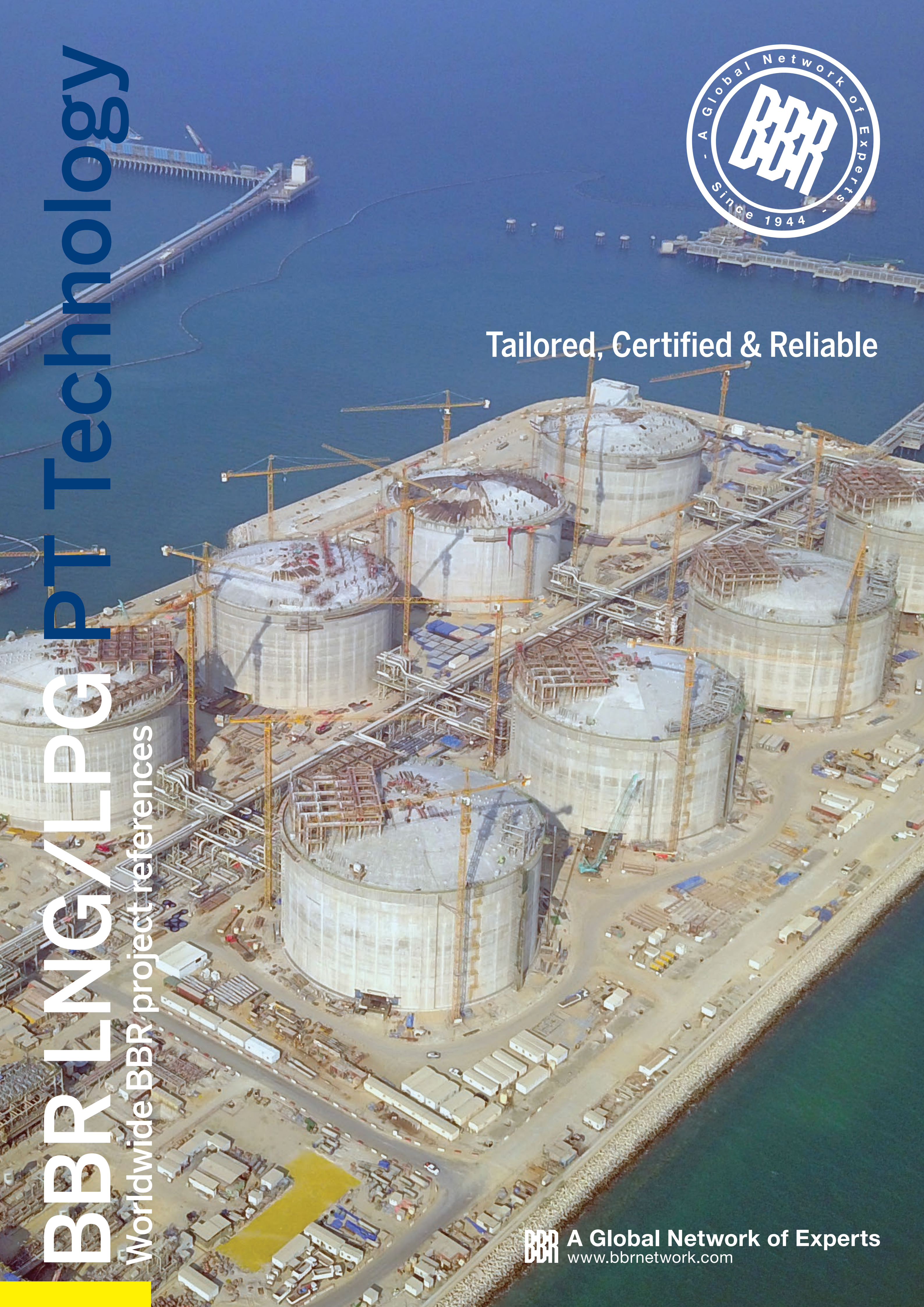
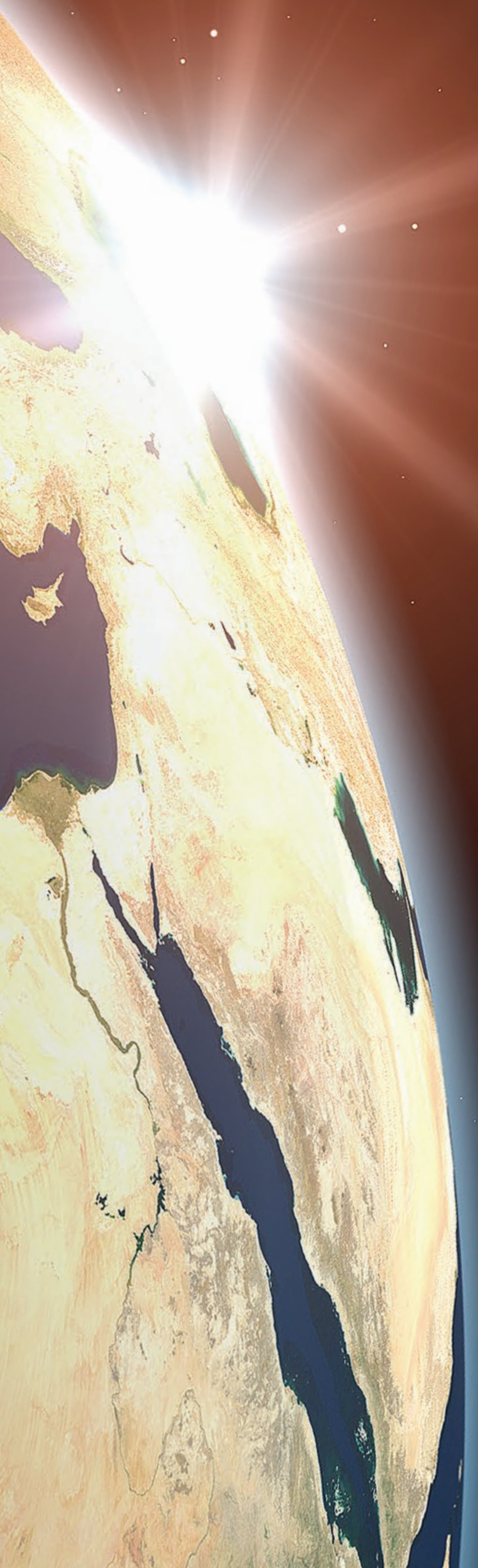


# BBR LNG/LPG PT Technology

Worldwide BBR project references

Tailored, Certified & Reliable

A Global Network of Experts
www.bbrnetwork.com



# A Global Network of Experts

www.bbrnetwork.com

The BBR Network is recognized as the leading group of specialized engineering contractors in the field of post-tensioning, stay cable and related construction engineering. The innovation and technical excellence, brought together in 1944 by its three Swiss founders – Antonio Brandestini, Max Birkenmaier and Mirko Robin Roš – continues, almost 80 years later, in that same ethos and enterprising style. From its Technical Headquarters and Business Development Centre in Switzerland, the BBR Network reaches out around the globe and has at its disposal some of the most talented engineers and technicians, as well as the very latest internationally approved technology.

## THE GLOBAL BBR NETWORK

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

## ACTIVITIES OF THE NETWORK

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

## BBR TECHNOLOGIES & BRANDS

BBR technologies have been applied to a vast array of different structures – such as bridges, buildings, cryogenic LNG tanks, dams, marine structures, nuclear power stations, retaining walls, tanks, silos, towers, tunnels, wastewater treatment plants, water reservoirs and wind farms. The BBR™ brands and trademarks – CONA®, BBRV®, HiAm®, HiEx, DINA®, SWIF®, BBR E-Trace and CONNÆCT® – are recognized worldwide. The BBR Network has a track record of excellence and innovative approaches – with thousands of structures built using BBR technologies. While BBR's history goes back nearly 80 years, the BBR Network is focused on constructing the future – with professionalism, innovation and the very latest technology.

BBR VT International Ltd is the Technical Headquarters and Business Development Centre of the BBR Network located in Switzerland. The shareholders of BBR VT International Ltd are BBR Holding Ltd (Switzerland), a subsidiary of the Tectus Group (Switzerland) and KB Spennteknikk AS (Norway), a subsidiary of the KB Group (Norway).

# Innovation
# Excellence
# Experience

**The BBR experience in design and application of post-tensioning technologies extends back over eight decades. The technology has been successfully applied to many projects with specific requirements and conditions, none more stringent and extreme than those encountered within the LNG/LPG industry.**

Globally, BBR has been involved in over 4.5 million cubic meters of post-tensioned LNG/LPG storage amounting to 60+ tanks in 10 different countries.

Our Swiss roots are deeply embedded in technological development and, through the years, our engineers have constantly strived to produce the most advanced products and technology.

Today, this combines with a strong international network – the BBR Network of Experts – who first listen, then advise and deliver best-in-class solutions to customers around the globe.

Front cover: Al Zour LNG Import Terminal Tanks, Kuwait

2001 – ADNOC Barouge LNG Tank, United Arab Emirates

2006 – Darwin LNG, Australia

2007 – South Hook LNG Tank, United Kingdom

2008 – 4th LNG Tank Cartagena, Spain

2012 – Ruwais Train LPG Storage, Abu Dhabi

# Tailored

LNG is a natural gas that has been condensed to a liquid for ease of storage and transport. The phase change is achieved by cooling the gas to below -162 °C, below the gas's boiling point. Under these conditions, minimal permeability and structural resilience are critical; which makes post-tensioned concrete tanks ideally suited as a structural system and 'secondary containment' skin.

Post-tensioning increases structural resilience while allowing reduced wall thickness, and reducing crack widths. Minimal permeability and high levels of corrosion protection are also required for all LNG/LPG structures; the post-tensioning system must therefore be designed and installed under strict quality controls, with materials and processes meeting specific certification and performance requirements.

BBR is used to operating in such environments with its long history in the Nuclear and Oil & Gas industries, where unique and tailored solutions are required to meet strict client, regulatory and construction demands.

# Unique

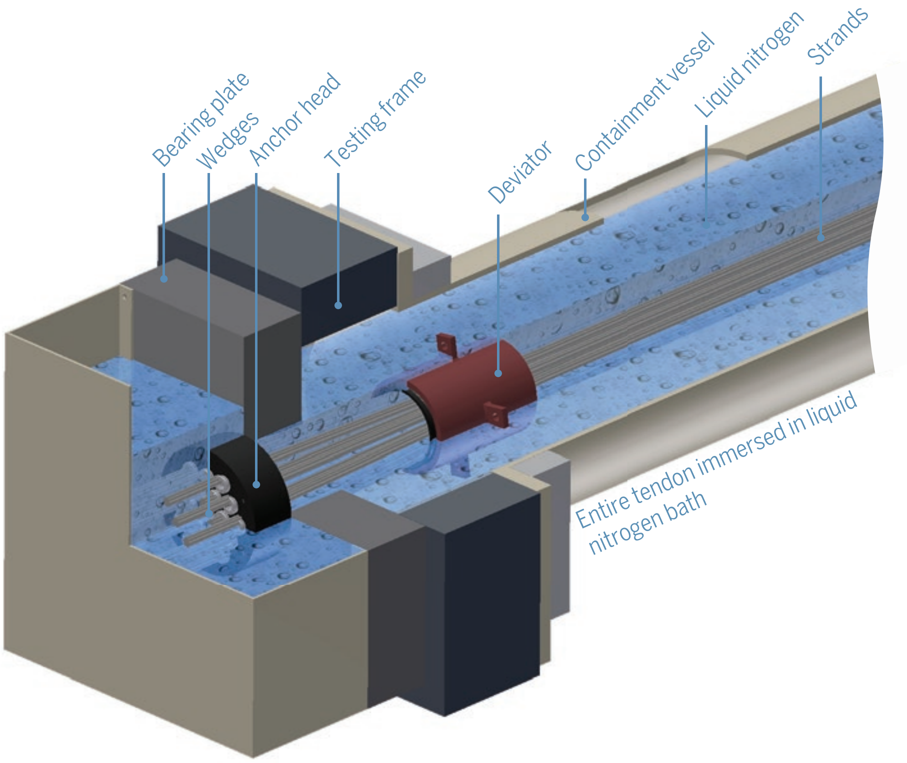
Design and construction of each LNG/LPG tank is unique, but large above ground storage facilities almost exclusively use post-tensioned concrete as the basis of their structures. The post-tensioning systems are generally run both horizontally and vertically to meet the requirements of the design.

Construction methodologies play a decisive role in the success of an LNG/LPG tank project. Processes such as slip forming are specialised, but have significant benefits. Climbing in-situ concrete formwork integrated with scaffolding can be used to save construction time and cost as well as improving the safety and quality of the workers. BBR has streamlined its supply and installation activities to meet the specific requirements of such systems, to the benefit of many satisfied clients.

# Certified

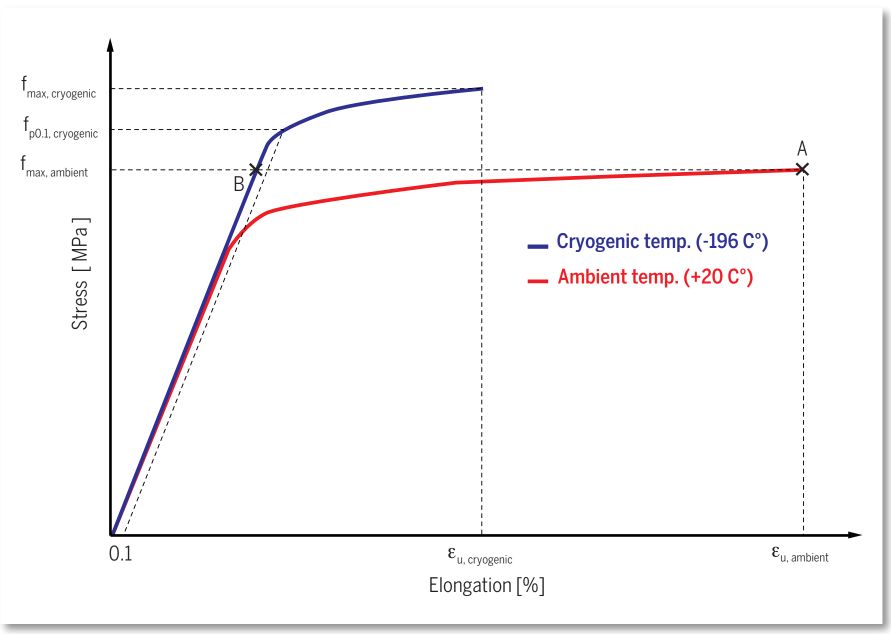
The European Organisation for Technical Approvals has set the benchmark for post-tensioning products operating in cryogenic conditions. As expected, BBR has met and exceeded every requirement.

The Guideline for European Technical Approval, ETAG 013, outlines supplementary requirements which apply to PT systems for certain optional use categories, for instance in cryogenic applications. The cryogenic test setup with only one anchorage cooled down to the cryogenic temperature is commonly used to verify the performance of PT systems for cryogenic applications. However, this setup cannot examine the ductility of post-tensioning systems under cryogenic conditions. When only one anchorage is immersed into a liquid nitrogen bath, the tensile elements (strands) at both ends of the test specimen will be at two different thermal conditions. Part of the tendon near the immersed anchorage is subjected to the cryogenic temperature (-196 °C) and the rest of the tendon, which is fairly far from the cooling zone, is almost under ambient temperature (+20 °C). As known, prestressing steel experiences strengthening behavior when subjected to cryogenic temperature (see graph).




Thereby, the ultimate failure is always occurring at the tendon side under ambient temperature (see point A on graph), while at this load level the tendon part, which is immersed into the liquid nitrogen bath, is still in the linear elastic zone (see point B).

This means that the obtained ultimate failure force ($f_{max,ambient}$) is never reaching the yield point of the strand subjected to the cryogenic temperature ($f_{p0.1,cryogenic}$). The outcome of this test setup does not verify the ductile performance of a PT system under cryogenic conditions.




The BBR R&D department has carried out static testing of single and multi strand tendons in which the entire tendon, including both anchorages, is completely subjected to cryogenic conditions. BBR has further carried out a load transfer test under full cryogenic conditions. These tests are able to examine the ductility and load transfer efficiency of the system under these extreme conditions. The successful test results verify the ductility performance of the BBR VT CONA CMI post-tensioning system with normal grade anti-bursting reinforcement and prove that it is in full compliance with the ETAG 013 testing regime under both temporary and permanent cryogenic conditions without any need of using costly low temperature grade reinforcement and thus bringing significant material cost saving.

# Reliable

Testing and development of BBR's product range is not the end of the story, a huge amount of resource goes into developing our people too.

A culture of continuous education within the BBR Network ensures high quality execution of all of our projects at every level. Our personnel have access to a huge depth of knowledge throughout the BBR Network, where practical and theoretical training courses are run throughout the world. At the end of each training course the attendees undergo an examination which is fully documented.


# Solid

The capability of personnel is always important to the success of a post-tensioning project, but it is critical in the world of natural gas. Grouting is a process which is synonymous with internal post-tensioning and the quality of the end product is dependent on the skills and attention to detail of the applicators and technicians.

BBR's thixotropic grout mixtures are homogeneous mixtures of cement, water and admixtures. The mixtures and procedures used by all BBR PT Specialists fulfil the latest European Standards and are certified by an Independent Notified Body.

To guarantee the highest level of quality, BBR Network Members employ qualified and trained personnel in grouting. These expertise, coupled with leading equipment and the best materials leads to over 70 years of successful projects, as well as a huge bank of knowledge throughout the BBR Network.

# CONA CMI for Cryogenic Applications

Development and certification is a day to day activity at BBR which goes hand in hand with a culture of innovation through continuous improvement of our products, systems and quality assurance.

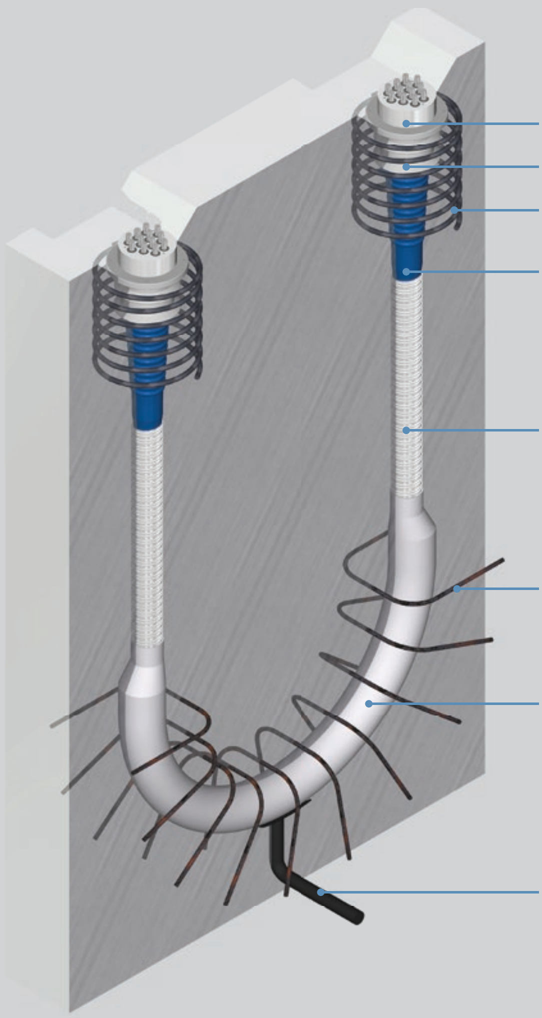
Design and construction of large LNG/LPG tanks which are often near 90m in diameter and 50m in height involves significant design loads and often congested and unique detailing. The CONA CMI system has been continuously improved over the last years to meet such requirements, which is why it is the best choice for LNG/LPG projects. The unique BBR VT CONA CMI post-tensioning kit is a multi strand system with sizes available from 1 to 73 seven-wire pre-stressing strands.

End anchorage of the tendons is available as either a standard square bearing plate, the CONA CMI SP anchorage, or via the proprietary CONA CMI BT Bearing Trumplate. The CONA CMI BT anchorage is available for sizes from 2 to 73 strands; it makes use of a three plane load transfer, which significantly reduces the peak bursting stresses, allowing for reduced tendon centre spacing and concrete edge distance as well as very low minimum concrete strengths at transfer.

Vertical post-tensioning can be achieved through single tendons starting at the top of the tank and terminating in a socket at the base, or more commonly through the use of the BBR Loop Tendon detail.
BBR Loop Tendons have been developed for use in the LNG industry as an alternative to straight tendons as a result of experience from a number of projects where reinforcing congestion was a challenge.

## BBR Loop Tendon PT Technology

Loop tendons are often used when there is no access to the dead end – for example for vertical post-tensioning in tanks and silos. In this scenario, the straight part of the tendon is inside the concrete wall and the loop is in the base of the tank. Whilst termination of PT strands at the base of a tank is not impossible, the reinforcing steel is usually already congested in this area and therefore adding a PT strand termination here can be problematic. Use of the BBR Loop Tendon system reduces congestion at the base of the tank and allows anchorage and stressing detailing to be minimized to the top of the tank. Minimum radii of curvatures of up to 0.7m are achievable, which is considerably less than the minimum bending radius of a normal prestressing strand. Due to the reduced radius of curvature, the contact pressure between the strands and the duct becomes very high, $p_{R,max} > 800$ kN/m. For the straight part of the tendon, corrugated steel or plastic ducts can be used, whereas a smooth steel duct is selected for the curved portion in order to dissipate the high contact pressures. For ease of installation, the degree of filling chosen for the curved part of the tendon should be very low. Please contact your nearest BBR representative to find out more.

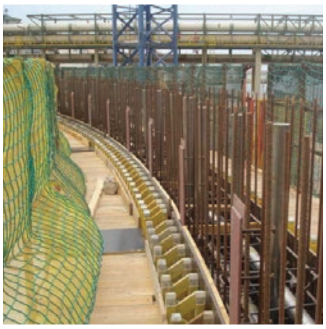


| # | Year | **Name** | Region | Capacity [ m³ ] | Tank Dia. [ m ] | Tank Height [ m ] |
|---|---|---|---|---|---|---|
| 69 | 2018 | **Al Zour LNG Import Terminal Tank 8** | Middle East | 225,000 | 96 | 45 |
| 68 | 2018 | **Al Zour LNG Import Terminal Tank 7** | Middle East | 225,000 | 96 | 45 |
| 67 | 2018 | **Al Zour LNG Import Terminal Tank 6** | Middle East | 225,000 | 96 | 45 |
| 66 | 2018 | **Al Zour LNG Import Terminal Tank 5** | Middle East | 225,000 | 96 | 45 |
| 65 | 2018 | **Al Zour LNG Import Terminal Tank 4** | Middle East | 225,000 | 96 | 45 |
| 64 | 2018 | **Al Zour LNG Import Terminal Tank 3** | Middle East | 225,000 | 96 | 45 |
| 63 | 2018 | **Al Zour LNG Import Terminal Tank 2** | Middle East | 225,000 | 96 | 45 |
| 62 | 2018 | **Al Zour LNG Import Terminal Tank 1** | Middle East | 225,000 | 96 | 45 |
| 61 | 2016 | **Ethane Tank, Stenungsund** | Europe | 50,000 | 59 | 26 |
| 60 | 2016 | **LNG Tank Pori** | Europe | 30,000 | 42 | 35 |
| 59 | 2014 | **Rafnes Ethane Tank** | Europe | 30,000 | 45 | 32 |
| 58 | 2013 | **Barouge 3 - Ethylene Storage Tank 1** | Middle East | 21,000 | 34 | 30 |
| 57 | 2013 | **Ruwais Refinery Expansion Tank 3** | Middle East | 50,000 | 52 | 32 |
| 56 | 2013 | **Ruwais Refinery Expansion Tank 2** | Middle East | 50,000 | 52 | 32 |
| 55 | 2013 | **Ruwais Refinery Expansion Tank 1** | Middle East | 50,000 | 52 | 32 |
| 54 | 2012 | **LNG Tanks Gijon Tank 2** | Europe | 150,000 | 80 | 40 |
| 53 | 2012 | **LNG Tanks Gijon Tank 1** | Europe | 150,000 | 80 | 40 |
| 52 | 2012 | **Ruwais Train LPG Storage Tank 6** | Middle East | 75,000 | 67 | 36 |
| 51 | 2012 | **Ruwais Train LPG Storage Tank 5** | Middle East | 75,000 | 67 | 36 |
| 50 | 2012 | **Ruwais Train LPG Storage Tank 4** | Middle East | 75,000 | 67 | 36 |
| 49 | 2012 | **Ruwais Train LPG Storage Tank 3** | Middle East | 75,000 | 67 | 36 |
| 48 | 2012 | **Ruwais Train LPG Storage Tank 2** | Middle East | 75,000 | 67 | 36 |
| 47 | 2012 | **Ruwais Train LPG Storage Tank 1** | Middle East | 75,000 | 67 | 36 |
| 46 | 2011 | **Tank INEOS** | Europe | 57,000 | 49 | 43 |
| 45 | 2010 | **LNG Tank Risavika** | Europe | 30,000 | 49 | 29 |
| 44 | 2010 | **LNG Tanks in Barcelona Tank 8** | Europe | 150,000 | 82 | 50 |
| 43 | 2010 | **LNG Tanks in Barcelona Tank 7** | Europe | 150,000 | 82 | 50 |
| 42 | 2009 | **Barouge 2, Propylene Storage Tank** | Middle East | 23,000 | 38 | 32 |
| 41 | 2009 | **South Hook LNG Tank 5** | Europe | 155,000 | 92 | 35 |
| 40 | 2009 | **South Hook LNG Tank 4** | Europe | 155,000 | 92 | 35 |
| 39 | 2009 | **South Hook LNG Tank 3** | Europe | 155,000 | 92 | 35 |
| 38 | 2008 | **LNG Tank Cartagena** | Europe | 150,000 | 78 | 40 |
| 37 | 2008 | **Gasco LPG Tank 4** | Middle East | 96,000 | 63 | 34 |
| 36 | 2008 | **Gasco LPG Tank 3** | Middle East | 96,000 | 63 | 34 |
| 35 | 2008 | **Gasco LPG Tank 2** | Middle East | 96,000 | 63 | 34 |

| # | Year | Name | Region | Capacity [ m³ ] | Tank Dia. [ m ] | Tank Height [ m ] |
|---|---|---|---|---|---|---|
| 34 | 2008 | **Gasco LPG Tank 1** | Middle East | 96,000 | 63 | 34 |
| 33 | 2007 | **Adriatic LNG Terminal Tank 2** | Europe | 125,000 | 88 | 47 |
| 32 | 2007 | **Adriatic LNG Terminal Tank 1** | Europe | 125,000 | 88 | 47 |
| 31 | 2007 | **South Hook LNG Tank 2** | Europe | 155,000 | 92 | 35 |
| 30 | 2007 | **South Hook LNG Tank 1** | Europe | 155,000 | 92 | 35 |
| 29 | 2006 | **Darwin LNG** | Pacific | 188,000 | 92 | 35 |
| 28 | 2006 | **LNG Tanks in Barcelona Tank 6** | Europe | 150,000 | 82 | 50 |
| 27 | 2004 | **LNG Tanks in Barcelona Tank 5** | Europe | 150,000 | 82 | 50 |
| 26 | 2001 | **ADNOC Barouge LNG Tank 2** | Middle East | 29,000 | 37 | 27 |
| 25 | 2001 | **ADNOC Barouge LNG Tank 1** | Middle East | 29,000 | 37 | 27 |
| 24 | 1997 | **Shell Tank T-0208** | Europe | 10,000 | 25 | 31 |
| 23 | 1996 | **North West Shelf Gas Project Tank 2** | Pacific | 81,000 | 60 | 31 |
| 22 | 1995 | **North West Shelf Gas Project Tank 1** | Pacific | 65,000 | 53 | 32 |
| 21 | 1990 | **Arco Butane Storage Tank** | Europe | 62,000 | 50 | 45 |
| 20 | 1990 | **Low Temperature Tank 6 Kaarstoe** | Europe | 8,000 | 25 | 30 |
| 19 | 1990 | **Low Temperature Tank 5 Kaarstoe** | Europe | 8,000 | 25 | 30 |
| 18 | 1989 | **Du Pont Tank 2** | Europe | 5,500 | 20 | 25 |
| 17 | 1989 | **Du Pont Tank 1** | Europe | 5,500 | 20 | 25 |
| 16 | 1987 | **Kwinana LPG Tank 3** | Pacific | 26,000 | 35 | 30 |
| 15 | 1987 | **Kwinana LPG Tank 2** | Pacific | 26,000 | 35 | 30 |
| 14 | 1986 | **Kwinana LPG Tank 1** | Pacific | 26,000 | 35 | 30 |
| 13 | 1986 | **Du Pont Tank 1** | Europe | 5,500 | 20 | 25 |
| 12 | 1984 | **Low Temperature Tank 4 Kaarstoe** | Europe | 20,000 | 39 | 30 |
| 11 | 1984 | **Low Temperature Tank 3 Kaarstoe** | Europe | 20,000 | 39 | 30 |
| 10 | 1984 | **Low Temperature Tank 2 Kaarstoe** | Europe | 20,000 | 39 | 30 |
| 9 | 1984 | **Low Temperature Tank 1 Kaarstoe** | Europe | 20,000 | 39 | 30 |
| 8 | 1982 | **Oxirane Tank 2** | Europe | 10,500 | 25 | 30 |
| 7 | 1982 | **Oxirane Tank 1** | Europe | 10,500 | 25 | 30 |
| 6 | 1982 | **Botany Bay LPG Tank 2** | Pacific | 19,000 | 34 | 24 |
| 5 | 1982 | **Botany Bay LPG Tank 1** | Pacific | 19,000 | 34 | 24 |
| 4 | 1981 | **Eurogas Terminal Tank 2** | Europe | 62,000 | 50 | 45 |
| 3 | 1981 | **Eurogas Terminal Tank 1** | Europe | 62,000 | 50 | 45 |
| 2 | 1981 | **Dow Chemical Tank 2** | Europe | 62,000 | 50 | 45 |
| 1 | 1981 | **Dow Chemical Tank 1** | Europe | 62,000 | 50 | 45 |

# Our Commitment



Having reached this page, you can certainly be in no doubt as to our commitment to the finest technology and our enthusiasm for delivering our projects.

Our seven decades of experience have resulted in BBR Technology being applied to countless LNG/LPG tanks and, in the process, we have continued to refine and enhance our range.

Technology does not however develop itself – through the years we have been fortunate enough to have attracted some of the best engineers in the business. It is their dedication which has maintained the BBR reputation – and continues to do so today.

Our well established worldwide network is supported in the development of LNG/LPG tanks and structures who will help to specify and procure the systems required. So, local knowledge synchronises with international know-how to realise projects – some large, some smaller, but always technically excellent and fit for purpose!

- A Global Network of Experts - Since 1944

*"Innovation distinguishes between a leader and a follower."*

Steve Jobs

Co-founder & CEO of Apple

1955 – 2011

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