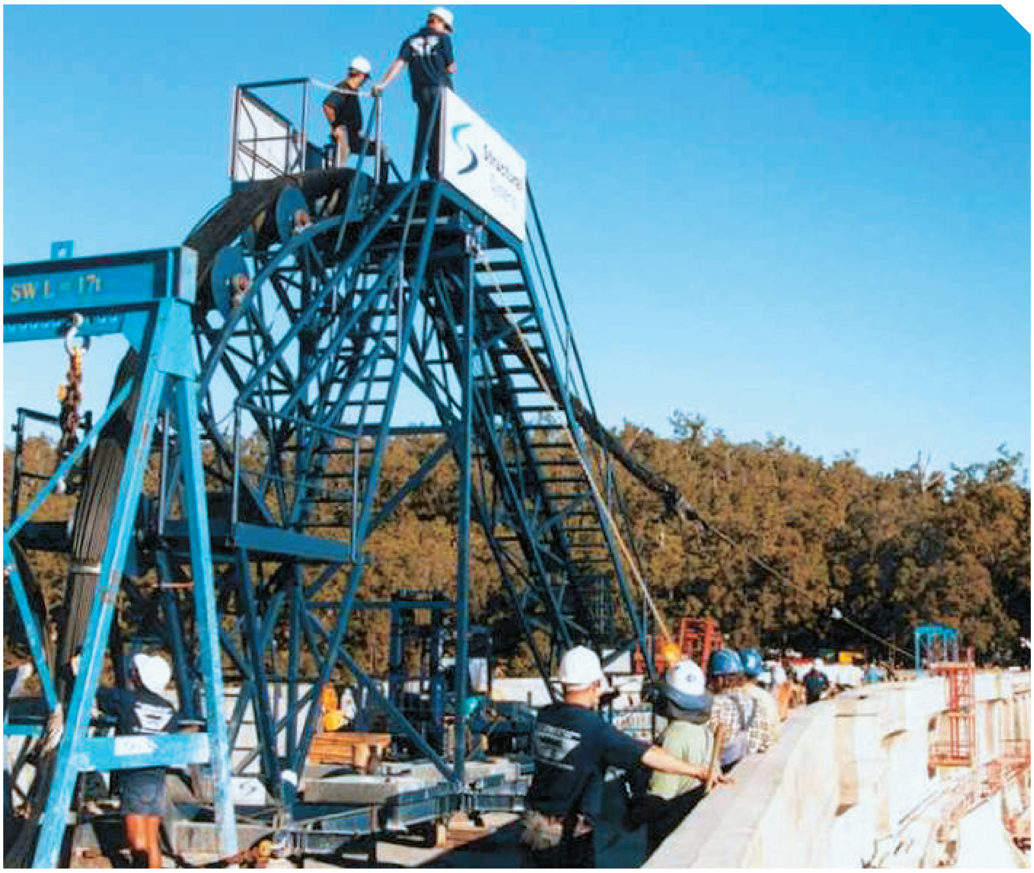
Initial enquiries from Geo-Eng asked if the size of anchor could be increased. This is easily suggested, but the reality of achieving this is complicated and would not only require larger equipment, but the development of new materials and components. The greatest concern is the bond zone region of the anchor where the force from the steel tendon is transferred through the grout, corrugated sheath, and grout then finally into the rock. To allow a 91 strand anchor (M.B.L.= 23,751 kN) to work several favorable conditions are necessary. These are that the rock has to be able to sustain the shear force applied and the corrugated sheath does not rupture or become damaged during loading. The foundation granite at the site yielded UCS of over 200MPa, making this amongst the hardest ever found.

View of the installation setup

Construction product, BBR applications

The bond length corrugated sheath had been tested in the early 1980's, but it was only subjected to a load of around 1,000 kN over a short length, yielding a failure at just over 5MPa. As an averaged working load (theoretical and a false assumption that load transfer is linear or steady) the shear on the corrugated sheath would be 3.2 MPa, and in localized areas this load may reach 10 MPa. As the early data had been extrapolated many times, it was clear that to proceed with confidence, a full size test would be required. A full scale test was commissioned and completed including strain gauging during 1998. This confirmed that the sheath could perform satisfactorily with working shear loads averaging in sections up to 7.3 MPa. Structural Systems developed and detailed the permanent anchors to enable each tendon to be monitored and adjusted at any stage over the minimum design life of 100 years. Careful choice of components was to maximize corrosion protection, as

Region/Location	**Western Australia, City of Perth, Australia**
Purpose/Usage of the structure	**Major Water Supply Dam for City of Perth**
Client	**Water Corporation**
Designer/Supervisor Engineer	**Geo-Eng/Brown and Root**
Main Contractor	**Walter Construction Group Ltd**
BBR Subcontractor	**Structural Systems Ltd (Western)**
Key Data	**Strengthening of Concrete Dam Wall 466 m long across the crest by installation of 166 permanent Ground Anchors Construction time: 12 months**
BBR Product/Technology/System used	**Main Quantities in BBR product involvement: 15.2 mm Strand Ground Anchors as follows: BBR Cona Sol 1906, BBR Cona Sol 2706, BBR Cona 5506. Total 1115 tonnes of 15.2 mm strand.**
Contact	**Hudson Lun, E-Mail: hlun@wa.structural.com.au**



BBR Cona Sol installation

poor component specification may lead to premature corrosion and / or loss of load capacity. All of the materials were developed in conjunction with and sourced from Australian manufacturers. All of the equipment was locally designed and sourced from Perth based fabricators.

Quality was paramount during Structural Systems works and each anchor required up to 26 record sheets to adequately document and control the procedures from manufacture through to final capping. The site activities were monitored and reviewed to confirm that the design intent was accurately carried out. Internal and external quality audits were undertaken to ensure that quality was maintained.

The BBR Cona Sol anchored solution enabled the public supply to be maintained and strict environmental management procedures were enforced to ensure zero water supply contamination.

BBR Cona Sol anchor manufacture involved site preparation and part greasing of nearly 1,200 t (1,025 km) of 15.2 mm strand. Each anchor consists of two main regions, the free length and bond length of up to 12 m. The tendon is gradually assembled from individual completed strands. The free length is prepared by introducing a fully greased strand into a polyethylene sleeve, which will allow for the strand to slide during stressing. Bare strand forms the bond length and is fully cleaned to allow for the maximum adhesion for load transfer. Tendon manufacturing required two fabrication beds one of 143 m and the other 100 m. Two crews fabricated the 13 km of completed tendons over 14 months. Prior to installation proper commencing in June 2000, some 450 t of completed anchors were held in storage. Before homing the tendon into the hole, a HDPE sheath was installed into the drill hole as the primary corrosion protection.

Installation and grouting was completed in under 7 months and involved mixing and pumping nearly 51,000 bags (over 1,200 tonnes) of cement. Individual anchors consumed up to 15t of Class «G» oilwell, and GP cement. Over 130t of galvanized steel bearing plates, up to 900 x 900 x 200 mm, and were loaded to 18,526 kN during stressing of the 91 strand anchors. Five different stressing jacks were used ranging from 300 t to 2,000 t in capacity. Structural Systems anchoring works were completed February 2001.

The permanent anchoring works at Canning Dam is an extension of concrete technology, and is an example of how anchoring can assist the performance or extend the life of existing structures and can be used to benefit the performance and economy of new structures.

World largest stressing jack 2000 t!

Olympic Stadium, Sydney

Heavy Lifting/Sliding

Author: Hudson Lun

BBR fully automated control panel

Detail of rail and bogies system for sliding operation

Overview and Location

After the completion of the Sydney 2000 Olympic Games, reconfiguring commenced on the Olympic Stadium, renamed Stadium Australia, to suit the future uses of the Stadium. The original stadium seated 110,000 but was reconfigured after the Games to seat 80,000.

Scope

Structural Systems were awarded a second major contract to project manage, procure and install the necessary systems to allow the 100 m * 30 m east and west lower tiers to move 15.575 m forward to suit national rugby league and soccer match games. Each tier seats 7,500 patrons and can be transferred from the rear Australian Rules Football mode to the forward rugby/soccer mode in less than eight hours. The 15.575 m travel time takes less than 20 minutes.

Construction method

Sliding of the North and South stands, seven pieces 700t to 2000t each piece, completed June 2001, one month ahead of schedule. Based on the success of this project we were well positioned for the subsequent works, due to Multiplex's trust and confidence in us.

The placement of rails & bogies for the east & west stands, to enable each 100 m wide x 30 m deep 3,000t section to move in and out 16 m depending upon which code of football is played.

Finally project management and procurement of the bogies/electrics and conversion to a movable system was executed under the highest quality and safety conditions.

Construction product, BBR applications

Besides being the first time a post-tensioned structure has been set up for regular moving, the works from detailed design to operation were completed in around four months. The system uses bogies similar to those found in wharf cranes, but is controlled by state of the art electronic systems to maintain a +/– 0.1mm tolerance across all 14 driven bogies. Each stand is set up with 14 identical raking concrete beams, each with three bogies, two on the lower level and one above to allow for moving. Surprisingly to move this mammoth structure, it uses only 14 No. 1.1 kW motors, through a reducing gearbox. Due to the very stringent safety requirements, the system has been set up with 14 times redundancy and interlocks to preclude incorrect operation.

Important experience made with system/product application

Structural Systems worked closely with Multiplex, Sinclair Knight Mertz and key suppliers to deliver the project on time and under budget. The close relationships formed were based on cooperation and trust, essential to the enable the success of the project given the world first nature of the task.

Region/Location	City of Sydney site of 2000 Olympics
Purpose/Usage of the structure	Sports Stadium
Client	Government of New South Wales
Designer/Supervisor Engineer	Structural Systems/Sinclair Knight Mertz
Main Contractor	Multiplex
BBR Subcontractor	Structural Systems Ltd
Key Data	Heavy Lifting/Sliding of 7 pieces from 700 to 2000 t/piece Construction time: 6 months
BBR Product/Technology/System used	BBR Heavy Lifting Equipment BBR CONA Stay 706 – 1206
Contact	Hudson Lun, E-Mail: hlun@wa.structural.com.au

Railway Station Refurbishment, Wellington

Design and Installation of Ground Anchors

Author: Paul Wymer

Wellington Railway Station

Overview and Location

The Wellington Railway Station is located in New Zealand's capital city and was built in 1937. It is located on an active earthquake fault line and was the first major New Zealand structure to incorporate a significant measure of earthquake resistance. When built, it was the largest building in New Zealand.

Although the railway station continued to be a fully operational transport hub, the large administration facility was no longer required and much of the building was converted into a central city university campus. This change of use required an extensive building upgrade coupled with a building-wide earthquake strengthening to modern seismic standards. Structural modifications included the construction of new shear walls and installation of uplift anchors. During the conceptual stages of the project, the anchors were recognized as being an important part of the seismic upgrade and BBR Contech was consulted at an early stage to provide specialist services to contribute to the design and installation of a suitable uplift anchor mechanism.

The railway station was built on reclaimed land and was designed in accordance with studies of seismic effects on contemporary buildings in Japan. The steel frame is encased in reinforced concrete and supported on groups of reinforced concrete piles. The solidly built structure was a bonus for the seismic-strengthening design team. However, the challenge lay in having to deal with the reclaimed earth and underlying marine sediments.

Scope

The scope of the ground anchoring subcontract included the drilling, supply, installation and testing of 11 bar anchors and 13 BBR strand anchors with capacities ranging from 1780 kN to 2232 kN. The anchors were installed in groups into newly constructed foundations located at the base of each shear wall.

Full scale proving trials were carried out under a separate contract to determine the likely capacity of an anchor in this type of ground. Two trial anchors were fabricated from 45mm diameter high grade stress bar with UTS 1780 kN. The anchors were installed in 125 mm diameter holes and included a series of bells or underreams in the bond length as the anchorage mechanism.

Construction product, BBR applications

Following an evaluation the results of the proving trials, the production anchors were designed using a mixture of under-reaming and post-grouting. A combination of bar and BBR strand anchor types was selected to provide the range of uplift forces finally required.

The bar anchors comprised a 45 mm diameter tendon (UTS 1780kN) located in a 125mm diameter drill hole with six 200mm diameter under-reams evenly spaced in the 6m bond length.

The strand anchors were BBR CONA SOL with tendons comprising 12 No. 0.5" strands (UTS 2232kN) located in a 200 m diameter drill hole and post-grouted. No under-reams were required over the 6m bond length and the anchorage mechanism relies on enhancement of the installation grout using the technique of post-grouting which relies on the enlargement of the bond zone of the anchor by hydro-fracturing the ground mass to provide a bulging effect beyond the core diameter of the drill hole.

All anchors were permanent and constructed in accordance with FIP 1996 and comprise double corrosion protection in accordance with BS8081:1989.

The stressing operations included proof testing and subsequent locking off to the specified working load. Stressing was carried out against the newly constructed anchor foundation beams using a 200 tonne centre hole jack and trestle. The strand anchors were proof tested to 1700 kN and the bar anchors were proof tested to 1379 kN in a single load cycle in increments of 20 % UTS.

Important experience made with system / product application

The underlying marine sediments were variable in nature and as a result, several of the anchors did not achieve the specified proof load during testing. This could not have been foreseen by the designer or contractor and remedial options were openly discussed to determine how the required uplift loads could be provided. In most cases, this could be achieved by a combination of down-rating the load factors of the anchor in conjunction with additional post-grouting operations using the spare post-grout tube installed with the anchor. When further enhancement was required, BBR Contech proposed a remedial option that involved the concept of enhancing the ground in the vicinity of the bond zone of the anchor to improve its performance. This was achieved by installing a pair of steel tube-a-manchettes approximately 500 mm from the centre of the underperforming anchor complete with a series of valves adjacent to the bond length.

After 24-hours, the initial cement grout used to seal the tube-a-manchettes in place was broken using a high-pressure pump and cement grout was introduced to each of the valves using an inflatable straddle packer. After the final post-grout cement had been allowed to cure, the anchor was re-tested with favorable results.

Stressing Jack

The reclaimed land and underlying marine sediments that formed the foundation block for the Wellington Railway Station when originally constructed presented a real engineering challenge to both the designer and contractor. However, a proactive approach by all parties involved at both the design, and, during the construction phase ensured that the best possible solutions were provided.

The combination of BBR ground anchoring techniques including under-reaming, post-grouting and ground enhancement is quite unique and enabled the seismic upgrade to proceed relatively unhindered. The railway station remained operational throughout the upgrade and isolated work areas were progressively handed over to the main contractor to enable the conversion work to proceed with as little disruption as possible.

Region/Location	**Wellington, New Zealand**
Purpose/Usage of the structure	**Combined Use – Railway Station and University facility**
Client	**Tranzrail (NZ Government) and Victoria University**
Designer/Supervisor Engineer	**Holmes Consulting Group (structural), Connell Wagner (geotechnical)**
Main Contractor	**Fletcher Construction**
BBR Scope of work	**Design and installation of ground anchors**
Key Data	**11 bar anchors with 45 mm diameter and UTS 1730 kN and 13 BBR CONA Sol strand anchors with UTS 2232 kN (CC1205 configuration)**
BBR Product/Technology/System used	**Ground Anchors**
Contact	**Paul Wymer, E-Mail: pwymer@akl.contech.co.nz**

Retaining Wall Strengthening, Cannes

The «BBR Auto-Tensioning» Solution

Author: Dr Pietro Brenni

Overview and Location

Villa Gadina is a private residence in Cannes in southern France. The villa is located on the top of a hill with a beautiful view of the sea. The private property of the villa is delimited by a wall, in south, west and east directions with a circular form. These walls separate the garden from the main street.

The wall was overloaded in the southern direction, probably from heavy rainfalls during the last two years. Due to an increase of active pressure of the ground behind the wall, a rotation about the wall base with a corresponding displacement of 10 cm at the top of the wall was measured. The movement of the wall – due to saturated soil – caused some damage, cracks and displacements of elements in the walls and tiles.

As no technical drawings of the wall were available, before commencement of works, BBR first had to survey the effective dimensions of the wall. In addition, BBR proposed to drill through the wall to decrease the active water pressure behind the wall and to install drainage pipes.

Scope

The preliminary idea to fix the wall was to install a group of ground anchors in the longitudinal direction, orthogonal to the wall. The idea had to be abandoned because of the particular geometrical disposition. In fact with such a geometry there was a serious risk of concentration of anchorage zones in the theoretical centre of this «circular» wall.

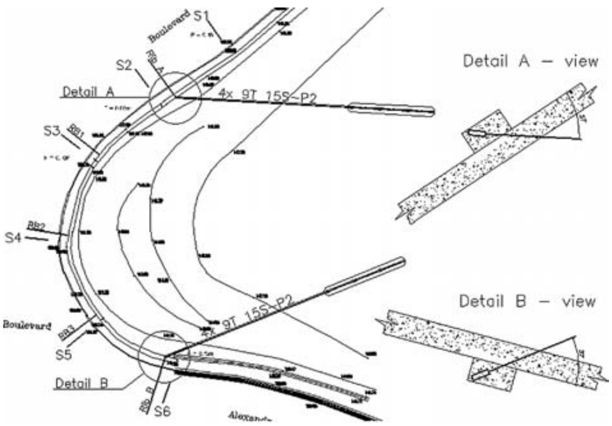
As a result, BBR chose an alternative solution; namely, «BBR auto-tensioning system» to retain the slope at the two ends of the wall using ground anchors while the wall was longitudinally strengthened with external tendons.

View along the wall

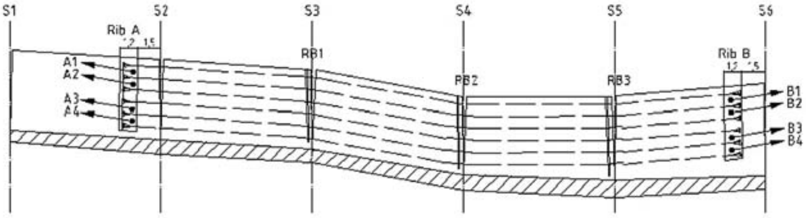
Future controlled wall displacements were considered to activate the tendon mechanical properties in addition to the the effective initial tensile force. This proposal had the advantage in relation to the initial solution of reducing the impact on the outside of the wall.

Construction method

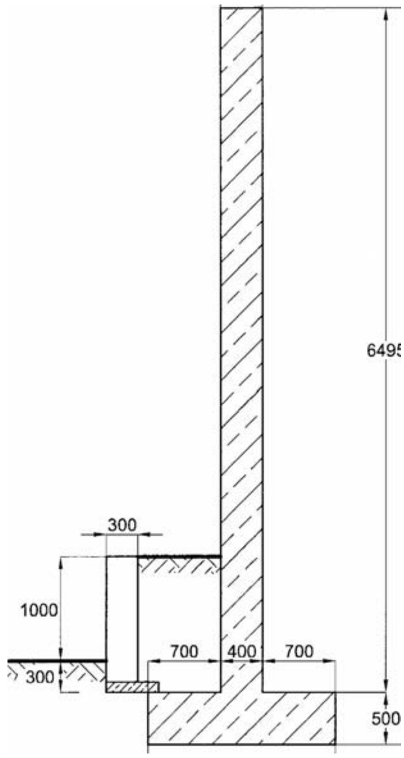
BBR analysed the effective loads on the wall numerically. This analysis was necessary to determine the forces to interact with the increasing active pressure of the soil and to determine the anchor locations. BBR's aim was to maintain a low value of Fe/Fu, in other words – increasing the factor of safety with the capability to increase the forces of a low relaxation PT strand by controlled deformation.



Layout of the auto-tensioning solution, plan view



Layout of the auto-tensioning solution, elevation view



Typical retaining wall section

In order to connect the anchorages to the wall, two vertical ribs with recesses were designed with 12 anchors BBR CONA 206 and four anchors BBR CONA SOL 906 in each rib. Ground anchor tendons were placed with an angle to the wall in order to divide the force in two directions: perpendicular and parallel to the wall.

BBR Cona 206 external tendons

The reinforcement of the ribs contains vertical bars and stirrups to resist the anchorage forces and to connect the rib to the existing wall. The «auto-tensioning» effect was provided by six pairs of BBR CONA 206 external tendons.

BBR CONA SOL ground anchors and the BBR CONA external tendons were stressed in an appropriate studied stressing sequence in order to avoid local stress concentrations and failure near the stressing zone during the operations. All tension elements were approximately stressed finally to 30% of the working load. During the procedure deformations were continuously measured and we could observe that the gaps from to the wall deformations could partially be reduced.

Construction product, BBR applications

Eight Ground Anchor BBR CONA SOL 906 with capacity of = 1'215 kN per anchorage.
Twenty-four BBR CONA 206 with PE coated and greased strands, with a capacity of 318 kN per anchorage.

Important experience made with system/product application

The quite original «BBR auto-tensioning» solution was characterized by the following aspects:

- Reduction of the impact on the wall, which was already in a critical state of equilibrium
- Reduction of the impact on the wall for aesthetical considerations
- Reduction of the impact on the soil, which could lead to unforeseen consequences for the structures in the property, e.g. additional decompression of the soil
- Optimization of the material usage for the solution
- Important reduction of the execution time
- Flexibility to apply in a controlled manner the forces to the wall in relation to the observed behaviour.

BBR with its designer team was able to meet the expectation of the owner with a clever solution based on a quick assessment evaluation, submitting a global solution with design, supply of qualitative BBR products and the coordination of a proper and safe execution.

Rib for force introduction into the retaining wall

Region/Location	**Cannes, France**
Purpose/Usage of the structure	**Boundary retaining wall supporting building and swimming-pool.**
Designer/Supervisor Engineer	**BBR Systems, Simecsol**
Main Contractor	**ETIC, Heaven Climber**
BBR Scope of work	**Design, supply and execution of PT material and reinforcement**
Key Data	**Circular retaining wall with a total length of 50 m, height of retaining wall 6 – 10 m. Construction time: 1 month, August 2003**
BBR Product/Technology/System used	**8 Ground Anchors BBR Cona Sol 906, 24 BBR CONA 206; total PT steel: 4 tons**
Contact	**Dr. Pietro Brenni, E-Mail: pbrenni@bbrsystems.ch**

Monaco Dock, Monte Carlo

Author: J. M. Illescas

Overview and Location

The project of enlargement of the Condamine Port in Monaco was carried out using the semi-floating caisson technique. The lot # 2 of the project consisted of the construction in a dry shipyard of the floating dock in Algeciras (Spain) and its sea transportation to the final emplacement in Monaco.

Project Description

The floating dock is a prestressed concrete structure 352 m long, 44 m wide at its base, 28 m at the main body and 19 m high, 25 m including the superstructure. The thicknesses of the walls are 52 cm for the bottom slab, 55 cm for the sides and 50 cm for the deck.The following quantities have been used for the construction of this floating dock:

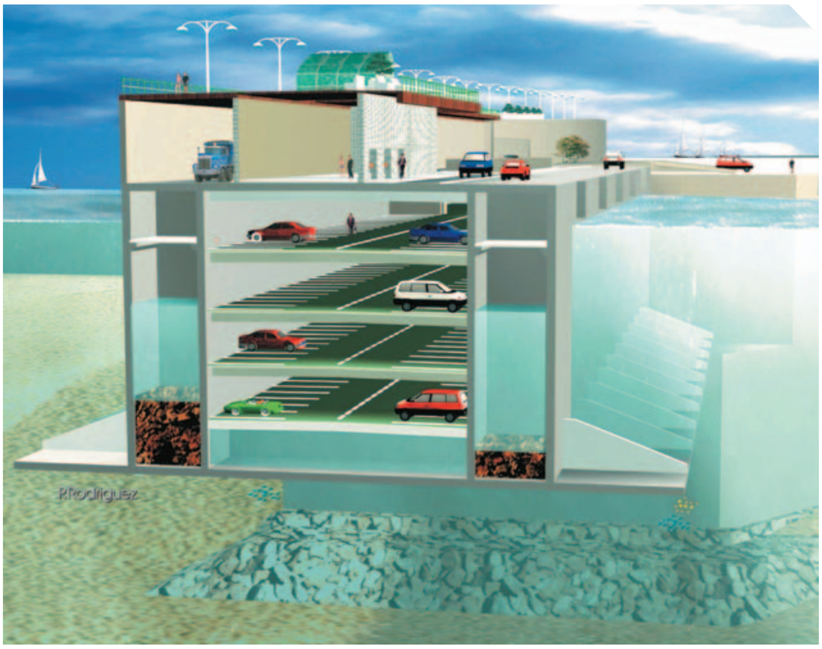
- 44,000 m^3 of concrete with 54MPa specified minimum compressive strength;
- 10,500 t of reinforcement steel
- 3,152 t of Ø 0.6" prestressing steel with BBR CONA Anchorages;
- 119 t of Ø 50 mm prestressing bars;
- 770 t of steel for the articulation.

It was decided to meet not only the current French specifications in force for prestressed concrete works (BAEL and BPEL), but also the Norwegian standard specifications NS 3473, which is the most commonly applied standard for offshore structures.

Construction product, BBR applications

The most significant characteristics of the prestressing works in this project were:

- Structure three-directionally prestressed, with lengths between 8 m and 254 m. Vertical tendons type loop.
- Use of 2 mm thick steel pipes instead of corrugated steel sheaths. These pipes were bent in the factory to match the required geometry. Plug-in connections using thermo-shrinking sleeves to ensure water-tightness were used in the different joints between pipes or between a pipe and the anchorage polyethylene trumpet.
- Double corrosion protection for the BBR CONA anchor heads: steel cap and grout at the anchorage recess.
- Cathodic protection of the prestressing pipes and bearing plates.
- The threading of the cables was carried out strand by strand for all the tendons even for the longest cables (254m) and for the vertical loops.
- Determination of tendon elongations by means of friction tests conducted before to stress each group of tendons.
- High quality cement grout. The definitive formula was stated after performing a complete series of tests, including stability tests using oblique pipe 5 m long and vertical pipe 17 m high.
- Vacuum grouting technique was used to ensure complete grouting of the prestressing ducts.
- The prestressing works were completed in 15 months while threading, stressing and grouting of 80 % of the PT required three months.



Animation of the dock

During construction in the dry shipyard

After floating in the dry shipyard

Transportation
of the dock
to Monte Carlo

During construction
in the dry shipyard
in Southern Spain

Region/Location	Construction in Algeciras (Spain), final emplacement in Monaco
Owner	Department of Public Transport of the Principality of Monaco
Consultants	DORIS ENGINEERING
Prestressing Contractor	JV FCC Construcción – BBR Systems
Main Contractor	JV BEC – FCC Construcción – DRAGADOS – HT – SMMT
BBR Scope of work	Supply and installation of BBR CONA prestressing system and PT bars
Key Data	Construction time: 2000 – 2002
BBR Product/Technology/ System used	Dock Data: Floating dock, length 352 m, width 44 m, height 25 m Quantities: 3,152 tons of PT strands and 120 tons of PT bars
Contact	José Manuel Illescas, E-Mail: jmillescas@bbrpte.com

High Speed Railway, Netherlands

Author: W. B. Grundlehner

Overview and Location

The High Speed Railway (HSL) runs from Amsterdam, via Schiphol Airport and Rotterdam past Breda, to the Belgian border. Besides the existing rail route, the HSL comprises almost 100 kilometres of new rails.

In this way, high speed trains can serve the railway stations in these cities. Breda will get fast train connections with Rotterdam, as well as with Antwerp.

Scope

At the crossing HSL/national highway A12 a railway-arch has been built. Here the HSL runs across approx. 160 prestressed decks of 35 m length each. In view of the large number of decks and the available time the contracting firms invented a special procedure for the realization. On central locations, all along the route, sites had been constructed for the pre-fabrication of reinforcement and prestressing.

Construction product, BBR applications

For each double-troughed deck three reinforcement meshes, with a length of 35 m each, had been prefabricated. The BBR CONA anchors, the sheating ducts and the strands had been fixed in these meshes. The cables had a cast-in blind anchor on one side. The complete coils of 35 m each had been brought to the site and placed in the ready-made mesh. Afterwards the floor reinforcement with the transverse prestressing had been joined with the beam reinforcement in situ. When after approximately three days con-

crete quality B20 had been reached, the cables were partly tensioned and the formwork could be moved to the next position. After curing, up to B45 the cables were tensioned completely and the sheating ducts could be injected.

For the overall contract 2,100 pieces of anchorage, type BBR CONA 3106 / 3706, were used. In addition, smaller cables BBR CONA 2206 were also used.

Important experience made with system/product application

Considering the limited space between the various decks, tensioning had to take place with special short-stroke jacks. In this way even heavy cables (31 x 0.6") in a chase bonding of approx. 1 m can be tensioned. For longitudinal prestressing the biggest cables BBR CONA 3106 and BBR CONA 2706 were fabricated according to the newly developed system. With this method small dimensions of anchor heads as well as small jacks (7,400 kN) can be used.

Region	**Amsterdam – Schiphol Airport – Rotterdam – Belgian Border at location Bleiswijk**
Client	**P.O. HSL-South**
Designer/Supervisor Engineer	**HSL-InfraRail**
Main Contractor	**HSL Comb. Zuid Holland Midden**
BBR Subcontractor	**Spanstaal, Soest**
BBR Scope of work	**Detail Engineering, Supply and Installation of PT-System**
Key Data	**2.100 pcs BBR CONA 3106 and 240 pcs BBR CONA 2206, Execution time: 2004**
BBR Product/Technology/System used	**BBR CONA PT System**
Contact	**W. B. Grundlehner, E-Mail: b.grundlehner@spanstaal.nl**

Millenium Bridge in Poland

A successful design and build bridge project of BBR Polska over Odra River in Wroclaw

Authors: Piotr Wanecki, Jan Piekarski

Millenium Bridge – view of the stay cable portion under construction

Overview and Location

The new crossing over the Odra River reaches its final stage in Wroclaw, the capital of Lower Silesia region of Poland. The city is located on five rivers, the 120 m wide Odra being the biggest one.

Scope

In May 2001 the Wroclaw Board of Roads and Public Transport issued a design and construction tender for a section of inner city ring road with a new bridge over the Odra. The contract was awarded in May 2001 to Skanska. BBR Polska was commissioned at a very early stage as a structural and temporary works consultant and took part in the preparation of the tender project. Later BBR Polska became the stays, post-tensioning and special temporary works subcontractor, as well as bearing and expansion joints supplier.

Project description

The new crossing itself consists of three concrete structures: left-bank approach, span by span built viaduct, cable-stayed main bridge and right-bank free-cantilevered bridge. The left-bank viaduct has seven spans, one 40 m and six 47.5 long. It is continuous, has a twin box cross section of girder. The main cable-stayed bridge is 290 m long, its biggest span is 153 m long and the two back spans are 68.5 m long. The twin towers of the pylon are 50 m high. The deck of the bridge is suspended on 56 BBR CONA STAYS installed in 28 pairs arranged in semi-harp pattern. The girder has a twin beam cross section. The right-bank bridge has five spans; the biggest is 126 m long, the other has the length of 50, 47 and two times of 67 m. Cross section of the girder is twin box shaped. Each of the three structures is 25.12 m wide. Two of them are locally expanded to 32.12 m for bus stops.

Construction method

The stay cable bridge is constructed using the balanced cantilever method with a pair of formwork travelers from each pylon. Two 10.55 m long and 25.12 m wide segments of superstructure were produced and two pairs of stay cables, spaced at 10.55 m, were installed over a period of three weeks. The cantilevers of the superstructure were built one after another and the travelers were reinstalled when the first cantilever had been completed. According to the construction process the built segments were step by step transversally and longitudinally post-tensioned.

The right-bank bridge is also constructed using the balanced cantilever method also with a pair of formwork carriers, but in contrast to the cable-stayed bridge the produced segments were wide for approx. a half of the superstructure (12 m), so the carriers, after the first installation, were reinstalled three times during the construction period.
At the same time as the cantilevering process the left-bank approach was built using scaffolds and the span-by-span method.

Construction product, BBR applications

BBR prepared documentation of structural design of the bridge with all

Detail of the deck anchorage zone

necessary drawings and computations. BBR engineers also prepared construction programs, technical specifications and temporary work manuals. BBR Polska technicians took part in assembly process and then handled the carriers on site; the carriers themselves were manufactured accordingly to BBR design. BBR technicians also installed the BBR CONA STAYS by means of the strand by strand method and carried out the final adjustment. All the post-tensioning works were completed by BBR Polska by means of the BBR CONA anchorages.
For this contract BBR Polska was responsible for bearing and expansion joint supply and installation. A 45.4 m long PROCEQ Tensa-Grip expansion joint which covers displacements of ± 120 mm and works at 45° skew angle was delivered and installed.

The whole project was supervised by BBR Polska engineers. The Millennium Bridge project is one of the biggest bridges successfully completed in Poland in recent years.

Formwork carrier shortly before closing pour

Region/Location	**City of Wroclaw, Poland**
Purpose/Usage of the structure	**Road Bridge**
Client	**Wroclaw Board of Roads and Public Transport**
Designer/Supervisor Engineer	**CEPAS Plan AG/BBR Polska Sp. z o.o./J.P.P. Consult**
Main Contractor	**KPRM SKANSKA S.A.**
BBR Subcontractor	**BBR Polska doo**
Key Data	**15 spans, max span length 153 m, overall length 971 m Cable-stayed bridge with beam access viaducts Construction time: July 2002 – September 2004**
BBR Product/Technology/System used	**Design for temporary works, design, construction and operation of formwork traveler, Installation of BBR CONA PT 680 t, BBR CONA STAY 190 t, Proceq Tensa Grip Expansion Joints, Bearings**
Contact	**Piotr Wanecki, E-Mail: j.piekarski@bbr.pl**

Sloboda Bridge in Novi Sad, Serbia and Montenegro

Reconstruction of a Historical Stay Cable Bridge

Author: Marcel Poser

The Danube River

The Danube River is the second longest river in Europe and its source is located in the Black Forest area of Germany. The Danube flows approximately 1,770 miles through the countries of Germany, Austria, Slovakia, Hungary, Serbia, Croatia, Bosnia and Herzegovina, Slovenia, Bulgaria, Romania, the Ukraine and many important cities such as Vienna, Budapest, Bratislava, and Belgrade. With the aid of canals, the Danube is connected to the Main, Oder and Rhine Rivers. This waterway is the only major European river to flow west to east and connects the North Sea and the Black Sea. For commercial transportation, the Danube is extremely important.

The three bridges of Novi Sad

Novi Sad with around 250,000 inhabitants is the capital of Vojvodina in northern Serbia. It lies on both sides of the Danube River and is connected with three rather different types of bridge – the Zezelj Bridge, the Petrovaradin Bridge and the Sloboda (Freedom) Bridge.

Sloboda Bridge

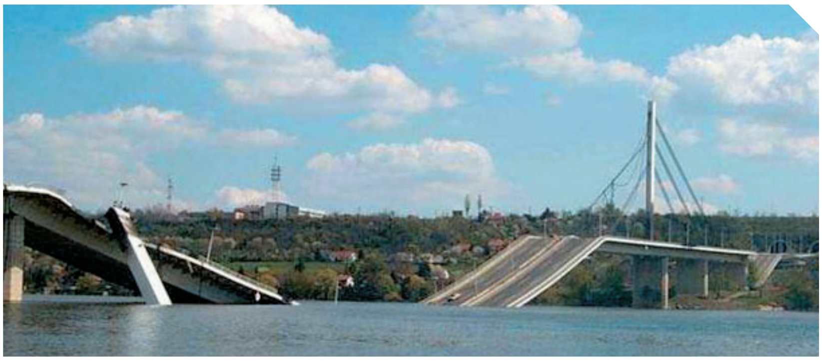
The original Sloboda Bridge was built from 1976 to 1981 and was one of the largest single plane stay bridges at that time. The entire Sloboda Bridge with a total length of 1312 m consists of three different structures – the prestressed concrete access bridges on the left bank with 10 spans of 30m the composite concrete steel structure with 4 spans of 60 m on the left bank and with 3 spans of 60 m on the right bank and the 591m steel structure (orthotropic deck) main bridge with a harp type stay cable arrangement with a central span of 351 m and two side spans of 60 m each. The entire bridge has a width of 27.6 m to accommodate six traffic lanes. The stay cables of the original bridge were prefabricated BBR HiAm Stay Cables, composed of a compact bundle of 7 mm wires instead of an HDPE duct.

NATO attacks

In total eight bridges over the Danube, including the three bridges in Novi Sad, were destroyed or damaged during the NATO air strikes against Yugoslavia. The three bridges in Novi Sad were struck by Tomahawk missiles launched from the Adriatic Sea in April 1999. All three of them collapsed into the river with the amount of rubble in the Danube causing great problems to the residents and navigation. The Sloboda cable-stayed main bridge was destroyed by an air strike on 3 April 1999 at 19.55 hours, when two Tomahawk missiles hit the base of both pylons. While the left bank pylon and therefore all the stay cables were completely destroyed, the right bank pylon was only damaged and only the upper cables towards the river have been destroyed. At the base of both pylons plastic hinges formed and allowed the main span to sink to the bottom of the river bed, causing a longitudinal movement of the entire bridge structure of approximately 6 m on the left bank and 2 m on the right bank.

Effects on Navigation

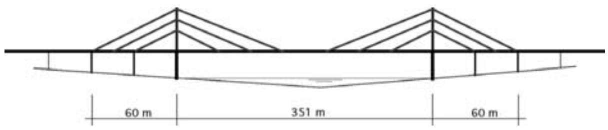
With many bridges lying on the river bed, only the lightest and smallest ships were able to navigate the Danube. The significant drop in traffic has affected shipping companies, shipyards and river ports in all Danube countries. The Danube community suffers from monthly financial losses of about EUR 30 million. Romania, Bulgaria and the Ukraine have suffered most. In Romania alone, about 4,500 jobs have been lost, leaving employment for only one thousand people in the shipping industry.
With the latter mentioned clearance project a navigable and provisional channel was opened and marked for safe navigation in November 2001. However, the temporary pontoon bridge in Novi Sad still blocks navigation and is opened only three times per week. Full navigation will be restored only with the removal of the pontoon bridge after the completion of the re-construction of the Sloboda Bridge, which is expected early in 2005.



Collapsed Bridge after NATO attacks in April 1999

Reconstruction of the Sloboda Bridge

In July 2002 a Euro 34 million reconstruction agreement was signed between local authorities and the European Agency for Reconstruction. This



Bridge Longitudinal Section

Situation after the Bombing of the Bridge

is so far the largest project in Yugoslavia and Montenegro, which is financed with funds of the European Community
It was decided to reuse existing bridge elements wherever possible and to rebuild the bridge, considering the latest European Code provisions. Before the reconstruction could start, the Danube River had to be cleared of the damaged parts of the old bridge and the intact bridge parts had to be repositioned.

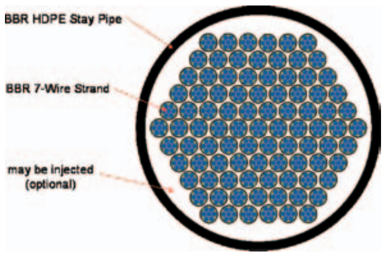
Installation of new BBR CONA STAY Cables

BBR Scope of Work

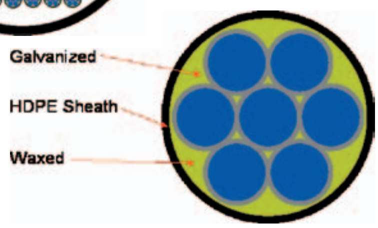
Besides the de-tensioning works of the original BBR HiAm stay cables, BBR Systems Ltd. was entrusted with the supply and complete installation (see Figure 4) of the new stay cable system. During the de-tension works of the original BBR HiAm cables, it was noticed, that these cables were completely intact in terms of their corrosion protection, this although the HDPE stay pipes have only been cement grouted at that time for corrosion protection.
For the reconstruction the BBR 7-wire strand based CONA STAY cables have been chosen as the new stay cable system. The site assembled BBR CONA STAY cables provide excellent flexibility in terms of last minute on-site adjustability, which makes it the ideal stay cable system for a reconstruction project.

BBR Construction Product

The standard BBR CONA STAY cables are composed of diameter 0.62 in. (15.7 mm) strands with a nominal cross-sectional area of 150 mm^2 inside a UV Resistant HDPE Stay Pipe (see Figure 5). The strands are galvanized, waxed and individually sheathed with a continuous high density polyethylene (PE) sleeve. The PE-coating is continuous from anchorage to anchorage, where each strand is individually gripped with the proprietary BBR 3-piece stay cable wedge. Lock nuts screwed on to the BBR CONA STAY anchor heads transfer the cable loads to the supporting bearing plates. The lock nut allows for a length adjustment of the cable. Hence, additional stressing and de-stressing operations of already installed and stressed stay cables can be performed on the whole strand bundle without re-gripping of the strands at the wedges. Individual strands are replaceable at any time after the installation. Protection caps filled with a special corrosion-inhibiting compound protect the anchorages, the strands and the wedges from damage and corrosion.
All anchorage components are designed to withstand the nominal ultimate breaking load of the strand bundle with adequate safety. The anchorage system was designed to develop a minimum fatigue resistance of over 2,000,000 load cycles for a 200 N/mm2 stress range at an upper stress limit of 45 % of the strand bundle ultimate tensile strength.



Cross Section BBR CONA STAY



BBR Strand Configuration

Region/Location	Novi Sad, Serbia and Montenegro
Purpose/Usage of the structure	Motorway Novi Sad – Belgrade
Client	City of Novi Sad
Engineer	Louis Berger SA, France
Main Contractor	DSD Industrieanlagen, Germany
Subcontractor	BBR Systems Ltd.
BBR Scope of work	Installation of Stay Cables
Key Data	Construction time: 2004–2005
BBR Product/Technology/System used	48 BBR CONA STAY cables, 440 tons
Contact	Marcel Poser, E-Mail: mposer@bbrsystems.ch

Brnik Airport Parking Centre, Slovenia

BBR PT Flat Slab solution for a large building in Ljubljana

Authors: Zelimir Bodiroga, Luigi Giannattasio

Overview and Location

Brnik Airport Parking Centre near Ljubljana, Slovenia, is the first project with post-tensioned slabs that BBR Conex undertook for design and execution. The design has been executed in collaboration with Dreibau Ingenieurs Conseils, Switzerland.

Scope

The scope was to evaluate for the main contractor and the client an optimal alternative solution for the slabs in order to meet the strict schedule conditions and to improve the slabs behavior in terms of serviceability.

Project description

Parking Centre is a three storey slab-column frame structure with overall dimensions in plan of approx. 109 x 80 m. Column grid is 8 x 8 m with 10-m lateral spans. The original reinforced 35 cm thick concrete flat slab was redesigned and converted into 22 cm thick post-tensioned flat slabs offering both technical and economic advantages.

Detail of PT layout under the column

The design is based on a superimposed dead load of 1 kN/m², live load of 3.5 kN/m² for static parking areas and live load of 5.0 kN/m² for the runways. The goal was to balance the PT/rebar ratio in such a way as to allow both direct material economy and the extremely fast pour sequence required by the contractor. Large pours of more than 2000 m² should be done in the same cycle time of one week.

This was possible by combining some design directives, common to ACI/PTI slabs, with the code requirements of Eurocode prEN1992. The resulting design was economical and easier to build. Thickness was also checked to allow for upper slab levels to be cast over the lower slabs without requiring re-shoring. The full design of the three levels, involving the modeling of 12 slabs, was done using CUBUS Cedrus software, in just two weeks, including full documentation, shop drawings and tendon fabrication/elongation tables. The main designer for the structure later incorporated the specific reinforcement for the seismic requirements, the mass reduction compared with the RC solution allowing for substantially lower seismic demand.

Formworks and propping

Curing of the concreted plot

Site view of the Brnik Airport

Construction method, product, BBR application

The flat slabs were post tensioned with BBR CONA Single 0.6" greased and sheathed 7-wires mono-strand tendons. All tendons were equipped with one stressing and one fixed anchorage, with one or three intermediate anchorages in the short and long building directions respectively. The cable extensions, recorded systematically after the prestressing operations, yielded consistent values throughout. The total consumption of prestressing steel amounts to approx. 80 tons.

Concrete grade is C35/45 and average passive St500 rebar quantity below 8.0 kg/m² for gravity, plus the seismic reinforcement. Steel shear-heads, fabricated locally with welded HEA100 profiles proved to be the most economical way to provide both punching capacity and seismic node ductility. Due to site requirements, the shear-heads should be installed outside of the column reinforcement cage, so a strut-tie mechanism for shear transfer was checked.

Each floor slab was executed by pouring in six plots, with one active joint with intermediate anchors, located at 1/4 of the span in the short building direction and three joints in the long span direction. The tendons were stressed at the joint by intermediate anchors, using twin-jacks, a more economical solution than using couplers.

A detailed cycle schedule for each pour was prepared, to improve coordination between the main contractor and BBR Conex's site workers.

Important experience made with system/product application

One of the main advantages of PT-slabs is the reduction of formwork equipment, which can only be done with fast cycling after stressing. The learning curve was quite fast, and after four weeks, the site was only marginally late for four full cycles and almost 8,000 m² done, with only 2,200 m² of DOKA formwork in use.

As the concrete was exceeding the specifications (45MPa were reached after 48Hrs), some 0.1 shrinkage cracks were shown perpendicular to the joint between the first two pours; to avoid this in subsequent pours, the stressing of the tendons parallel to the joint was scheduled to be done as earlier as 36 hours, reducing the cement content on the concrete at the same time.

The general use of Eurocode after 2005 will make the BBR post-tensioned slab a very competitive alternative to both reinforced concrete and composite/steel structures, not only for parking and office buildings, but also for residential structures. Some special design rules, as well as clear cost directives in the design parameters should be applied, to make sure that the design fulfils both economical and structural requirements.

PT layout at stressing end

Region/Location	Ljubljana, Slovenia
Client	Airport Ljubljana
Designer/Supervisor Engineer	EKO ART Ljubljana, MM Projekt Ljubljana, BBR Systems Zurich, Dreibau Ingenieur Conseils, Switzerland
Main Contractor	SCT Ljubljana
Subcontractor	BBR Conex, Zagreb
BBR Scope of work	Design Supply and installation of BBR PT Flat Slab.
Key Data	25,000 m² BBR post tensioned flat slab, 80 t greased and sheathed 7-wires mono-strand tendons, BBR CONA Single 06 anchorages. Year of Execution: 2004
Contact	Zelimir Bodiroga, E-Mail: bbr-conex@zg.htnet.hr Luigi Giannattasio, E-Mail: luigi_giannattasio@dreibau.ch

5th LNG Tank in Barcelona

Author: Roberto Sanchez

Tank during construction

Overview and Location

The prestessed concrete structure of the 5th LNG tank in Barcelona port is designed like a secondary containment of liquid gas. It is a cylindrical structure with a height of 49.56 m and a diameter of 81.80 m. The concrete structure was built by means of climbing formwork.

Scope

The storage temperature of liquid gas is –165° C, so a series of static tension tests with the BBR CONA anchors were made under cryogenic conditions (–196° C). The test results were in accordance with the ETAG 013 acceptance criteria for cryogenic applications.

Construction product, BBR applications

The prestressing system used for this project is the BBR CONA for cables with 15, 19 and 24 strands 0.6". Galvanised steel corrugated ducts were installed for vertical and longitudinal tendons. Provisional covers were placed in the top mouths of the vertical ducts to prevent the accidental entry of concrete or any object into the vertical prestressing ducts.
To push the strands into the horizontal and loop vertical ducts, standard pushing equipment was used.

Important experience made with system/product application

The stressing sequence is very important since the application of prestressing forces might, in some conditions, be harmful for the structure. In defining the stressing sequence the following conditions were taken into account:

– Vertical cables mainly generate a vertical compression in the wall with very little bending at the base of the wall; then stressing may be executed at any time provided that the wall has been finished.
– Horizontal cables introduce horizontal compression forces and

important vertical bending in the wall. Corresponding tension stresses have to be compensated by vertical compression forces coming from vertical prestressing.

To ensure the protection of the tendons the grouting has been carried out using the vacuum grouting technique and special high-turbulence mixers.

The prestressing work took four months from the supply to the end of grouting.

Vertical ducts

Region/Location	Barcelona, Spain
Owner	REPSOL YPF / ENAGAS
Consultants	JV Principia – Carlos Fernandez Casado
Prestressing Contractor	BBR PTE (Spain)
Main Contractor	JV FCC CONSTRUCCION – FELGUERA – IHI
BBR Scope of work	Supply and installation of BBR CONA prestressing system
Key Data	Construction time: 2003 – 2004
BBR Product/Technology/System used	Tank Data: LNG Tank for 150.000 m³ of liquid gas 49.56 m height, 81.80 m diameter Quantities: 12 horizontal BBR CONA tendons in the external ring of the foundation slab type 2406 140 horizontal BBR CONA tendons in the vertical wall type 1506 140 loop vertical BBR CONA tendons in the wall type 1906 Total net PT steel = 596 tons
Contact	Roberto Sanchez, E-Mail: rsanchezpablo@bbrpte.com

Flat Slab Post-Tensioning, Lucerne

A BBR Application for post-tensioned slabs in buildings

Autor: Robert Bossart, Stahlton AG

Anchorage zone

Overview and location

Transportation and logistics are fundamental elements of an economy. Logistics centre buildings play an important part for such services. Flexibility, big spans, short realisation time and low costs are the characteristics which are sought after by the owner companies. Post-tension cables «Stahlton-BBRV flat» for the slabs have played an important role in the building of a logistics centre for Galliker Transportation Ltd in Dagmersellen in the canton of Lucerne, Switzerland.

Scope

Since the sixties the method of post-tensioning is well known as a good means to realize big spans and thin slabs. Today a new argument is gaining importance: The construction time has become one of the main concerns of an owner in an economy which is defined by quick changes. By post-tensioning the slabs, the schedule of construction can be considerably reduced. A good number of important realisations in Switzerland proves this fact.
The inhabitants of Dagmersellen marvelled at the speed at which the new building took shape. As a matter of fact, each week 665 m^3 of concrete and a slab surface of 1700 m^2 were realized. In parallel, 1200 m of cables were tensioned to give the concrete the desired compression reserve.

Project description, Construction product, BBR applications

The building has four stories with the impressive dimensions of 80 x 139 m. All slabs have a thickness of 40 cm

General view of the PT flat slab

and are executed in eight stages. The spans are 16 x 14.5 m. To allow these dimensions Stahlton-BBRV flat cables with a tension force of 1900 kN each were used. These cables present a flat duct to adapt in an optimal way to achieve a low construction height. At each column connection strip 6 cables were placed. To cope with the ambitious construction schedule the full post-tension force was applied only three days after concreting. Stahlton AG has developed the new cable Stahlton-BBRV flat 1900 which was used for the first time in the building in Dagmersellen. The flat duct is only 32 mm thick and adapts perfectly for slabs with spans greater than about 10 m. The cables contain 42 7 mm wires giving a post-tension force of 1900 kN.

Important experience made with system/product application

Stahlton AG as the main post-tensioning company in Switzerland was a pioneer in the post-tensioning of slabs. We have developed our own method of placing the cables in the column connection strips. This method leads to a simple geometry of the cables and thus produces an economically interesting solution. And the designers work gets quicker and easier as well!

With the experience of constructions losing prematurely their serviceability, owners as well as civil engineers and architects are concerned about the durability of new constructions. Post-tensioning leads here to an additional value. The reduction or even elimination of cracks means longer life and less aesthetical problems.
With the compression reserve in the post-tensioned concrete less or even no joints have to be placed. Knowing that joints are always a weak point of a construction this fact is highly welcomed by all parties.

Flat slabs are of great importance for numerous different types of buildings. Besides logistics, also school buildings, office or administration buildings, hospitals etc. present the same tasks. This part of the construction market can still to be developed and represents a non-negligible field, apart from bridges and other civil engineering classics.

Example of BBR Carbon Fibre Reinforced Polymer Cables

Dedicated R&D teams were key success factors throughout the 60 years

Author: Prof. Urs Meier, EMPA

The Storchenbrücke, Winterthur

Preamble

Since the first days of BBR there has always been a close R&D co-operation between BBR and the Swiss Federal Laboratories for Materials Testing and Research, EMPA. This is not surprising as the father of Mirko Robin Roš, one of the three founders of BBR, was president of EMPA from 1924 to 1949. In the following sections pilot projects with carbon fibre reinforced polymer cables for stays and post-tensioning are presented as one example of this long lasting fruitful collaboration. EMPA congratulates BBR on its 60th anniversary and wishes it all the best for the coming 40 years.

Introduction

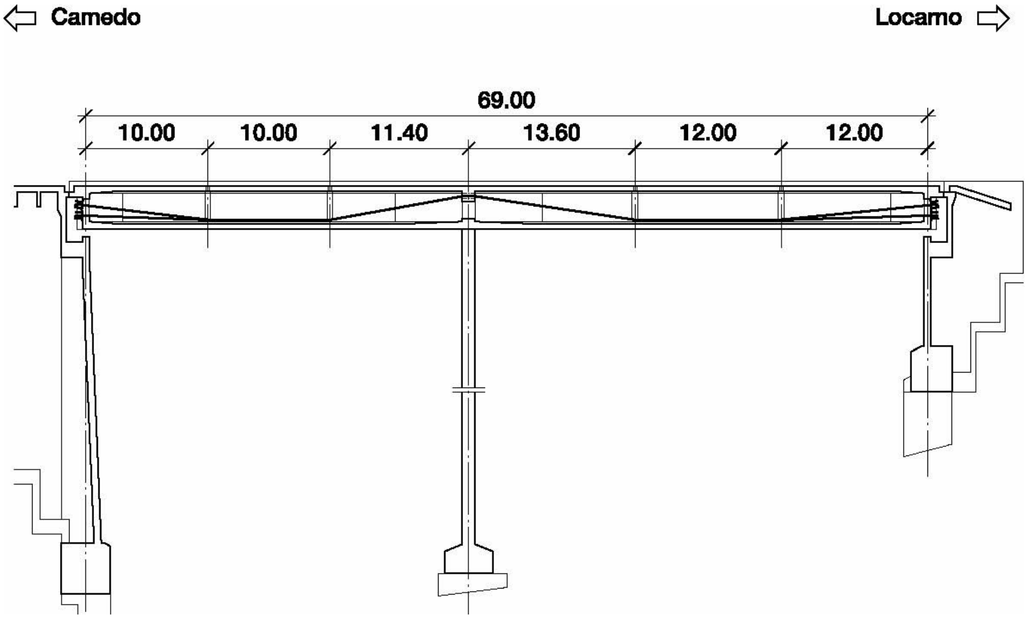
Carbon Fibre Reinforced Polymers (CFRP) offer an outstanding fatigue performance, they are very lightweight, they have excellent specific strength and stiffness and they do not corrode. The purpose of the BBR-EMPA R&D work was to develop an anchorage system capable of successfully handling the huge potential of CFRP wires and to achieve a high reliability of cables made of such advanced composites.

One pilot project with BBR CFRP cables – the Storchenbrücke, erected in 1996 – is situated over the tracks of the railway station in Winterthur and has a central A-frame tower supporting two approximately equal spans of 63 and 61 meters. The superstructure has two principal longitudinal girders spaced at 8 m and supporting a reinforced concrete slab. The two BBR CFRP cables used for this bridge consist of 241 wires each with a diameter of 5 mm. The CFRP cables with their anchorage and the neighbouring steel cables have been equipped with conventional sensors and also with state-of-the-art glass fibre sensors.
The bicycle and pedestrian bridge over the Kleine Emme River near Lucerne was built in 1998. Two BBR CFRP cables used as the chord members were produced by a team of BBR Systems Ltd and EMPA. This bridge is significant for the future development of CFRP cables in two respects: firstly in view of the innovative integrated use of fibre optical sensors and secondly due to the sustained high stress of 1350 MPa.
The external post-tensioning method is for repair more «powerful» than using external bonded BBR CFRP strips if a high degree of strengthening is needed. The retrofitting of the Verdasio Bridge represented the first attempt to make practical use of the results of extensive experiments per-

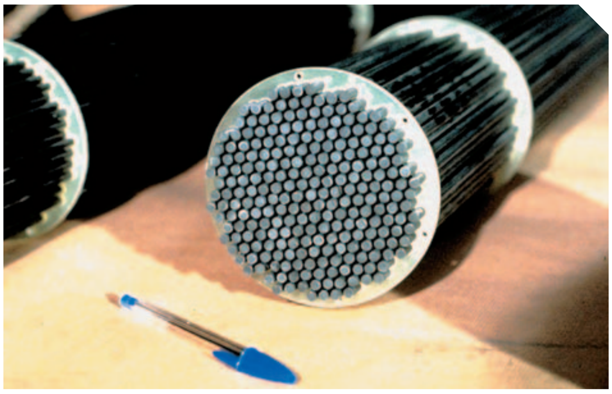
formed at EMPA in recent years on continuous two-span beams post-tensioned with BBR CFRP cables. Four cables each comprising nineteen 5-mm-diameter BBR CFRP wires were used for external post-tensioning to replace corroded steel cross-sections.

Future scenario for BBR CFRP cables

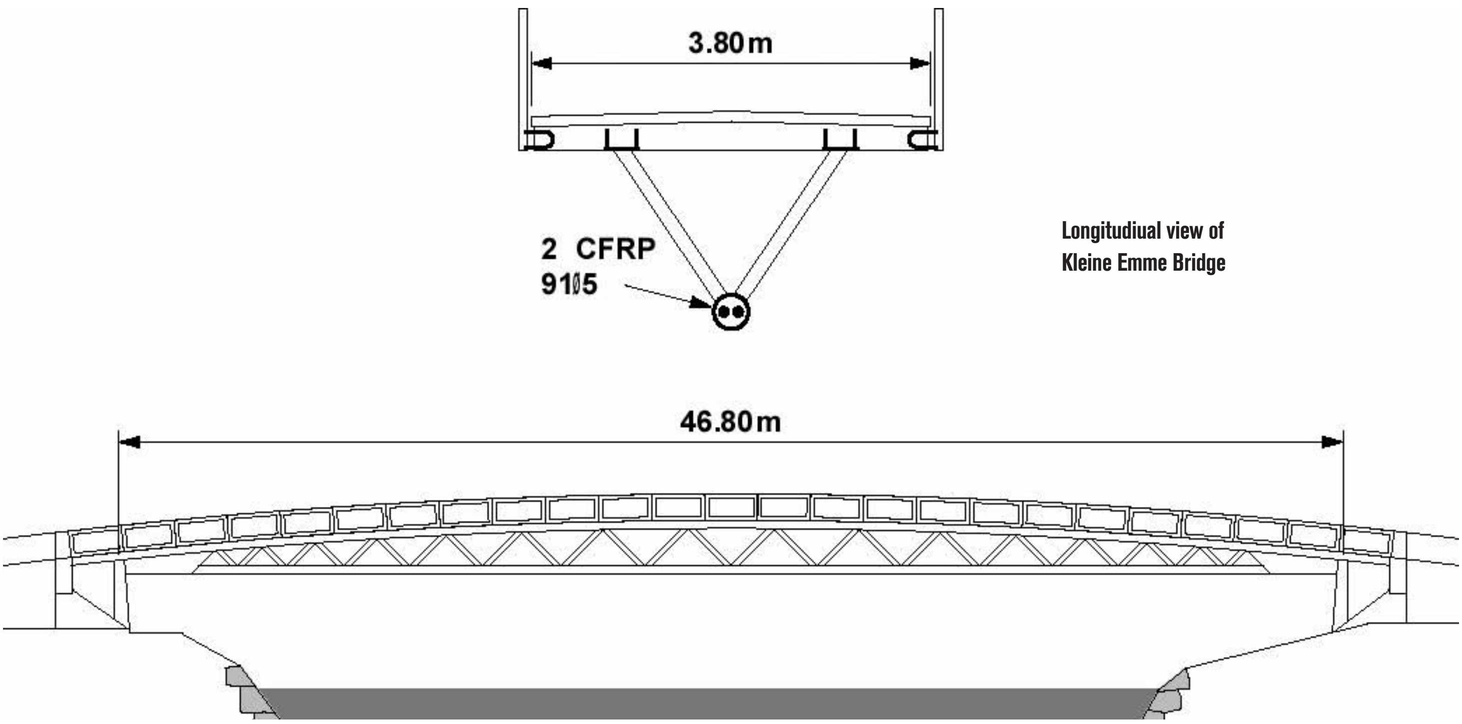
Within its first eight respectively six years the results of all these pilot projects are fully satisfactory. What does the future hold? What are the prospects for BBR CFRP cable in structural applications? Let us move forward to the year 2010. The long-term experimental data collected from these pilot projects have met all the requirements originally specified. The prices for carbon fibre have now fallen to a mere US $ 10 per kg compared to US $ 30 per kg in 1998. The pultrusion process for the production of BBR CFRP wires is 50 times faster than in 1996 and production costs have sunk accordingly. Sustainable construction is now a serious issue among clients. In assessing projects, close attention is paid not only to the new-build or retrofitting costs but also to life-cycle costing. Given the above conditions, BBR CFRP cables would probably be preferred in applications where steel cables would be prone to corrosion, stress-cracking and/or fatigue. For long spans, the low dead load of BBR CFRP cables and resulting substantial improvement in the equivalent modulus would also tip the balance in favour of these advanced materials.



CFRP tendon layout Vedario Bridge.



CFRP cable



Longitudiual view of Kleine Emme Bridge

Processes and Equipment: BBR and Proceq SA

Author: Michael Kompatscher, Proceq SA

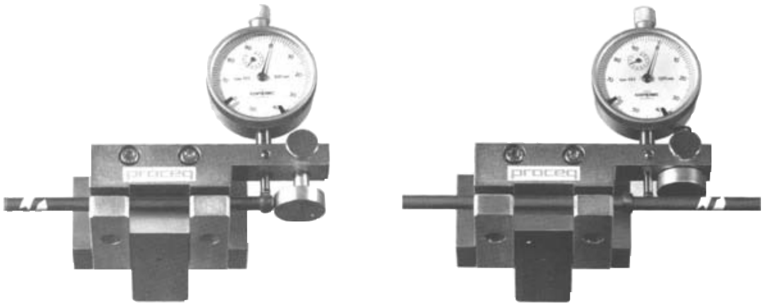
Introduction

The rapid development of pre-stressing and post-tensioning technology between 1940 and 1960 has made such concrete structures the most widely used construction material for today's bridges and other concrete constructions. This technology made slim and elegant constructions of bridges and other special concrete framework feasible as well as new prefabricated bearing construction. BBR Group, founded in 1944 by three Swiss engineers: Max Birkenmaier, Antonio Brandestini and Mirko Robin Roš, has lead in this development with pioneering contributions, e.g. the patented button head wire post-tensioning system.

In response to the increasing demand for specific engineering excellence, Antonio Brandestini established Proceq SA in 1954. The company name is taken from a combination of the words «processes» and «equipment». In its early years the main focus was the development and selling of specialized equipment for pre-stressed and post-tensioned concrete engineering, e.g. of the BBRV tension system. Proceq could benefit from significant contributions brought in by Mr. Brandestini from his co-partnership in BBR. Aiming to continuously improve the quality of pre-stressed construction engineering, i.e. in manufacturing processes and the realization of projects, Proceq placed particular emphasis on the development of new and innovative equipment, processes and applications in various special fields of modern construction engineering.

With its growing success, Proceq assembled a group of specialists to handle the detailed design work and technical specifications of both its own and third-party products and projects. This group was involved in coordinating external development and manufacturing units and controlling the manufacture of prototypes and their testing, as well as the execution or supervision of materials testing. As a result of such research and development, Proceq extended its product range from concrete constructions to metering and material testing techniques for paper, metal, wood and other materials.

This article for BBR's celebration of its 60th anniversary highlights the close partnership between BBR and Proceq, presenting main contributions with respect to pre-stressing and post-tensioning technology.

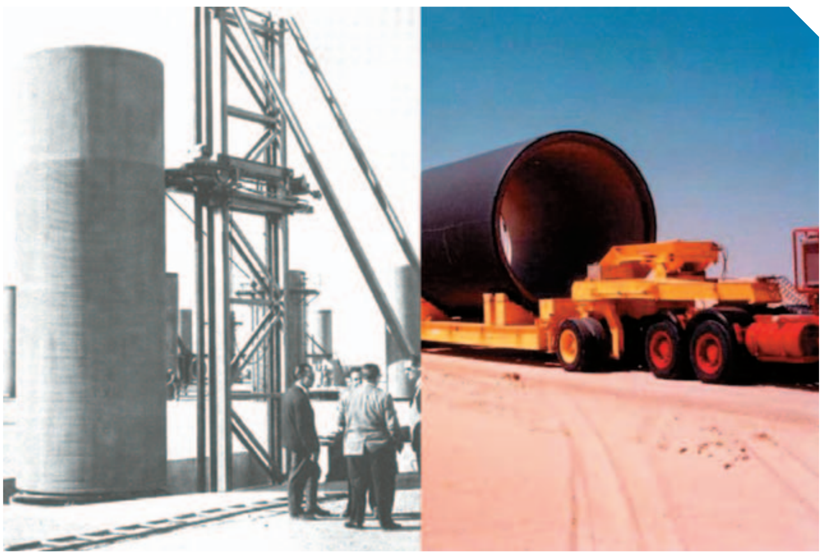


Proceq Measuring Instrument for BBRV Button heads (end and intermediate)

Machines for BBRV stressing systems

a) BBRV Wire Upsetting Machine. A hydraulic wire upsetting machine for the BBRV button heading technique. Optimized deformation process with highest dimensional accuracy results in increased quality of the BBRV button heads.
b) Measuring instrument for BBRV button heads. Measures the eccentricity of upset BBRV end button heads and the axis offset at intermediate BBRV button heads.
c) BBRV Pipe Prestressing Machine. E.g. used in the Great Man-Made River Project of Libya for prestressed concrete cylinder pipes (PCCP) each 7.5 m long and weighing up to 80 tons for transporting the water over a network exceeding 4,000 km in length.

Proceq BBRV Pipe Prestressing Machine used in the Great Man Made River (GMMR) Project in Libya to fabricate water transporting prestressed concrete cylinder pipes



Mecca. Al Jamarat pedestrian bridge built on 3600 pieces of Proceq LASTO Block bearings

Bridge construction elements

a) LASTO Block. First rubber/steel slide and deformation bearings developed by Proceq in the early 60s. In 1976, Proceq delivered 3600 pieces for the gigantic Al Jamarat pedestrian bridge in the holy city of Mecca.
b) RESTON. Superior bridge bearings also combined with the WIGA load cell measuring system. WIGA is designed for deep pile static load testing using BBR bridge bearing technology.
c) TENSA Flex Fingers. Bridge joining systems with reduced noise production and outstanding maintenance flexibility for roadway constructions.

Bridge inspection

a) Original SCHMIDT concrete test hammer for on-site, non-destructive testing of concrete. Concrete/mortar compressive strength is determined dynamically and the control of the uniform concrete quality (in situ concrete and prefabricated structures) is detected as well as weak spots in the structure.
b) PROFOMETER. Technology leader used for locating reinforcing bars and welded wire meshes as well as for measuring the concrete cover and for determining the diameter of steel reinforcing bars in placed concrete. All these features are housed in one universal probe working according to the eddy current measuring method with pulse induction to ensure a high measuring stability.
c) CANIN. This corrosion analysing instrument is used for a condition analysis of concrete buildings as basis for restoration. The corrosion potential of the reinforcing bars is determined by the electrical voltage measurement of large concrete surfaces.
d) EQUOTIP Portable Metal Hardness Testing System. Based on the dynamic Leeb rebound principle (named after the Proceq scientist Dietmar Leeb) and the static low load Rockwell principle the hardness of metal is determined. A quick and economic assessment of the mechanical properties of metals like tensile strength of steel is possible.

Bridge inspection with Proceq testing instruments like SCHMIDT, PROFOMETER, CANIN

BBR Post-tensioned slabs on ground

Author: Paul Wymer, Contech

Overview

In response to growing demand, BBR Contech has specialised in the design and construction of post-tensioned slabs on ground. These flooring solutions have become the preferred choice for high performance, superior quality and maintenance-free floors for commercial and industrial buildings. Main applications include large retail stores, warehouse facilities, transport distribution and bulk storage.

In recent years, BBR Contech has been associated with slabs ranging in size from 2,000 m² to 32,000 m² and a number of innovative techniques have been developed to couple slabs together which allows very large joint-free areas to be constructed.

One such example is a distribution centre for a large superstore retailer, which occupies 31,828 m² of a seven hectare site.

Construction product, BBR application special design software has been developed and each floor solution is configured to ensure maximum pour size and a minimum number of joints. The level of post-tensioning is varied depending on the rack and vehicle loadings but tendons are typically configured using BBR CONA Flat 405 bonded cables at 1.5–2.0 m centres.

Scope

Built to improve the movement of stock to smaller stores, the site is located close to main arterial roads, an international airport, the main national rail link or a major port. The floor slab is designed to resist loads related to container handling hoists, large trucks, high rack loads and smaller fork lift trucks. A 175 mm thick post-tensioned floor was installed over 29,028 m² of the main building in twelve pours, with four rows of three coupled slabs separated by reinforced joints oriented in one direction only. The total floor area was completed in two three-week windows and was scheduled to follow after the staged completion of the roof and walls. A 150 mm thick adjoining canopy slab of 2,800 m² completed the floor area and was poured in two separate pours on consecutive days.

Casting of the slab

Completed Slab

Important experience made with system/product application

Because of the preference for post-tensioned floors and the growing database of knowledge, the building design is integrated with the floor system at an early stage. Careful consideration is given to the interfaces between foundations, column supports, walls, storage systems and door openings. It is important that the slab is free from restraint following construction and this can be readily incorporated into the design of the foundations and superstructure.

The strong partnerships formed between building owner, designers, main contractor, concrete supplier, placer and post-tensioning contractor throughout this process results in an effective team which can collectively deliver a quality and high performance solution in a very fast time frame.

Plastic Ducts

A new Application for Corrosion Protection of Internal Post-Tensioning Tendons

Author: Holger Jung, PES.TEC

General information

Due to increasing notice of significant failures of corrugated steel ducts when used for corrosion protection of internal tendons in the past, the idea of an effective protection based on a corrosion resistant and leak tight encapsulation of the tendon became popular.

First generation

Since the early 1990´s, the first generation of specific corrugated plastic duct systems was introduced for bonded post-tensioning. These systems provide a complete encapsulation of the post-tensioning tendon. If prestressing steel is sealed, the ingress of water and chlorides from outside into the tendon will be completely blocked and tendon corrosion is impossible even if there are some voids in the grout.

Second generation

The second generation of plastic ducts was introduced in 1996 using HDPE material in an advanced circular flat corrugated design with increased wall thickness for improved performance. During an increasing number of projects using plastic ducts, more and more experience and tests have shown different performance of the pipes relating to installation temperatures, distance of tendon supports and minimum radius of curvature in relation to duct sizes and tendon forces.

Third generation

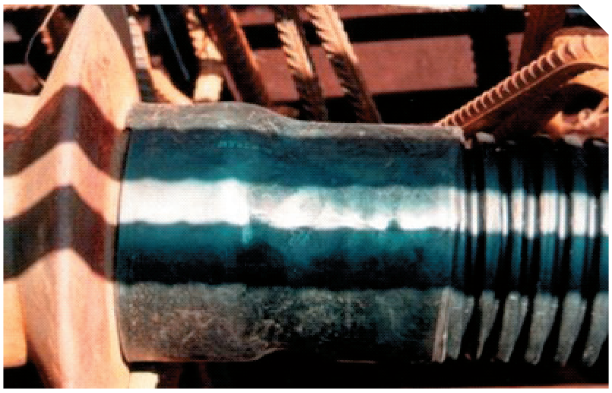
Considering these experiences, FIB (International Federation for Structural Concrete) released the Technical Report Bulletin 7 with material and at the end of 2002 test recommendations for the third duct generation at end of the 2002. In addition FDOT (Florida Department of Transport) released final drafts for USA requirements in 2004, very similar to the FIB technical report.

Main duct requirements

The new requirements specify dimensional duct tolerances, flexural behaviour, duct flexibility, a lateral load resistance of 1050 N on 1100 mm duct length, a longitudinal load resistance of 2200 N on 1100 mm duct length, a leak tightness of 0.5 bar water or 0.1 bar air, wear resistance with residual wall thickness of minimum 1.0 mm and the bond behaviour.

Polyolefin ducts

In order to comply with the new specification, most of the ducts are nowadays produced in PP (Polypropylene) material, a polyolefin material close to



Plastic duct connection

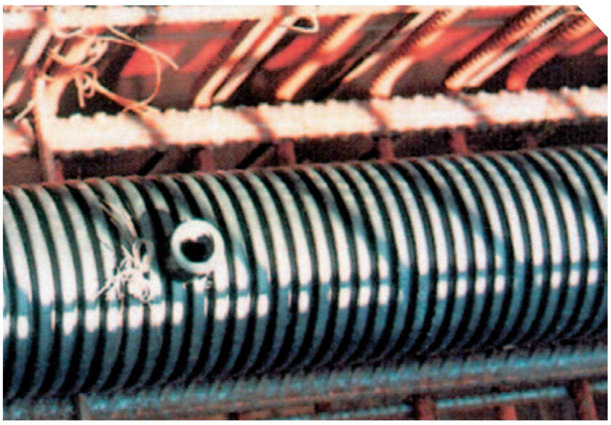
HDPE (High Density Polyethylene) but stiffer and more rigid and applicable for higher temperatures.
No minimum wall thicknees and minimum radii of curvature are specified in the FIB technical report, but from experience the pipe wall thicknees average is now 3.0 mm to comply with the required minimum wall thickness of 1.0 mm, after stressing even on projects with minimum radii of curvature lower than 10.0 m.
Internal PT-pipes in HDPE material are still produced for cold installation temperatures close to 0°C as well as for applications with requirements regarding low radii of curvature and tendon forces as the material price for HDPE is lower than PP.

PES.TEC IP-3 ducts

PES.TEC started supplying of first generation ducts in the early 1990´s and now provides IP-3 ducts of the third generation complying with latest FIB Technical Report Bulletin 7 recommendations.
The brand new PES.TEC IP-3 ducts are available in PP and HDPE material with different pipe wall thickness.

IP-3 duct wear resistance compliance test

Critical was to pass the most important FIB Annex A7 wear resistance test to simulate a 37 strand tendon stressing with 199.9 KN (75 % stres-



Plastic duct

Calculation:

Strand 0,6" A_s = 150 mm^2 F_u = 265.3 kN
Stressing force F = 0.75 x F_u = 199.9 kN
Cable factor: k = 8,25
Sample length: l = 100 mm
Radius: R = 9.0 m

Clamp force $Q_c = F \cdot k \cdot {}^{l} = 199.9 \cdot 8.25 \cdot \frac{0,100}{} = 18.32\ kN$

Plastic ducts in a congested rebar environment

Plastic duct under wear resistance compliance test

sing force of 265.2 KN strand breaking load) in a PESTEC IP-3 145/128 mm duct with a calculated 9 m radius. The structure of the IP-3 duct does perfectly resists the applied load and the remaining wall thickness of 1.5 to 2.5 mm (required minimum is 1.0 mm) after stressing provides in conclusion an excellent corrosion protection quality for stressed tendons. PES.TEC IP-3 duct also passed the other FIB tests.

Duct jointing and fittings

Duct jointing is made by mirror welding, PFS push fit coupler with integrated sealing or heat shrink sleeve. A big variety of grouting fittings as vent pipes, vent ports, valves, end caps and vent pipe couplers is available to complete the duct system.

Grout port welding

Professional fast, easy and pressure tight installation of grout ports to all kinds of PT corrosion protection ducts for vent pipe and grout tube connections.

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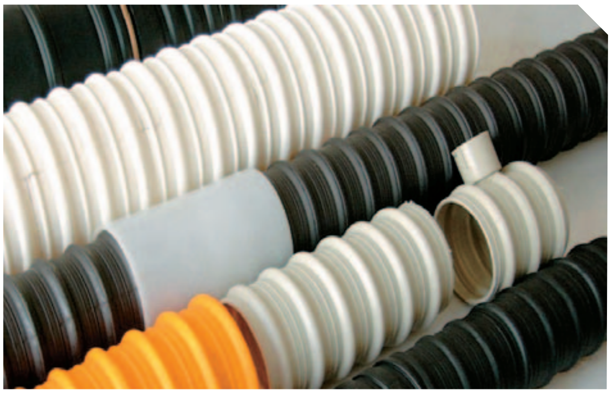
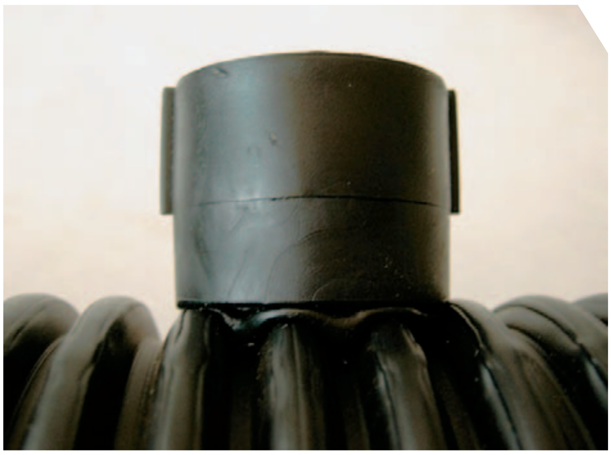


Different duct sizes



Joint and fitting for plastic ducts

BBR Cantilevering Construction of Arch Bridges

Authors: H.P. Hoeltschi and R. Meichtry, CEPAS Plan Ltd

Introduction

The construction of arch bridges has challenged the skills of engineers and builders from ancient times up to today. In the past most arches were built on conventional timber scaffolds.

The picture shows the scaffolding of the Lavoitobel Bridge in Switzerland, which was built 1966/1967.
Depending on the topographical and geotechnical situation (deep gorges, rivers, etc.) the erection of the scaffold was in many cases very difficult and therefore costly and time-consuming. Economic considerations have therefore dictated the development of construction methods which should be highly mechanised with a minimum labour content. These techniques together with the scaffolding for the Lavoitobel Bridge, economical production of high tensile steels and high strength concrete, have led to the development of the well-known methods of free cantilevering, suspended cantilevering and cable-stayed construction as well as incremental launching and construction on various systems using launching girders. In all these applications, the main construction activities are concentrated in relatively confined working stations, with operations reduced to standardised and repetitive procedures.

Arch Bridges with Spans greater than 200 m

Bloukrans Bridge

The Bloukrans Bridge in South Africa was constructed from 1980 to 1983. With an arch span of 272 m, the bridge had to cross a 216 m deep gorge at the Garden Route between Cape Town and Port Elizabeth. The arch was constructed simultaneously from both banks in stages of approximately 6 m segments, using the suspended cantilevering system with temporary suspension and tie-back cables.

Temporary works, Bloukrans Bridge

The picture shows one half of the arch during construction with the temporary stays, the temporary pylon above the arch springing column, the tie-back cables as well as the carriage at the tip of the arch. A total of two times 30 elements had to be cast within a period of one year.

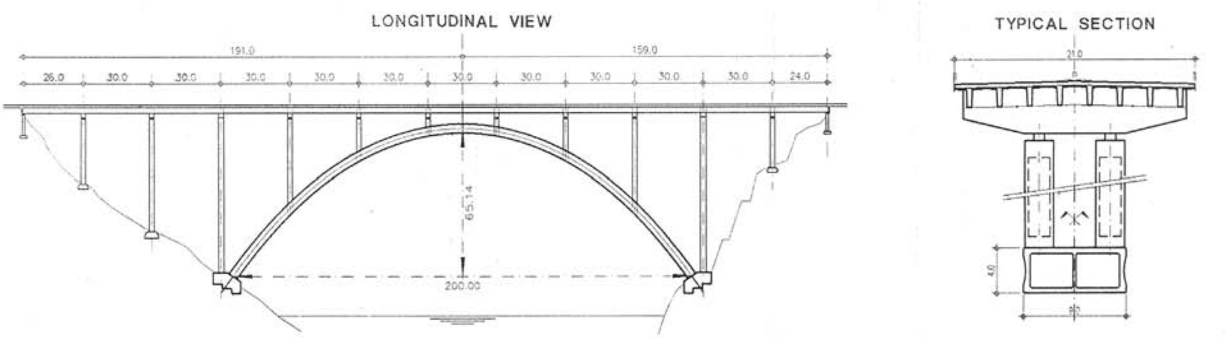
It is to be noted that the temporary stays have been spaced at a remarkable distance with every fourth segment suspended at the arch springing and every third segment towards the arch crown. This arrangement was possible due to the considerable bending resistance of the arch and the provisions of sufficient space in the four webs of the three-cell box section for the anchorages of the locally concentrated suspension cables.

Maslenica Bridge

Construction method and concept of arch carriages for the Maslenica Bridge in Croatia, which was built some 15 years later, are provided similar to the Bloukrans Bridge and now reported in more detail.

Project description

The new open spandrel arch bridge across the Maslenica in Croatia was constructed from 1993 to 1996. The bridge has a total length of 380 m. The arch with a span of 200 m and a rise of 65.14 m is constructed step by



Maslenica-Bridge, Croatia

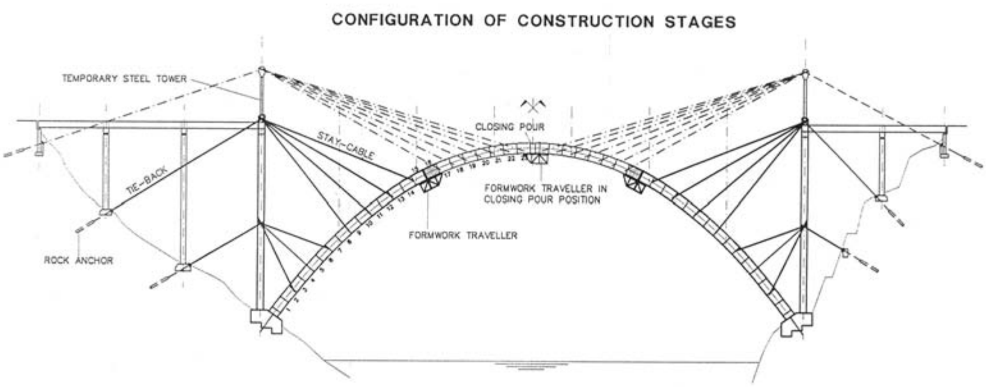
step from both banks by the suspended cantilevering method. The double cell cross section of the arch has a constant width of 9.00 m and a constant depth of 4.00 m.
Transverse vertical diaphragms are provided at the base of the spandrel columns to distribute the local forces into the webs. The deck structure is supported by 11 twin columns spaced at 30 m. The deck consists of prefabricated, prestressed T-beams (eight per span) with a cast in situ deck slab on top. In order to get a continuous superstructure the diaphragms at the column locations are cast together with the deck slab.

Arch construction

The arch is constructed from both banks simultaneously in stages of 5.25 m using temporary stay- and tie-back cables. The two columns situated over the arch springings serve as pylons during construction which transfer the vertical forces in the tie back and suspension cables down to the arch foundations. The twin piers above the arch springings serve temporarily to transfer the vertical components of the stay and backstay cables into the foundation.
Care must be taken that the horizontal components are in equilibrium in order to minimise the bending moments in the piers. In order to get sufficient height for the anchorage of the last seven suspension cables, a temporary pendulum tower in steel has been mounted on top of the columns. In order to minimise the bending moments in the arch and at the same time to ensure that the required final arch profile is achieved, the suspension and tie-back cables had to be precisely adjusted at each construction stage.
The construction of the arch started immediately after having completed the arch springing structure and the corresponding columns with the installation and assembly of the form carriers.

The closing pour

After completion of the two halves of the arch, a closure gap of 2 m remains. One of the two formwork travellers is dismantled and the other moved forward to cast the closure segment. In order to avoid movements due to temperature variations, wind and increasing dead load, the closure gap is blocked prior to casting. First the arch is pre-compressed by means of two hydraulic jacks which are placed at the center of the outer webs in the closure gap. Six steel struts are then installed in the gap. Finally the jacks are released and removed, thus transferring the compression force into the six steel struts. Once the arch is blocked, it becomes very sensitive to temperature variations. As soon as the concrete gains strength the suspension cables and tie-backs are removed in steps keeping the opposing forces in balance.



Maslenica Bridge, Temporary works

Arch bridges with span less than 200 m

The free cantilevering construction method is not limited to big arches but is also competitive for arches with spans around 100 m as the two following projects show.

Bridge over the Crotta Valley in Switzerland

The bridge over the Crotta Valley in the southern part of Switzerland was constructed in the years 1985 and 1986. The quite slender twin arch

Arch of Val Crotta-Bridge during construction

with a span of 90 m was erected by the suspended cantilever construction method.

The two arches had the concrete dimensions of 1.00 x 1.80 (1.30) m each and have been connected to a vierendeel truss by prefabricated beams at the column positions to achieve the required stiffness in transversal direction. The arches have been built in two times eight stages with a length of about 6 m each, leaving a short closure gap at the crown. The first seven segments on each side were suspended by temporary stay cables, while the top elements cantilevered. The formwork carriages with an overall weight of about 15 tons each, including formwork, have been designed and constructed for the specific requirements of this bridge. Both concrete struts have been poured simultaneously and the carriage moved forward as a whole by means of come alongs. Construction procedure and stressing programme of the suspension cables are similar to the procedure as described for Maslenica Bridge.

Third railway bridge across the Godavari River in India

Project description

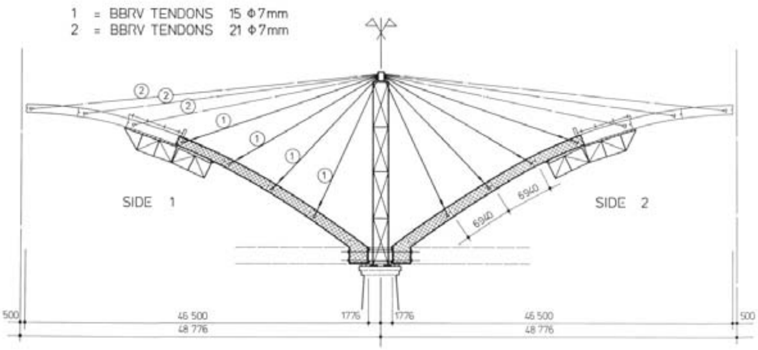
The third Godavari Railway Bridge in India was constructed from 1993 to 1996. The new crossing replaces the more than 90 year old steel bridge which crosses the Godavari River near Rajahmundry close to the east coast. The superstructure with a total length of 2,731 m has 28 identical spans of 97.55 m. The simply supported bowstring girders consist of a slender twin concrete arch tied at the bottom by a stiff centrically prestressed box girder which is continuously suspended to the arch by twelve pairs of hanger cables.

Arch construction

The twin concrete arches are erected by the balanced suspended cantilever construction method using temporary stay cables which are fixed to a temporary steel tower erected on top of the pier. First the starting elements of two adjacent arches are cast on top of the previously placed pot bearings using temporary steel frames which are clamped to the pier by means of high tensile steel rods. After removing the shutters two intermediate steel frames are placed between the starting elements, which are then stressed together by means of four temporary cables, thus allowing the supporting steel frames to be released and moved forward to the next pier.

The two starting elements, now resting as one self-carrying unit on the four final bearings are tied down to the pier by means of two vertical tendons. These tie-downs are coupled to the fixation cables embedded in the pier cap and anchored at the top of the intermediate steel frames. They provide the required resistance against unbalanced moments during the arch construction. The temporary tower is erected on top of the starting elements. Four reusable tendons passing through recess pipes on the end diaphragms ensure a rigid fixation of the tower to the starting elements. The half arches on both sides are then cast symmetrically in seven counter-balancing stages by means of two formwork travellers one on each side. The segments of 6.94 m length are consecutively secured by temporary stay cables, which are coupled to the fixation cables embedded in the segments and anchored on the top of the tower. Throughout the arch construction the

Godavari Bridge during construction



verticality of the tower is checked to ensure that both arches are exactly in balance. After the completion of the seven segments on both sides the formwork travellers are dismantled and moved to the next location.

Arch closure

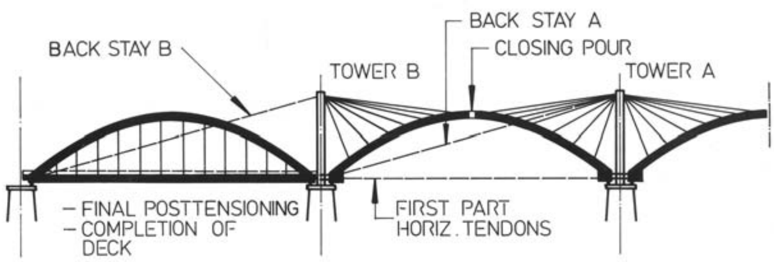
The closure of the arch was the most delicate construction phase of this project. In order to release the suspension cables, a rather complicated stressing programme has to be followed to ensure that the opposing forces are kept in balance at each step. First the gap is blocked by means of four steel struts and precompressed, unlike for the Maslenica Bridge, by partly releasing the four longest suspension cables. At the same time four of the total sixteen tie-girder tendons have to be installed and slightly stressed to counteract the developing horizontal arch thrust. Before the suspension cables are released, two back stay cables are fixed on top of the tower in front (tower A) and anchored through the deck slab to the end diaphragm of the starting element at the base of tower B. These back stays keep the half arch in the next span (waiting for the next closing pour) in balance while the suspension cables are released. The suspension cables are released in steps. At each stage the opposing forces at the top of the two towers are kept in balance by releasing the rear (backstay B) and stressing the front back stay cables (backstay A) accordingly. At the same time the tie-girder tendons in the previous span have to be stressed to a higher force in the backstay B. After all suspension cables are released tower B is free and can be shifted to the next location.

Tie-girder construction

After the completion of the arch the twelve pairs of hanger cables are installed. At the bottom ends short temporary extension cables are mounted to allow the suspension of the tie-girder formwork, which consists of five intermediate and two end elements. They have to be installed in such a sequence that the arch is loaded symmetrically. Prior to the installation the four already placed tie-girder tendons are stressed to a higher force to balance the increasing horizontal arch thrust. Once the formwork is erected the remaining twelve longitudinal tendons are installed and the reinforcement put in place. First the webs and the bottom slab of the box section are cast in symmetrical stages over the full span leaving a shrinkage gap at both ends. Before each concreting stage in the tie-girder tendons are stressed higher to balance the growing dead load. The same procedure is used for the casting of the deck slab. After the pouring of the two shrinkage gaps, all sixteen longitudinal cables are stressed to the full force, inducing a residual compression force of about 3,000 tons in the tie-girder.

Conclusions

The experience gained shows that the erection of arches using the cantilevering construction method does not pose any particular problems during the execution, as long as all the single construction stages are carefully planned and computed in detail. The theoretical predictions for the behaviour of the arch during construction coincide very closely with the measurements on site.
The suspended cantilevering construction method may look sophisticated but essentially does not represent particular difficulties to a contractor.



Configuration at arch closure

For the design of the construction stages it is important that the engineer is familiar with the proceedings on site. The preparation of a detailed construction manual containing step by step descriptions of each single stage leads to a successful application of the free cantilevering construction of the arches.

Lengthy issues

As engineers design bridges with longer and longer spans, demands on expansion joints are getting correspondingly higher

Author: Gianni Moor, Mageba

The behaviour of large scale bridges is quite different from that of standard structures. Normally, a bridge moves constantly in a steady and predictable manner under influences such as temperature, traffic loads and winds. However, with large scale bridges, their movement characteristic becomes more complex and more intense. Cable-stayed and suspension bridges in particular, where expansion joints may only be positioned at the ends of the span, need joints that can cope with extraordinarily large longitudinal movements. For instance, today's suspension bridges have longitudinal movement requirements already exceeding two metres.

It is not only the large longitudinal movement capacity that is necessary, but also the daily, monthly and yearly movement frequency that demands high performance solutions from expansion joint manufacturers.

For example, changes in the solar radiation intensity have a strong influence on the movement frequency of the bridge. For instance, if the sun is covered by a cloud, the large scale bridge, usually made out of steel, immediately cools down due to the reduced solar radiation intensity, and contracts, although the ambient temperature has not changed yet. A few minutes later, when the cloud moves and the sky has opened again, the sun's radiation immediately warms the steel structure again and the bridge expands back to its original length. This kind of movement may quite easily take place a hundred times a day. Assuming a daily movement range of 300 mm as well as many micro movements due to solar radiation variations, variable traffic load influences, and wind loads, and taking into account an expansion joint's expected life of 40 years, this would result in a total movement requirement of several hundred kilometres; far higher than the generally applied durability test requirements of 5 km to 20 km.

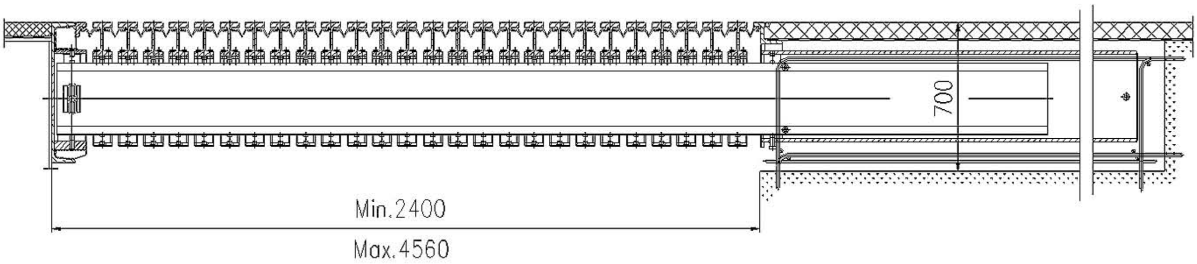
Such ever-increasing wear and tear requirements mean that continuous development and testing of its individual components is necessary in order to guarantee an optimal performance during an expansion joint's lifetime.

The final requirement, in order to protect the inside of the superstructure from dirt, polluted water and dangerous liquids – for instance petrol from a traffic accident – expansion joints must be made watertight at the bridge surface and not just be covered with a drainage channel underneath the expansion joints.

The Runyang suspension bridge will be the third largest in the world (Iain Masteron)

Apart from tailor-made designs, today there are basically only three different expansion joint types on the market that allow longitudinal movements of greater than 1 m.

The supported cantilever finger-type joint is a development of the finger joint. Normally cantilever finger joints have a maximum movement capacity of about 400mm. But by supporting the cantilevered fingers with auxiliary devices from below, very large movement capacities can be achieved. However, this joint has three main disadvantages. No transverse movements of the bridges can be tolerated, otherwise the fingers would immediately touch each other and large con-



Schematic of a modular expansion joint

straining forces would result. No vertical movements are acceptable either, as the fingers would stick up into the carriageway and would be dangerous to traffic. Finally, the connection between the finger plates and the support is usually built as a hinged steel connection that under dynamic load impacts is very sensitive and can become a big source of problems, as past records show.
Roller shutter joints were introduced in the 1930s and over the course of several decades were installed in numerous bridges requiring high longitudinal movement capacity. Over the last twenty years, however, this type of joint has almost disappeared from the market as it has disadvantages such as limited movement capabilities – only possible in one direction – extremely high initial cost, the fact that it generates high noise levels, has limited adaptability to the bridge geometry and of course its lack of watertightness.
Watertight modular expansion joints, first introduced in the 1970s have been continuously developed since then. Today, several types are available on the market, but their capabilities differ greatly. The fourth generation is the latest development of modular expansion joints, differing completely from the original design.
They have an extended lifetime, and constraint forces can almost be eliminated, thanks to the expansion joint's elastic steering and damping system. Such joints can be designed with movement capacities over 2m in the longitudinal direction and +/–500mm in the transverse direction. The movement system is durable: with the introduction of sliding and elastomeric elements the system's resistance to fatigue and wear and tear has been increased considerably.
Installation is easier – due to the minimal space required beneath the support bar, the placement of reinforcement becomes very easy and the danger of concrete air pockets creating heave beneath the support bars can be practically eliminated.
As the system has a single support bar, the space below the lamellas is easy to access for inspection and maintenance activities.
Engineers on what will be the world's third largest suspension bridge, part of the Runyang Bridge had a tough challenge to decide what type of expansion joint to use. The requirements are enormous: the joint needs to be able to accommodate a movement capacity of 2160 mm – a record-breaker.
After a comprehensive evaluation process, the client awarded the contract to Mageba, to supply fourth generation modular expansion joints not only to the 2.5km-long Bei Cha suspension bridge but also to the 1.4km-long Nan Cha cable-stayed bridge.
The contract was signed in August last year, and by last month, the first batch of expansion joints left Mageba's workshop and is currently on its way to China. They have a longitudinal movement capacity of 800mm, and are expected to be installed on the cable-stayed bridge by the end of this year.
Meanwhile the design for the largest modular expansion joints ever built, with 27 gaps totalling an overall longitudinal movement capacity of 2160mm, is in progress. Manufacturing of these units will start around July and the shipment of individual parts is due to take place in November.

Underside of one of the expansion joints for the smaller cable-stayed bridge

Unloading of the expansion joint

Due to its large size, the expansion joint must be assembled in situ, a process that has already been carried out successfully on other projects, such as the Tsing Ma Bridge in Hong Kong. However, assembly on site will take several months and will require precise workmanship, bearing in mind that each joint is composed of more than 40t of special steel and material components.
An expert team from Switzerland will to supervise the complete assembly process on site in order to guarantee that the final product achieves the highest possible quality standards.
With the official Italian announcement to go ahead with the world's largest suspension bridge with a main span of 3000m, connecting southern Italy with Sicily across the Messina Straight, there will be new challenges for expansion joint manufacturers.
It is very likely that also for this bridge a modular expansion joint will be chosen as it best can fulfil the requirements in terms of movement capacity, durability and watertightness and moreover will guarantee to function properly under extreme conditions for a life time of 40 years and more.

Design of BBR Post-Tensioned slabs based on the Eurocodes

Author: Luigi Giannattasio, Dreibau Ingenieur Conseils

Background

The widespread use of post-tensioned slabs, so common in the American and Asian region, has not been reflected in the past in European countries. Some exceptions were special buildings (long spans, unusual construction constraints and schedules, where PT was the last option) or the Nordic countries, where beam/slab parking structures are commonly post-tensioned.
The economy of the solution was not the issue, for countries with such a high labor/material ratio PT should be much cheaper than RC. Mainly, some restrictions in the design codes, and design directives were distorting the economics equation for PT-slabs.

The Eurocode

In the last years, with the progressive implementation of Eurocodes and their full validity after 2005, this equation will change. As now the potential market with one Code is huge, justifying the implementation of some design tools and procedures, which makes optimized PT-slab, as competitive as in the USA.

One of the main differences between the European and American/Asian markets is the high impact of the architect on the design, for which the plans in Europe are not regular, with complex shapes and non-regular column patterns. This makes the use of the simple Equivalent Frame Analysis software, so common in USA / Asia, very delicate and time-consuming to use. Finite Element software is thus mandatory, with some high-production tools now available. Still, a quick pre-design of PT-forces for complex slab is very cumbersome with the brute FE model. Special mix procedures, EFA-FEA have been developed to produce very fast and accurate designs. The bid stage is critical to get the job, as PT is still regarded as a «long-shot» construction option.

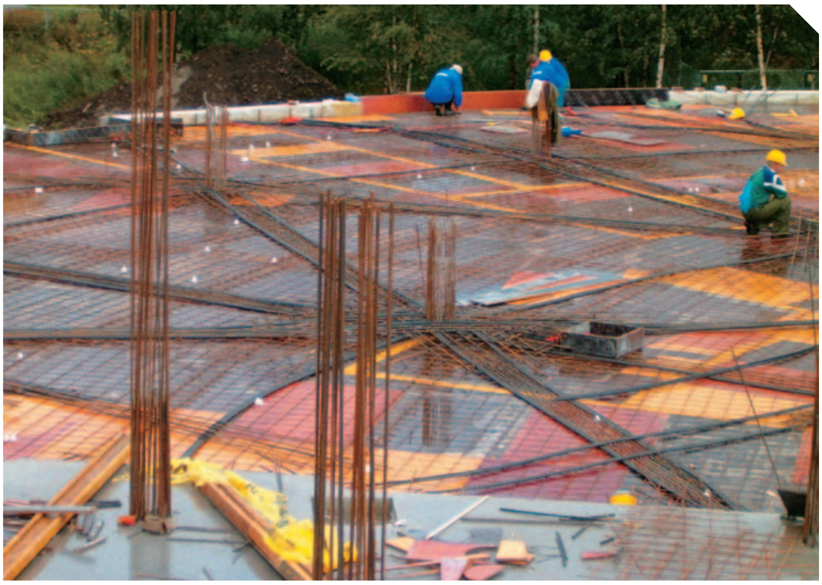
Common to the ACI/PTI design directives are «fork» values of some design parameters (like equivalent tensile stresses, mean PT, etc) which guide the designer towards a «functional» (and economic) structure. The Eurocode approach is different and more complex, but very flexible and its perfectly possible to relate the ACI/PTI parameter to a set of equivalent EC quantities, like crack width, etc. The implementation of many of the PTI detailing and design rules, even if not required by EC-2, will make sure that the slab will behave perfectly.

Critical to arrive to an economic EC design is to enter the design procedure at the right point and to have a detailed knowledge of the code assumptions, as many of the simpler and common design rules do not apply for PT-slabs, especially unbonded ones. For example, the standard method for crack-width calculation will require higher rebar areas, and it pays to use sophisticated non-linear methods to justify the minimum rebar requirements and Service Limit State checks.
Very common in some countries (Spain, etc.) is to dimension the PT force to provide full SLS control and crack-width check, based on simplified formulas (getting a very high PT content) and then to install all minimal rebar areas, as for a RC slab. What's good for a bridge is not for two-way slabs with much lower pre-compression and higher slenderness. Those designs are non-economic and cannot compete against good RC projects.

Design aspects

The design should be oriented to maximize site efficiency for the indirect cost (less labor, formwork systems, cycle redundancy, etc) and accounts for almost 60 % of the savings. The use of the «free tendon layout» concept, with very few control points and less saddles, is mandatory. This also forces the software to be able to model explicitly complex tendon shapes, not just parabolas.

Multi-parameter optimization techniques are good tools to use in order to arrive at a fast economic pre-design, even more if cost parameters are introduced in the model. Some simple ratios like labor/concrete, rebar/concrete, rebar/PT are enough to optimize thickness/structural system/PT-rebar ratio choice. Further optimization is made with more conventional structural tools.



Recent references

The applications of those directives made possible to build competitive BBR PT slab structures in Europe in the last year, like Igualada Hospital

(29,000 m²) in Barcelona, with BBR PTE, the new Brnik Airport Parking (28,000 m²) in Ljubljana, with BBR Conex, as well as some other 200,000 m² of slabs in the Baltic Countries, Italy and UK.

Conclusions

The general use of the Eurocode after 2005 will make the BBR post-tensioned slab a very competitive alternative to both reinforced concrete and composite/steel structures, not only for parking and office buildings, but also for residential buildings. In addition, some production techniques, like prefabrication of tendons, extrusion of the plastic-coated strand, special encapsulated anchors and the availability of both 0.62" and 0.5" tendons will further expand the scope of this solution.

Some special design rules, as well as clear cost directives in the design parameters must be applied in order to make sure that the design fulfils both economic and structural requirements.

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