THE BRIDGE FORMULA

INSTITUTE
GIPROSTROYMOST – SAINT PETERSBURG

50th ANNIVERSARY

2018

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Aerial video   3D model   Video

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A bridge is a structure designed to span obstacles. It is a link between riverbanks, cities and people. Bridges create integrity, span gaps and save time.

The design and architectural appearance of any bridge is predetermined by the obstacle it is meant to span.

Joint efforts by road constructors, architects, designers, engineers, project owners and construction workers bring to life a new bridge. Area, climate and landscape specifics are always different; therefore each bridge is truly unique.

Accuracy of engineering analysis is to refine design solutions up to perfection. Once every ounce of metal and concrete is in place, the bridge becomes a beautiful sight.

A bridge is the minimum energy required to span a given obstacle.

THE BRIDGE FORMULA

$$E_B = E_0 + \varepsilon \rightarrow 0$$

where E_B *stands for the "bridge energy"*

E_0 *stands for the "obstacle energy"*

ε *stands for the "spanning energy"*

Institute Giprostroymost – Saint Petersburg

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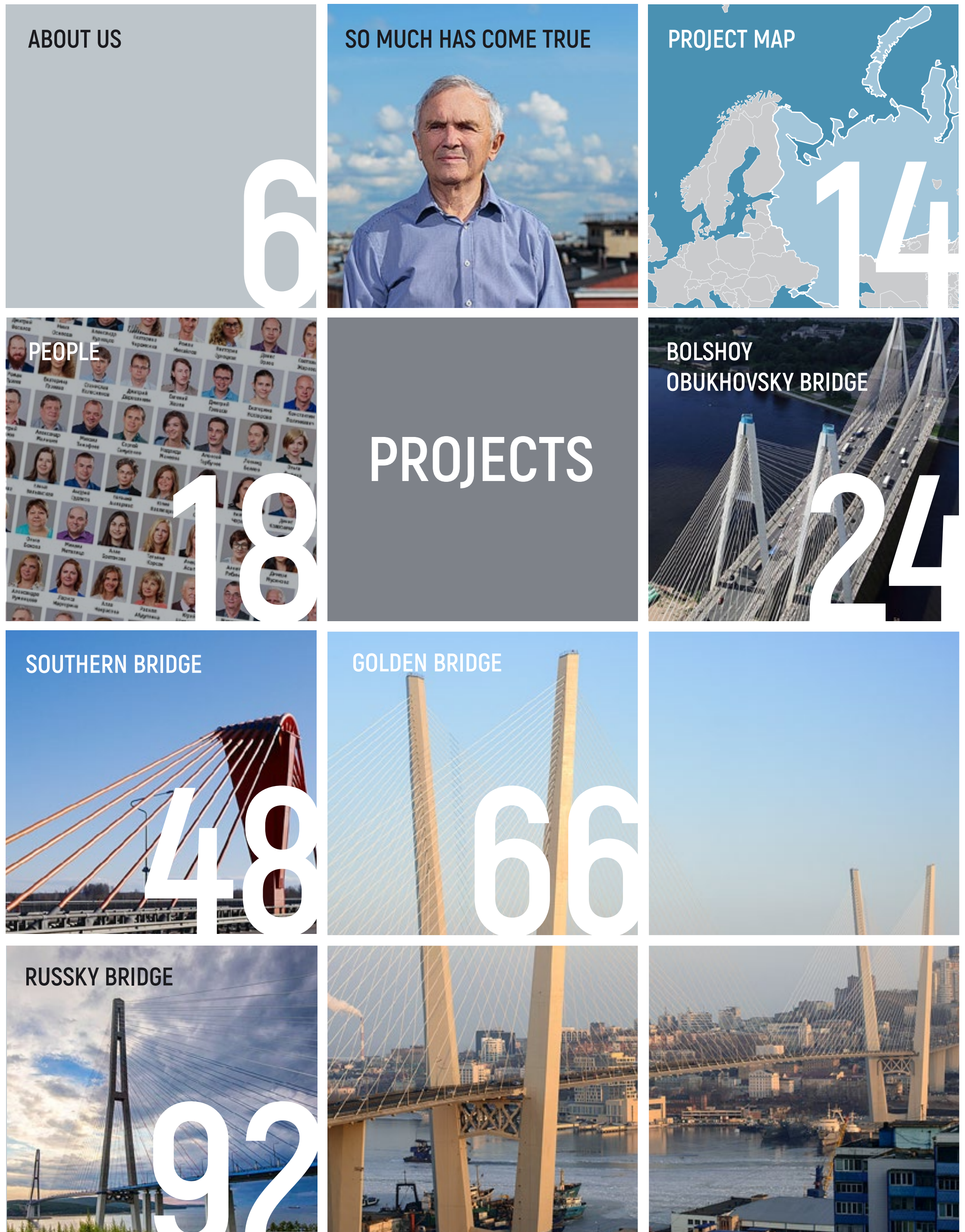

DESIGNING BRIDGES FOR 50 YEARS

Institute Giprostroymost – Saint Petersburg is one of the leading companies in bridge and transport infrastructure design in Russia. The Institute has celebrated its 50th anniversary in 2018. Throughout the years, the Institute team has accumulated a lot of experience that makes them able to overcome the most demanding challenges in designing complex non-standard structures.

DESIGN APPROACH

A rational engineering solution is at the heart of all projects developed and implemented by the Institute. Combining the expertise of both structure and technology developers, the Institute solidified its leading position among its peers in the industry.

Giprostroymost is widely recognized for their ability to resolve complex challenges with a lot of ingenuity involved. For each project, innovative solutions are implemented, which then often become the mainstay of transport infrastructure construction. Such an innovative approach produces truly unique structures that combine cutting-edge technologies, economic effectiveness and distinctive architectural appearance.

HIGH-TECHNOLOGY SOLUTIONS

The Institute relies greatly on fundamental knowledge and modern-day design technologies. The Company uses a wide array of design software for structural analysis and even develops in-house auxiliary software. At the project documentation stage, a special department within the Company also develops a detailed BIM model. 3D models enable all parties to promptly choose optimal solutions for project design and construction.

ENGINEERING SCHOOL

Engineers' qualification is one of the competitive advantages of the Company. In 50 years, a unique design and engineering school was formed in the Institute, with the outstanding specialists in advanced mathematics and structural mechanics at its helm. The scientific approach determines a close cooperation between research and industry institutes, as well as state examination boards. 20 years ago, a special engineering department was formed within the Institute for implementing unique practical and scientific know-how. An important feature of the Company's engineering environment has always been succession and continuity: several generations of engineers work at the Institute.

INTERNATIONAL COOPERATION

The Institute's most significant projects always gain credence among other professionals, and often get into the focus at industrial conferences. The Company is also in line with the latest advances in bridge design and construction across the globe. Engineers of the Institute adopt the European standards alongside effective Russian construction regulations. Igor Kolyushev, Technical Director of the Company, is a member of IABSE, the International Association of Bridge and Structural Engineering. Cooperation with foreign experts and exchanging engineering experience allows the Institute to stay on the forward track.

Yuri Lipkin
Chairman of the Board of Directors, Institute Giprostroymost – Saint Petersburg

SO MUCH HAS COME TRUE

Yuri Lipkin, Honored Construction Worker of the Russian Federation, reminisces on the history of the Institute. Mr. Lipkin was heading the Institute for more than 30 years, from 1975 to 2006, and currently holds the Chairman of the Board of Directors position with the Company.

50 years have passed since November 14, 1968, when a Special Design Bureau of Glavmostostroy was formed in Moscow by a decree of the Ministry for Transport Construction of the USSR. Nikolay Sentyurin, Head of the Design Bureau, then issued an order to develop the Leningrad Department of Glavmostostroy SKB from a small design group. The team was only 18 people strong then, headed by Lev Podoltsev. Seven yearslater, I took over the position and began my work as the head of that department.

It was an arduous yet exciting journey from a small department to aleading design company with 480 people on staff. The Institute participated in the design, construction and reconstruction of a number of bridges in Russia and abroad; several generations of highly qualified specialists were nurtured, new technologies implemented — some of which were a break-through for our country.

THE UNIQUE TUNNEL AND OTHER ACHIEVEMENTS

Fifty years is a proper landmark to take stock of the past accomplishments and set goals for the future. It is difficult to fit decades of designing unique projects into just a few pages. The Institute's accomplishments are best represented by the technologies mastered throughout this time. There were, in fact, a number of unique and technologically challenging projects of which we are very proud.

One of the most significant landmarks in the Institute's history was the design and construction project of the Kanonersky Tunnel in St. Petersburg. For the first time in the Soviet Union, a new technology was implemented in Leningrad: the tunnel was constructed using the technology of immersed tubes. The Kanonersky Tunnel consists of two conventionally excavated approaching sections, and five 75-meter-long submerged blocks.

Due respect has to be given to Vladimir Kostinsky, Raisa Kaliaskarova and many of their colleagues who contributed to this project, having successfully adopted international expertise while constructing the Kanonersky Tunnel. Approximately 20 similar structures were constructed across the globe, including tunnels in Europe, Asia and the USA. Unfortunately, this advanced technology, even with its significant advantages over the usual shield tunneling method, has never been used in our country since then.

The Kanonersky Tunnel in Leningrad (St. Petersburg) constructed using the immersed tubes technology widely used in Western Europe.

One of the greatest achievements of our Institute during that time was the development of bridge section incremental launching technology without the use of temporary piers — using auxiliary truss frames* and launching nose**. One of the first projects was the bridge across the Sukhona River in the city of Totma in the Vologda Region. 100-meter bridge sections were successfully launched without any temporary piers. The man behind this construction method was Igor Brantov, the Chief Engineer of the project.

Another accomplishment of the Institute was the technology for constructing bridge piers in permafrost regions. For the first time is was used for the construction of the bridge on the Obskaya–Bovanenkovo railway line, the northernmost existing railroad in the world. Chief Engineer Sergey Gilburd's contribution to the development of this sophisticated technology cannot be overestimated.

We also have to mention the development of floating support structures to transport extremely heavy metal and reinforced concrete bridge spans both to and from the bridge piers. This technology was used for the construction of the Volodarsky Bridge across the Neva River. For the first time in the entire history of bridge construction in the USSR, reinforced concrete arches weighing 5,000 tons each were floated to their position. One of the visionaries behind this complicated task was Lev Shapiro, who then imparted his engineering expertise on his colleagues and followers.

DIFFICULT TIMES

In 1986, a decision was made by Mikhail Koshelev, Director General of Glavmostostroy SKB, to rename our organization as Institute Giprostroymost. Our team was integrated into the Institute for Bridge Construction Design as its Leningrad branch.

One of the most difficult chapters in the Company's history was in the late 1980s, when there was no demand for our services, given the volatile and unstable situation the country was going through. Within a few years, the total number of employees of the Leningrad branch reduced from 110 to just 70 people. Back then, the organization stayed afloat performing contracts from abroad. It wasn't until late 1990s that the situation stabilized and the future no longer looked quite as grim.

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* Truss frame is an auxiliary structure that serves to support the loads from the deck and provide additional reinforcement.

** Launching nose is a temporary structure that is used for the assembly of bridge sections through incremental launching of bridge spans.

State Commission at thesis defense in the St. Petersburg State Transport University, July 2018

ROOTS IN LIIZHT

We maintain a close relationship with the St. Petersburg State Transport University (PGUPS), formerly known as the Leningrad Institute of Railway Transport Engineers (LIIZHT). Most of the Institute employees have graduated from this university. Many specialists on our staff are also part time lecturers with PGUPS, and I myself have long been the Chairman of the State Commission for thesis defense. It is quite often that our Institute becomes the first employer for the University alumni. Older experts mentor their younger colleagues, bringing up a new generation of bright and highly skilled engineers.

In 1990s, a fellow student of mine and an alumnus of LIIZHT, Vladimir Slivker, returned to Russia having spent some time abroad. It was he who founded the Bridge Analysis Department within the Institute, which evolved into the leader in bridge structural analysis among its Russian counterparts. Currently, we perform structural analysis of strength, stability and aerodynamics aspects here. This is truly one of the biggest achievements of our Institute.

PIVOTAL POINT

In 2001, through the foresight of Alexander Khomsky, Director General of the Institute Giprostroymost in Moscow, we have become an independent organization named Giprostroymost St. Petersburg, OAO. Not only has our status changed; the Company's scope of business expanded, too. Combining expertise in design and construction, the Institute at the same time mastered both structural design and development of technologies. The Giprostroymost designers were studying the Western technologies for cable-stayed bridges, having realized that the future of bridge engineering belongs to these tremendous structures. The Bolshoy Obukhovsky Bridge across the Neva River was the first cable-stayed structure that was designed by the Institute specialists from A to Z. The successful implementation of this advanced project has opened up new prospects for the Institute. Ten years later, two outstanding cable-stayed structures were built in Vladivostok: the Bridge of the Golden Horn Bay with its unique V-shaped pylons and the Bridge to the Russky Island with the central span of an unprecedented length.

Today, cable-stayed bridges have become quite common. A state-of-the-art wind tunnel laboratory was set up to cater to the needs of the Russian bridge constructors. Contractors succeed in mastering cable-stay technologies while manufacturers modernize their production lines. There is no doubt that Giprostroymost's contribution to the steady development of the bridge construction sector is outstanding.

The era of large-scale projects continues. Bridges become ever longer and ever more sophisticated. They are no longer just functional structures, but also dramatic architectural landmarks. A striking example of this technology is the cable-stayed bridge across the Petrovsky Channel in St. Petersburg that became another jewel in the city's architectural crown. The Institute specialists were much wanted for such national projects as the bridge over the Kerch Strait where Giprostroymost – Saint Petersburg was the General Contractor. Extensive practical experience, productive collaboration with scientists, constructors and the customer, as well as 3D-modeling technologies made it possible to complete the engineering design in a short time.

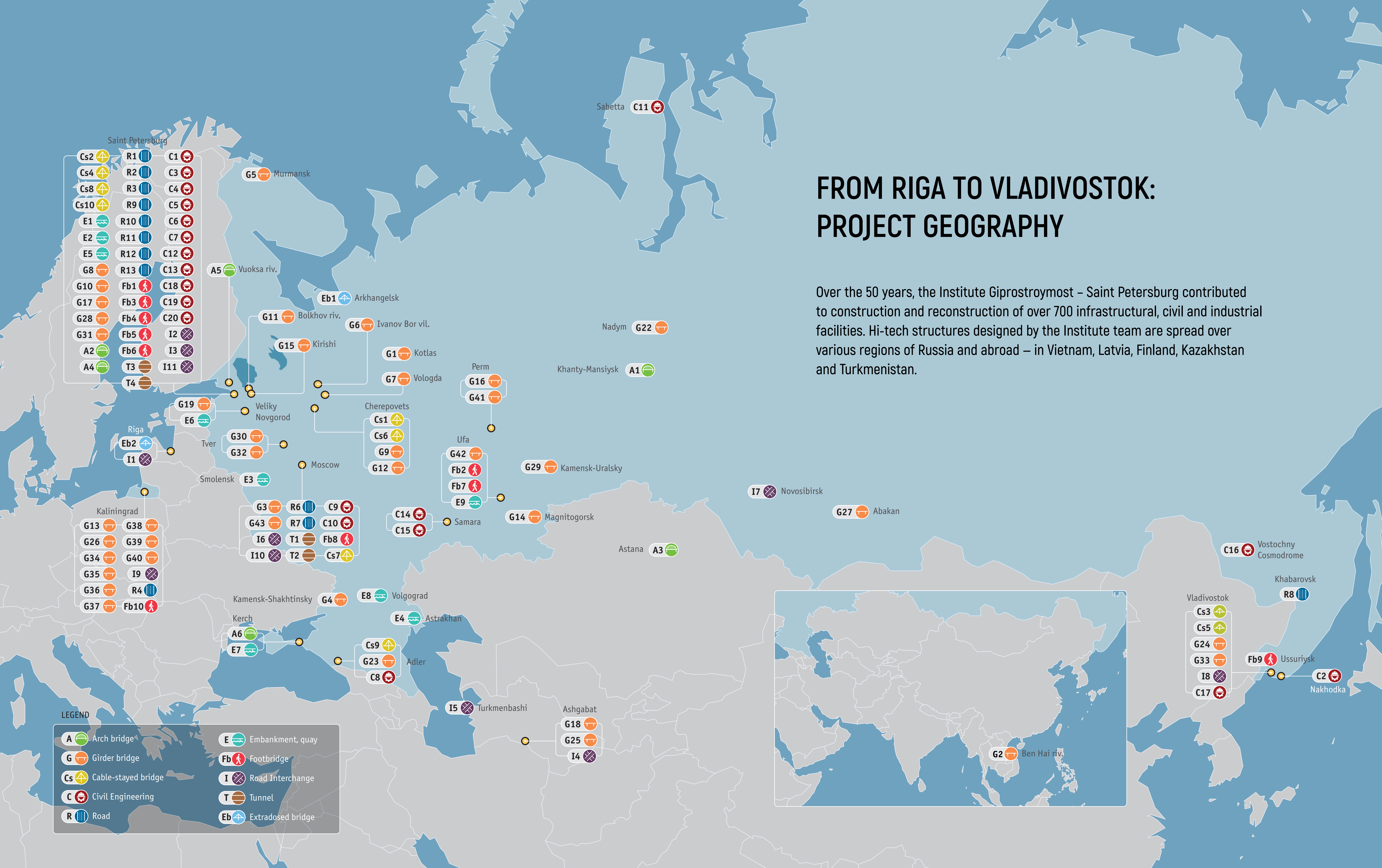
The recent projects prove that the Institute is well-versed in software, its engineers are competent in the local and international codes. In the economic terms, the Company is competitive on the global bridge construction market.

HIGH STANDARDS

Currently, the Institute has 480 employees. The management takes care of the comfortable workplace conditions for its specialists. For this purpose, the Institute bought a spacious 7-storey building on the Yablochkova street in the center of St. Petersburg. Employees enjoy free lunches. The Company's social package includes health resort treatment for employees and their families. The Institute grants interest-free loans and aid for those in need of commercial medical care. Well-off and confident in the future, people can devote themselves to engineering with an ultimate goal to make the Russian transport infrastructure comply with the top standards effective in Europe and across the globe.

FROM RIGA TO VLADIVOSTOK: PROJECT GEOGRAPHY

Over the 50 years, the Institute Giprostroymost – Saint Petersburg contributed to construction and reconstruction of over 700 infrastructural, civil and industrial facilities. Hi-tech structures designed by the Institute team are spread over various regions of Russia and abroad – in Vietnam, Latvia, Finland, Kazakhstan and Turkmenistan.



LIST OF PROJECTS

A ARCH BRIDGES

1. The bridge across the Irtysh River near Khanty-Mansiysk
2. The Beliayevsky Bridge across the Bolshaya Okhta River in St. Petersburg
3. The bridge across the Ishim River in Astana
4. Railway American bridges across the Obvodny Canal in St. Petersburg
5. Bridge across the Vuoksa River in the Leningrad Region
6. The Crimean Bridge across the Kerch Strait

G GIRDER BRIDGES

1. The motorway bridge across the Malaya Severnaya Dvina River near Kotlas
2. The Hien Luong Bridge in Vietnam
3. The bridge across the Moskva River near the Spas village on the Moscow Ring Road, Moscow
4. The bridge across the Seversky Donets River in Kamensk-Shakhtinsky, the Rostov Region
5. The bridge across the Kola Bay in Murmansk
6. The bridge across the Sheksna River near the Ivanov Bor village, the Vologda Region
7. The Vologda 800th Anniversary Bridge across the Vologda River
8. Viaduct in Sestroretsk, St. Petersburg
9. The Bridge across the Suda River in the Cherepovets District, the Vologda Region
10. Viaduct over the rail tracks at the Piskariovsky Avenue near the Piskariovka station, St. Petersburg
11. The bridge across the Volkhov River, the Kola M-18 motorway.
12. The bridge across the Yagorba River, Cherepovets
13. The bridge across the Staraya Pregolya and Novaya Pregolya Rivers, Kaliningrad
14. The bridge across the Ural River, Magnitogorsk
15. The bridge across the Volkhov River near Kirishi
16. The bridge across the Chusovaya River, Perm
17. The overpass extension of the Piskariovsky Avenue from the Rustaveli Str. to the KAD (Ring Road), St. Petersburg
18. The bridge across the Karakum River at the Niyazov Str., Ashgabat
19. The bridge across the Volkhov River, Veliky Novgorod
20. The bridge across the Karakum River at KM 160+50 KAD, north of Gyami village
21. The Blagoveshchensky Bridge in St. Petersburg
22. The composite bridge across the Nadym River at the 911 km on the Surgut–Salekhard motorway near Nadym.
23. Various structures on the composite road from Adler to Alpika-Service Alpine Resort
24. Low bridge across the Amur Bay between the De Friz Peninsula and the Sedanka village in Vladivostok.
25. The Choganly Bridge across the Karakum River at the A. Niyazov Ave., Ashgabat
26. The Berlin Bridge in Kaliningrad
27. The bridge across the Abakan River, the Republic of Khakassia
28. Reconstruction of the Palace Bridge across the Neva River in St. Petersburg
29. The bridge across the Iset River and motorway/footbridge approaches in Kamensk-Uralsky
30. The Vostochny Bridge across the Volga River in Tver
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32. The Zapadny Bridge across the Volga River in Tver
33. The bridge across the Artiomovka River on the motorway from Vladivoskok to Nakhodka to the Vostochny Sea Port
34. The overpass at PK 181+06 over the Gurievskaya Str. bypass, Kaliningrad
35. The overpass at PK 214+68.2 over the Moskovsky Avenue in Kaliningrad
36. The overpass at PK 212+47.94 across the Exit No.2 of the intersection at the Moskovsky Avenue in Kaliningrad
37. The overpass at PK 2+12.59 at the Exit No.2 of the intersection at the Moskovsky Avenue in Kaliningrad
38. The bridge across the Vitushka River at PK 91+22.63 in the Kaliningrad Region
39. The Wooden Drawbridge across the Pregolya River in Kaliningrad
40. The High Drawbridge across the Pregolya River in Kaliningrad
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43. The motorway bridge across the Molodtsy River as a part of the Ostafievskoye road, Moscow

Cs CABLE-STAYED BRIDGES

1. The Oktyabrsky Bridge across the Sheksna River, Cherepovets
2. The Bolshoy Obukhovsky Bridge across the Neva River, St. Petersburg
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4. The road junction at the Alexandrovskaya Ferma Avenue, St. Petersburg
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6. The bridge across the Sheksna River at the Arkhangelskaya Str., Cherepovets
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1. The Saint Petersburg Stadium in the Western End of the Krestovsky Island, St. Petersburg
2. Drilling platforms LUN-A and PA-B
3. Residential building in the historic center of St. Petersburg
4. Custom architectural design of a residential building, St. Petersburg
5. The Volna Sports and Wellness Center, St. Petersburg
6. Multifunctional business center with underground parking on the Leninsky Avenue in St. Petersburg
7. Residential building in the Primorsky District, St. Petersburg
8. Railway station in Adler
9. FC Spartak Stadium in Moscow
10. Municipal multifunctional center with parking, Moscow
11. LNG storage tanks in Sabetta village, the Yamal Peninsula
12. Underground parking at a residential building in Kolpino, St. Petersburg
13. Underground parking at a residential building, St. Petersburg
14. Indoor cycle track, Samara
15. Martial arts complex, Samara
16. The Angara space vehicle launching facility at the Vostochny Cosmodrome. Components of the Space Crew Boarding and Egress Unit (CBEU)
17. The Port Arthur Icon of the Holy Virgin Church, Vladivostok
18. Underground parking in a residential building at the Liotchika Piliutova Str., St. Petersburg
19. Historical building of the Mariinsky Theater, St. Petersburg
20. Light rail transit line between the Pulkovo Airport and the Kupchino metro station

R ROADS AND STREETS

1. The Western High-Speed Diameter (ZSD) road, St. Petersburg
2. The St. Petersburg Ring Road
3. High-speed motor road along the crest of the Protective Structures Complex (KZS) near the Bronka railway station, St. Petersburg
4. Ring road around Kaliningrad
5. Motorway along the Amur Bay
6. The Central Ring Road, the Moscow Region, startup complex (construction stage) No. 3
7. The Central Ring Road, the Moscow Region, 1st stage of construction, section No. 1
8. The Khabarovsk bypass, 13–42 km
9. The Kosmonavtov Avenue section from the Dunaysky Avenue up to the passage to the South of block 15 to the East of the Yuri Gagarin Avenue, St. Petersburg
10. The Komendantsky Avenue section from the Tupolevskaya Street to the Bogatyrsky Avenue, St. Petersburg
11. The Novokolomiazhsky Avenue section from the Verbnaya Street to the Shcherbakova Street, St. Petersburg
12. A passage to the South of the block 15, East of the Yuri Gagarin Avenue section between the Kosmonavtov Avenue and the Vitebsky Avenue, St. Petersburg
13. The Sitsevaya Street section from the Staroderevenskaya Street to the Planernaya Street, St. Petersburg

E EMBANKMENTS AND QUAYS

1. C-2 navigation pass within the flood protective structures, St. Petersburg
2. Hydraulic lock. C-2 within the flood protective structures, St. Petersburg
3. Reconstruction of the Dnieper River embankment, Smolensk
4. The Volga River embankment
5. The Makarov Embankment and the bridge across the Smolenka River, St. Petersburg
6. Reconstruction of the Volkhov River embankment, Veliky Novgorod
7. Freight jetties, Kerch
8. Landscaping of the 62th Army Embankment, the Volga River, Volgograd
9. Quays, ferry terminals on the Ufa and Belaya Rivers

Fb FOOTBRIDGES

1. Footbridge over the Ring Road, St. Petersburg
2. Pedestrian underpass at the Boulevard Slavy public transport stop, Ufa
3. Pedestrian pass under the Piskariovsky Avenue, St. Petersburg
4. Footbridge at the Tallinskoe Road, St. Petersburg
5. Footbridge at the Slavy Avenue and the Budapeshtskaya Street, St. Petersburg
6. Footbridge at the Slavy Avenue and the Belgradskaya Street, St. Petersburg
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8. Cable-stayed footbridge across the Moskva River, Krasnogorsk, the Moscow Region
9. Footbridge at the Chicherin and Krasnoznamionnaya Streets, Ussuriysk, the Primorsky Territory
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I FLYOVERS, INTERCHANGES

1. Flyover approaches to the Southern Bridge across the Daugava River, Riga, Latvia
2. Interchange at the Stachek Avenue and railway line, St. Petersburg
3. St. Petersburg Ring Road section between the Priozerskoe Road and the Russia motorway.
4. Motorway overpasses in Ashgabat and the Akhal Province, Turkmenistan
5. Overpasses on the Airport–Turkmenbashi road–Avaza National Tourist Zone motorway
6. Flyover above the rail track and the Dzerzhinskoe Road, Kotelniki, the Moscow Region
7. Traffic interchange at the Bolshevistskaya Street, the Krasny Avenue, the Kamenskaya Road and the Fabrichnaya Street, Novosibirsk
8. Flyover at KM 33+85 on the road from Vladivostok to Nakhodka to the Vostochny Seaport on the section between KM 18+500 to KM 40+800, the Primorsky Territory
9. The Vostochnaya flyover, Kaliningrad
10. The overpass above the rail track at the 19-km mark of the MMK–Pavlovskaya Sloboda–Nakhabino road
11. Overpass at the Pulkovskoe Road and the Dunaysky Avenue, St. Petersburg

T TUNNELS

1. The Volokolamsky Tunnel under the Moscow Canal, Moscow
2. The Lefortovsky Tunnel within the Third Transport Ring, Moscow
3. Motorway tunnel to the Kanonersky Island under the Morskoy Channel, St. Petersburg
4. Tunnel within the Murino traffic interchange at the St.Petersburg Ring Road

Eb EXTRADOSED BRIDGES

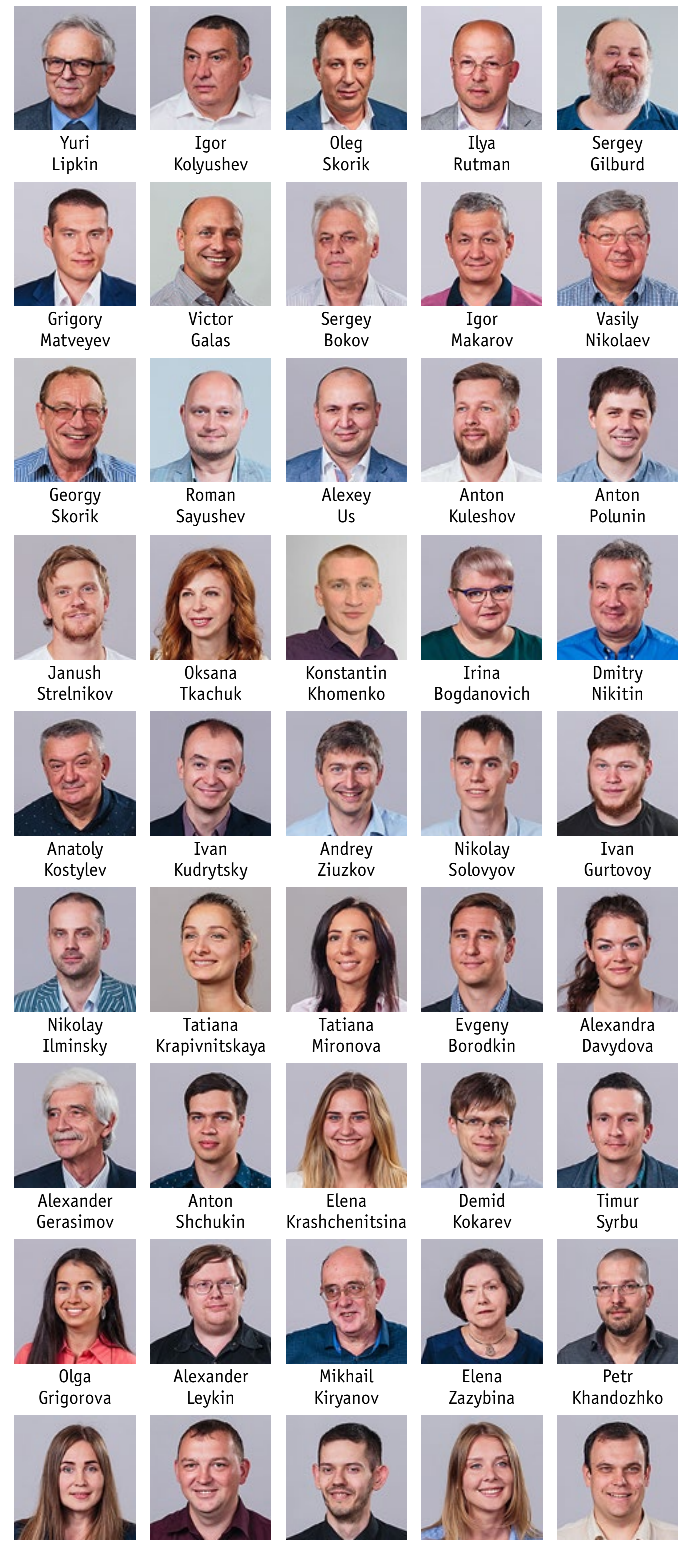
1. The bridge across the Kuznechikha River, Arkhangelsk
2. The Southern Bridge across the Daugava River, Riga, Latvia

YEARS AND PEOPLE

The list of the facilities constructed with the Institute contribution is impressive. Giprostroymost – Saint Petersburg has a well-deserved reputation both in the Russian bridge sector and among the foreign partners. This is the reason why the Institute is entrusted with the most prominent national projects.

Having passed the 50-year mark, the Company has a lot to be proud of. Its portfolio has several hundreds of completed projects, innovative approaches to design and construction technology, the first in Russia cable-stayed bridge and the longest cable-stayed bridge in the world. These are the facts. Behind the facts are the people, their everyday work, complex analyses and tests, doubts and solutions, mastering advanced practices and developing new approaches, the search for best solutions and the never-ending pursuit of perfection.

The Institute is proud of its accomplishments; but even more so of the people who committed themselves to designing bridges. This book is dedicated to them.



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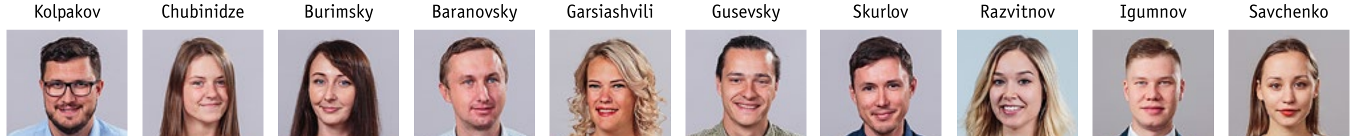

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Galina Marinina
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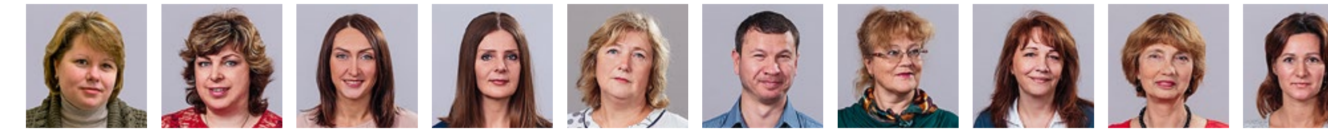
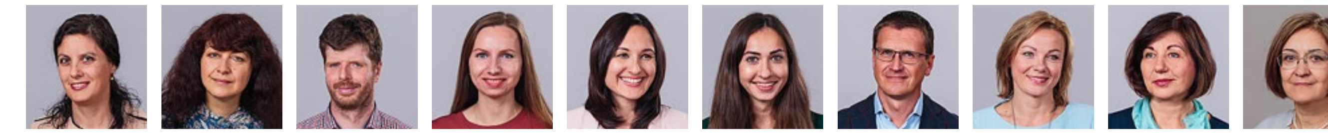


Irina Besetskaya
Tatiana Mikhaylova
Anna Viktorova
Yulia Khandozhko
Svetlana Vorobyova
Dmitry Ibraev
Anna Kalinina
Elena Lobanova
Marina Viaznikova
Maria Igumnova



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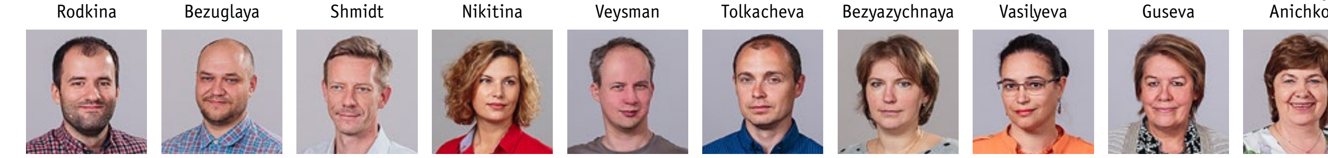
Yulia Fomenko
Vitaly Nagorny
Olga Glazova
Elena Borodina
Daria Koybagarova
Sergey Tikhonov
Ekaterina Kurnosova
Ludmila Goncharenko
Elena Dimaki

Anna Rodkina
Natalia Bezuglaya
Elena Shmidt
Inna Nikitina
Mikhail Veysman
Yulia Tolkacheva
Vera Bezyazychnaya
Natalia Vasilyeva
Galina Guseva
Andrey Anichkov



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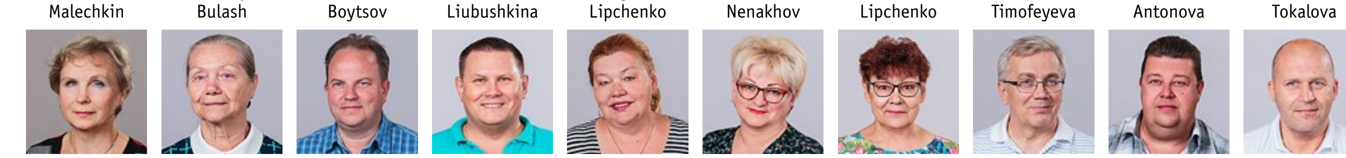
Andrey Bulash
Vadim Boytsov
Tatiana Liubushkina
Igor Lipchenko
Anton Nenakhov
Alexandra Lipchenko
Marina Timofeyeva
Natalia Antonova
Elena Tokalova



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Nadezhda Tushkevich
Roman Timofeyev
Vadim Lidvanov
Nadezhda Kozlova
Natalia Shakurova
Lydia Sadokhina
Alexander Rudny
Dmitry Rogov
Oleg Savchuk

Konstantin Volin
Valery Altynov
Igor Pavlov
Gerald Atlas
Inessa Fiodorova
Galina Grunicheva
Tatiana Baranova
Olga Kuzmina
Lev Shapiro

Alexey Sabitov
Alexander Kolchin
Igor Nikitin
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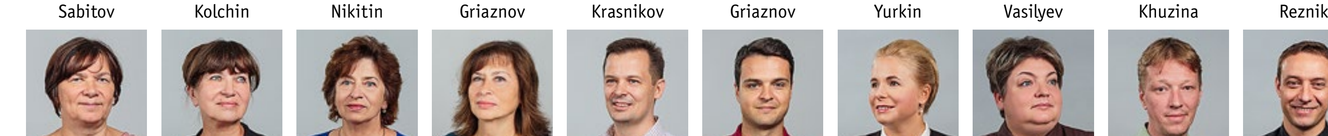
Vasily Krasnikov
Vladimir Griaznov
Sergey Yurkin
Vladimir Vasilyev
Daria Khuzina
Olga Reznik



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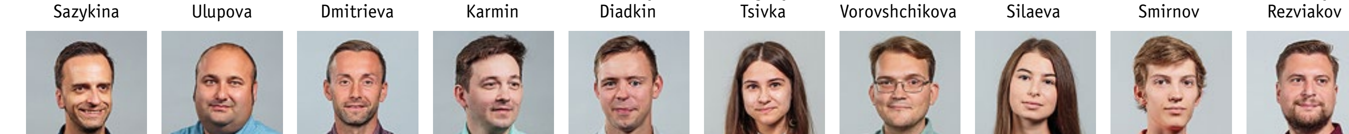
Galina Ulupova
Tatiana Dmitrieva
Zhanna Karmin
Nikolay Diadkin
Evgeny Tsivka
Liubov Vorovshchikova
Alexandra Silaeva
Roman Smirnov
Andrey Rezviakov



Andrey Vorobyov
Akim Ostretsov
Alexey Vorobyov
Marat Khayrulin
Nikolay Kiseliov
Alexandra Levko
Alexander Gurchev
Ekaterina Bobrova
Denis Rudoy
Aleksey Koskin

2000 2018 COLLECTION OF THE BEST PROJECTS

The history of eight projects that became landmarks for the Institute and the industry as a whole.

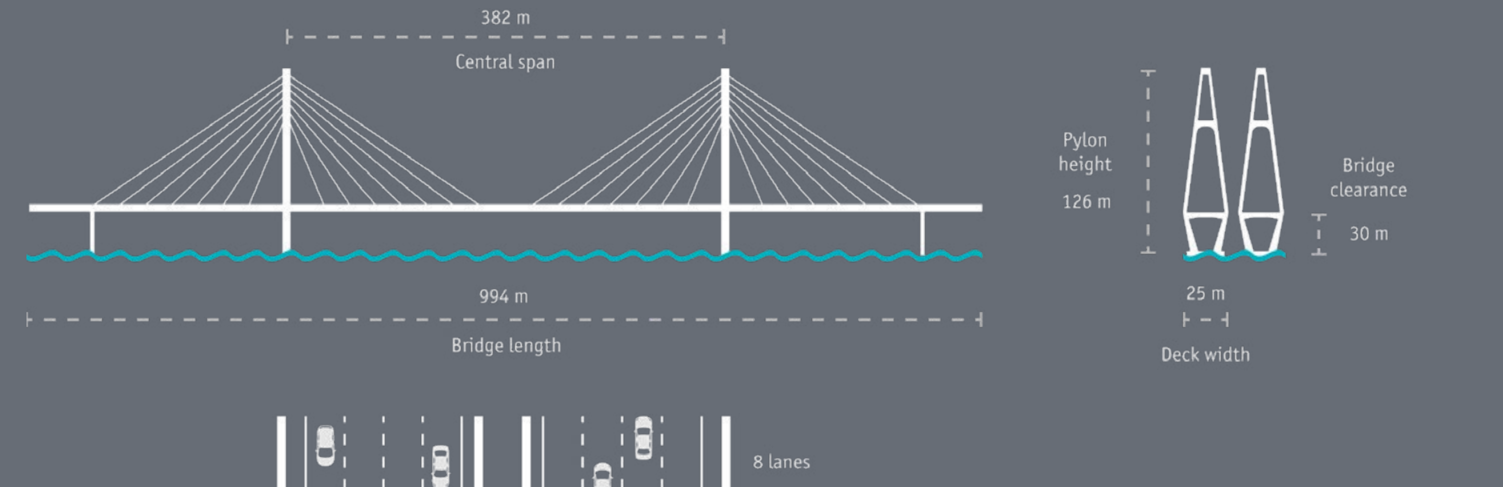
Bolshoy Obukhovsky Bridge St. Petersburg

A NEW-GENERATION BRIDGE

The first modern cable-stayed bridge in Russia – and the only fixed bridge on the Neva River – was constructed to mark the 300th anniversary of St. Petersburg.

The bridge is a key link of the Ring Road (KAD) around St. Petersburg, it connects the Obukhovskoy Oborony Avenue and the Oktiabrskaya Embankment. This modern cable-stayed bridge became a landmark for the entire country as well. It was the first time that a Russian project complied with the advanced European engineering standards; it had a huge impact on the further development of the Russian bridge engineering.

There are few instances in the global practice of one company developing a "turnkey" bridge design. The Bolshoy Obukhovsky Bridge is exactly the case. The Design Institute — for the first time in its history — developed a comprehensive design package including the concept of the bridge, complete analysis, design of major structures as well as construction technology.



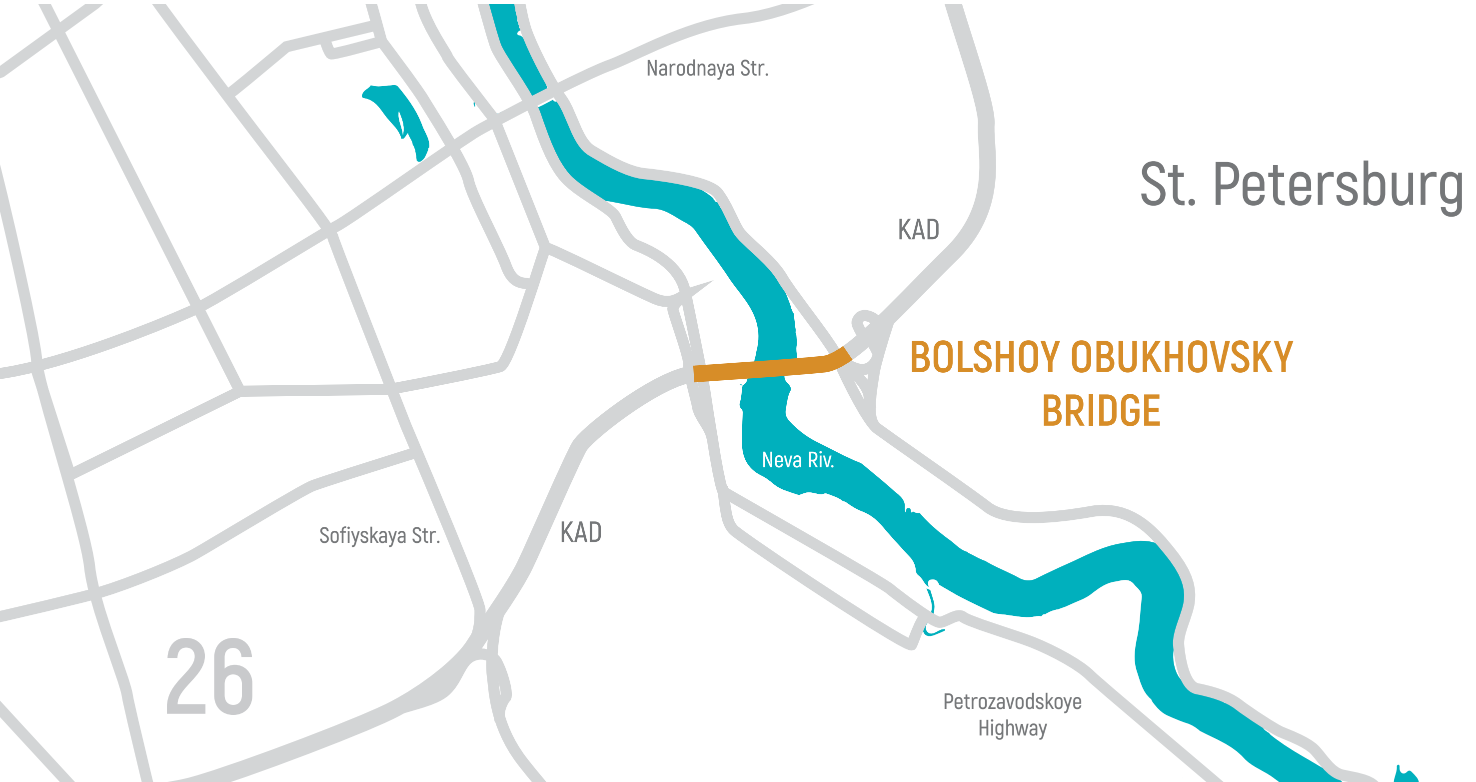
PACKAGE OF WORKS ON THE PROJECT

- Defining the bridge concept
- Structural design
- Developing construction technologies
- SAC&D (Special Auxiliary Construction & Devices) design
- Developing Construction Master Plan (CMP)
- Monitoring cable-stayed bridge structures during construction and operation
- Engineering supervision

PROJECT BACKGROUND

ANNIVERSARY GIFT TO THE CITY

The Ring Road connects all the major roads leading from the center of St. Petersburg towards Helsinki, Murmansk, Moscow, Kyiv and Tallinn. The Road construction began in 1998. Thirteen years later, in August 2011, the Ring was finally linked. The construction of the A-188 federal highway became a major transport infrastructure project in the history of the Russian Northern capital. The total length of the Road is 142 km. The Ring Road goes along the dam across the Gulf of Finland, rises on flyovers above rail tracks, connects with regional and urban roads at numerous interchanges, dives down into a tunnel under the navigable channel, and spans many a river with bridges. In total, there are 106 bridges, overpasses, flyovers and tunnels on the Ring.



Another thoroughfare — the river — became the most challenging obstacle of the Eastern semicircle for road and bridge constructors. At the point where the Ring Road meets the Neva River, the latter is almost 500 m wide. The bridge to be constructed over the river had to have the deck about 50 m wide. Moreover, designers had — if possible — to do without temporary mid-stream piers so that the bridge would not interfere with heavy river navigation which was already complicated by the river bend in that area. The design and construction had to be completed within a very tight timeline: the bridge was supposed to be a 300th anniversary gift to St. Petersburg. The design and construction works had to be completed within three years.

The project General Contractor Mostotryad 19, OAO entrusted the design of the central part of the bridge to the Institute Giprostroymost – Saint Petersburg which was to decide on the structural design of the bridge, design all the major structures and develop the construction technology. The Bolshoy Obukhovsky Bridge became a milestone at the beginning of a new era in the Russian bridge construction and in the Institute history. Having accomplished the project with credit, Giprostroymost promoted itself to be among the best international design bureaus.

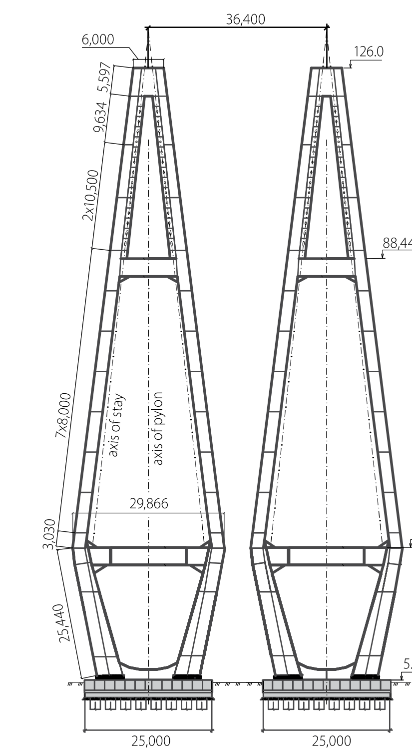
> *“The Institute, for the first time in its history, had to perform comprehensive engineering design: from the general concept to the construction technology. But there were no doubts that we would be able to complete the project. The Obukhovsky Bridge was an incentive for our engineers' self-improvement. The project took a huge amount of effort but we were all excited. It was a state-of-the-art bridge meeting all the international standards.*
>
> *Oleg Skorik, Director of Design*

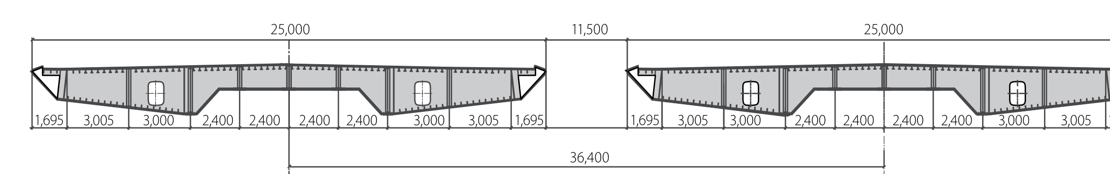
“ *The Bolshoy Obukhovsky Bridge is a sophisticated project as it consists of two parallel bridges. We collaborated with the Institute on the bridge design at the stage, when the issue of aero-dynamics came as a challenge to us, since the structures like this were not sufficiently studied. Aerodynamics of twin parallel spans is quite complicat-ed. The Bolshoy Obukhovsky Bridge remains an advanced structure despite the time that passed.*

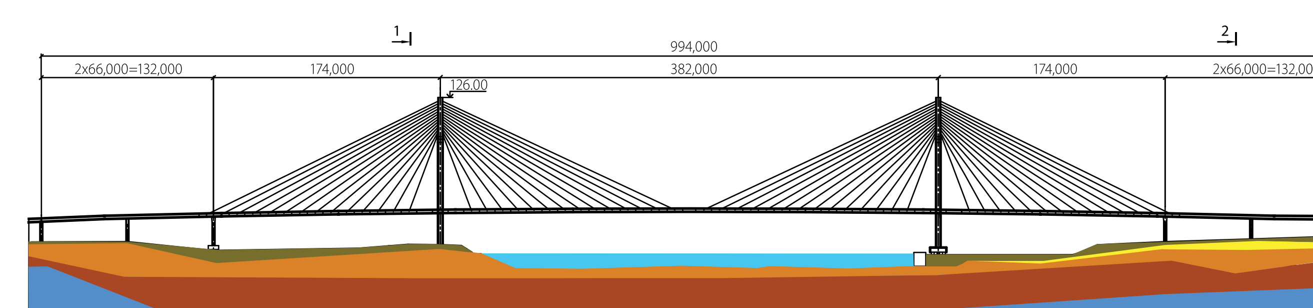
Esko Järvenpää
Senior Bridge Expert,
WSP Finland Ltd. Finland

3D model

BRIDGE ELEVATION







DESIGN PARAMETERS

PREDETERMINED SOLUTION

The major parameters that determined the structural features of the cable-stayed bridge across the Neva River were hydrological conditions, requirements to vertical clearance, navigation conditions in the Ring Road area as well as mandatory deadline set by the customer.

Since the bridge was to become a section of the Ring Road (KAD), it was the bridge location that KAD designers had to decide upon first, with the road to be "tied" to the bridge. Initially, the bridge was supposed to be constructed in the area of the so-called Bended Knee, the Neva bend in the Rybatskoe area. However, given the tight timeline, the location was moved downstream to the Utkina Zavod area near the river vessels winter berthing. The cable-stayed design was determined by the key condition set by the river transport operators: there should be no permanent piers mid-river. If it were a girder bridge, the piers would have to be installed every 150 m.

The main span of the future bridge had to be long enough to span the Neva River which is about 500 m wide in that area. The designers decided to put one of the pylons right on the Neva's left bank and the other one in the Utkina Zavod, some 100 m into the river, however, way outside the navigation line, already complicated enough. This determined the cable-stayed bridge span length of 382 m. The span runs 35 m above the river surface which allows for the passage of any type of vessels.

The Ring Road at the point of crossing the Neva River has eight lanes. The bridge construction deadline, contractors', metal structure manufacturers' and other suppliers' engineering capabilities determined the major decision to divide the structure into two parallel bridges running 36.4 m apart. The bridge was supposed to be opened for traffic by the City Day in 2003; however the period of three years was far from enough for construction of an eight-lane bridge. In terms of aerodynamics, dividing the bridge into two bridges running along each other was a complex and audacious engineering solution.

The mandatory deadline has determined all the major structures of the cable-stayed bridge: pylons, girder, stay cables. International experience of cable-stayed bridges construction proves that with 400-m spans a steel-reinforced girder is the most reasonable solution which translates to a combination of metal beams' and the reinforced concrete deck's forces. For the Bolshoy Obukhovsky Bridge design, however, a steel girder was opted for. Contractors preferred to deal with the prefabricated structures whenever possible, excluding the risks that might be incurred by casting the reinforced concrete deck at below-zero temperatures.

CABLE-STAYED BRIDGE AS A STUDY GUIDE

“We did not have much time. We were all just learning then, and could not take a risk, could not dare and try to create something exceptional, something way ahead of the international experience, within the given timeframe. We were keen to design something similar to what we saw in the West.

Igor Kolyushev, Technical Director

The design of pylons of the Bolshoy Obukhovsky Bridge was dictated by the limited construction timeframe. Traditionally, reinforced concrete is used to construct pylons in similar projects. However, just as with other design solutions in this project, the timeframe and capabilities of subcontractors had to be taken into consideration. Having discussed this issue with construction contractors — Mostootryad 19, OAO and Mostotrest, OAO — we agreed that the pylons of the Bolshoy Obukhovsky Bridge were to be made of metal.

Mostootryad 19, one of the construction contractors suggested erecting the bridge pylons right on the banks of the Neva River, which would result in a 500-m bridge span. The Institute designers came up with a different solution, however, that would produce an optimum bridge design with consideration to the construction site conditions.

Manufacturing metal structures of such a complex geometric shape as the pylons of the Bolshoy Obukhovsky Bridge was not a simple matter. At the very start of the project, the Institute designers concluded that 3D-modeling of the pylons was indispensable. Engineers from St. Petersburg went on a training course in Finland and, for the first time, used TekLa Structures software to develop 3D models of the pylons. Based on those models, drawings of the metal structures were created, which were then used by manufacturers and constructors.

Oleg Skorik
Design Director

“Digital modeling significantly facilitated the work of constructors and manufacturers of metal structures. There have been no misunderstandings of the complex geometry — all the pieces fit together perfectly. I cannot fathom how we would have completed the project having just 2D drawings. It was more than 15 years ago; all these years we have been widely using 3D technologies in the Institute; new software solutions have been created since then, and our engineers are getting more and more experienced. Currently, BIM technologies are widely used, and we are quite competitive in this area.*

* BIM — Building Information Modeling.

DESIGN FEATURES

A NEW APPROACH

The cable-stayed design of the Bolshoy Obukhovsky Bridge is fundamentally different from other cable-stayed bridges constructed by the Soviet engineers. Only three similar bridges were built in the Soviet Union. It was the Oktyabrsky Bridge across the Sheksna River in Cherepovets, the Rybalsky Bridge across the Dnieper River in Kyiv and the cable-stayed bridge in Riga across the Daugava River. In 2000, the Yugorsky Bridge was built across the Ob River in Surgut, Russia with a central span of 408 meters. However, the design was based on the input parameters without a due consideration to the structure's aerodynamics.

> *“All those predecessors of the bridge across the Neva River were, in essence, outdated at that point. How were the Soviet bridges being designed? If a central span girder was not rigid enough, another cable or two would be added to support it. European engineers abandoned this approach in the 1980s, and started designing bridges in such a way, so as to bear the whole weight of the span on cables which allowed making spans longer. When we first started working on the Bolshoy Obukhovsky Bridge, we wanted to design this cable-stayed bridge following the European vision.*
>
> *Igor Kolyushev,*
> *Technical Director*

Having reviewed proposals from four leading foreign companies, our specialists settled on the Swiss VSL stay cables manufactured under the monostrand technology. Each strand consisted of seven highly durable wires, each 7 mm in diameter, with a total tensile strength of 1,700 MPa. The total length of all the strands in the cables amounted to 900 km: this was six times the length of the St. Petersburg Ring Road! Monostrand technology had a number of important advantages to facilitate the construction. Firstly, it allowed contractors to assemble the cable system with lightweight equipment as the central span was getting longer. Secondly, steel cables could be manufactured to preliminary design drawings and shipped, without having to wait for the final design stage. Those factors played a major role in complying with the project timeframe.

AERODYNAMIC TESTS

AERODYNAMICS OR THE MATTER OF PROGRESS

Cable-stayed bridges, unlike arch and girder structures, are more susceptible to wind forces. When designing a cable-stayed bridge, the primary challenge is to find and maintain balance.

Dmitry Maslov
Project Chief Engineer

“ *From the structural perspective, a bridge is like a giant scales. Ideally, a side span should be in balance with the central one, but in reality this is often impossible to achieve due to a number of factors beyond our control. Therefore the designers are to find a fine line, the neutral state of the structure, which will be the best of all unbalanced states.*

Prior to the Bolshoy Obukhovsky Bridge, not a single design bureau in Russia had any experience in such analysis. Moreover, the very concept of bridge aerodynamics did not exist, apart from a few paragraphs in university textbooks. In preparation for the aerodynamic analysis, engineers and designers of the Institute researched numerous papers and articles, and delved into the best international practices. It was vital that they learned to perceive the whole structure in the context of aerodynamics, so that they could define the parameters that would minimize negative resonance impact on the bridge.

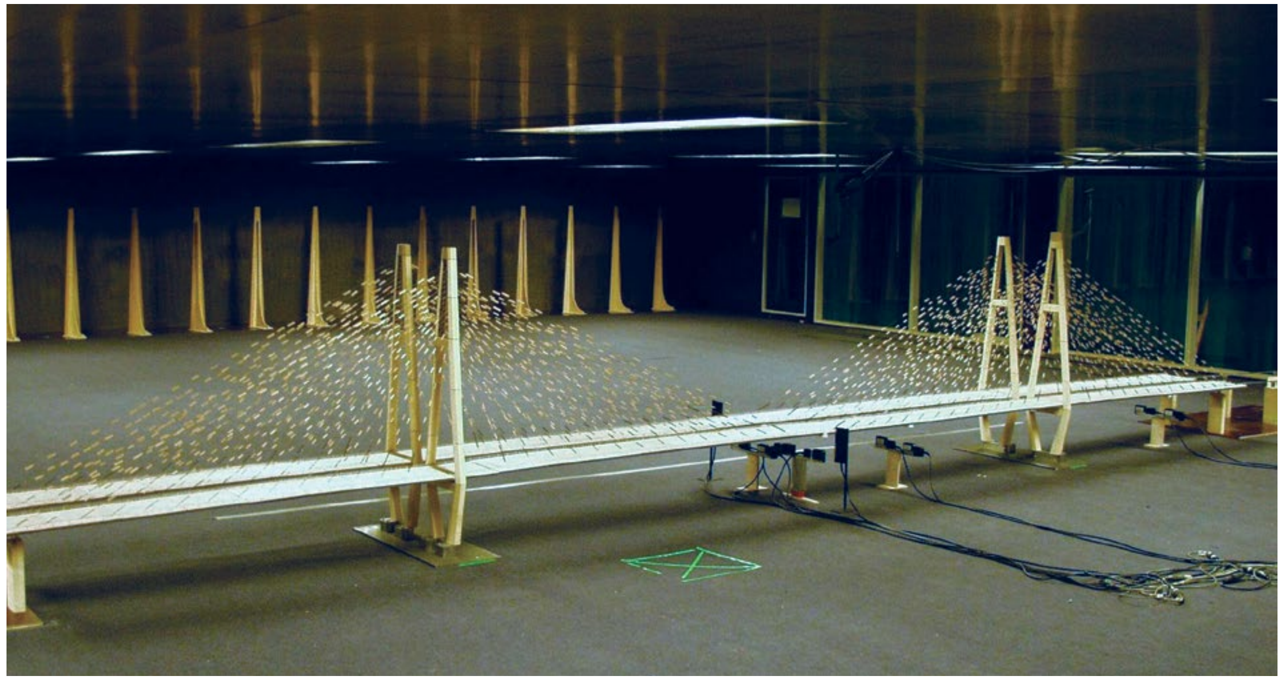
For the first time in the history of Russian bridge-building, a bridge model was tested in a wind tunnel. Separating the structure into two spans running parallel to each other significantly lowers the aerodynamic resistances of the bridge, as any air vortex created by the first span may pose a serious threat to the second one. Furthermore, the resonance phenomena may be unpredictable in such structures. Constructing two bridges in such a close proximity was another challenge to the designers. In order to find the optimal solution, the Giprostroymost specialists studied a similar bridge with two metal girders; it was the Meiko Nishi Ohashi Bridge in Japan with a central span of 405 meters and a 50-meter distance between two parallel spans. It was clear that the structure could not be fully researched through pure analysis, and the Institute engineers and designers opted to perform several aerodynamic tests of a draft bridge model in a wind tunnel.

COMPLICATED TESTS

Having researched the necessary facts and figures, the Institute designers approached the Danish Maritime Institute laboratory in Copenhagen, fitted out with state-of-the-art equipment. Danish specialists constructed a 6-meter model of the bridge at 1:100 scale specifically for those trials.

Several models of the designed bridge were tested in the wind tunnel: a standalone pylon, a cantilever model of one bridge under construction prior to the locking of the central span, a cantilever model of the second bridge under construction while the first one is already in operation, a single bridge and both bridges in operation. Every stage and condition was tested to see how the structure would perform both during assembly and after completion.

Aerodynamic tests of the bridge model in the Danish Maritime Institute laboratory in Denmark



Special software developed by another Danish company, Consulting Engineers and Planners AS, allowed to create a numerical simulation of aeroelastic behavior of neighboring sections of both bridges' central spans in the wind current. Of utmost importance was the fact that the results of those analyses were as accurate as the findings of the model tests. However, mathematical modeling is much less time-consuming and much cheaper.

The estimations performed by the Institute Giprostroymost specialists were corroborated at the Danish laboratory. Negative aerodynamic phenomena were observed neither at the construction stage nor at the operation stage of the project.

The central span exhibited substantial resistance to resonant vibrations caused by vortex excitations both during assembly and the operation of the completed bridge. The resonance in pylons prior to the installation of cables was only present under extremely strong winds with speeds far exceeding the readings standard for the area.

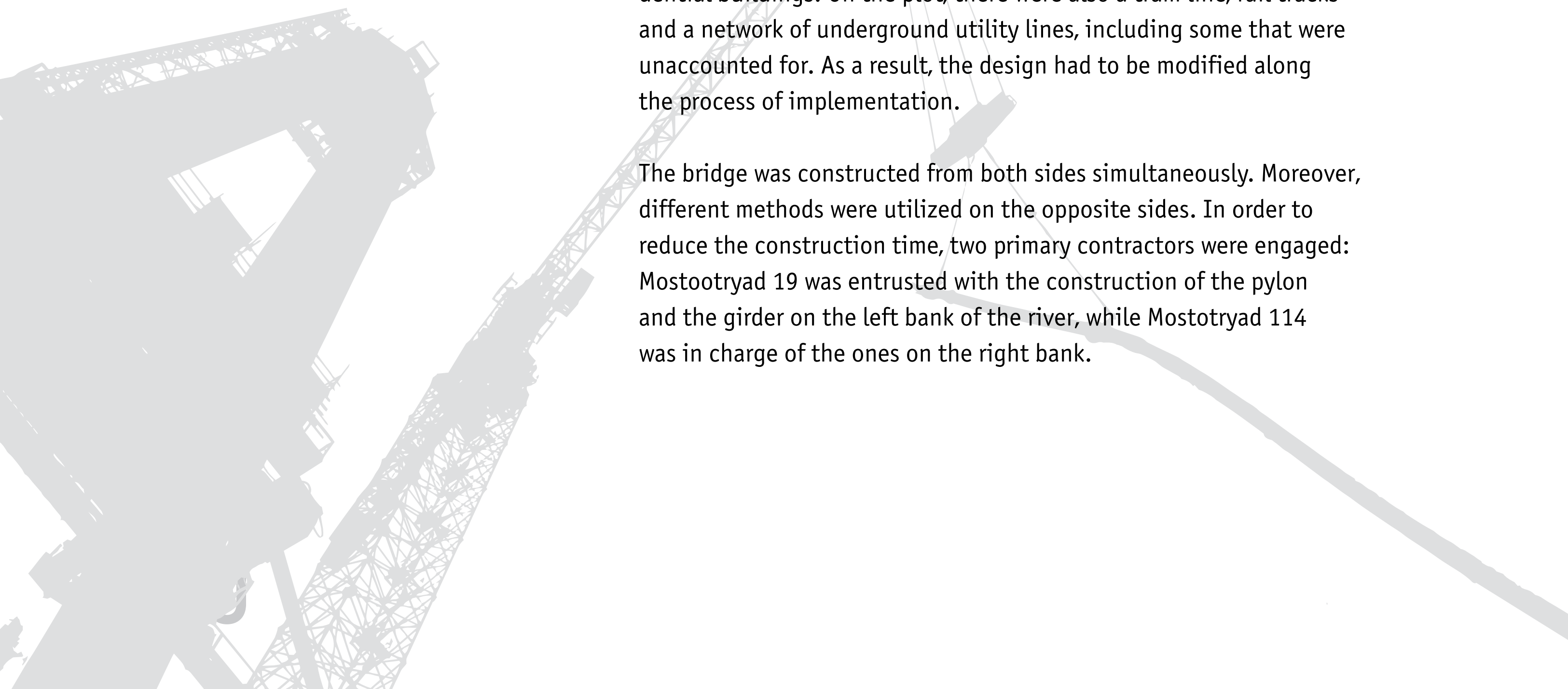
Colleagues from all over Russia lauded the enormous scope of work performed by the St. Petersburg engineers and recognized their outstanding competence in the subject matter. Subsequently, the Institute was often involved in aerodynamic tests for other projects in Russia.

CONSTRUCTION PLAN

TOWARDS EACH OTHER

When developing the construction plan of their first cable-stayed bridge, the Institute experts borrowed from vast experience and knowledge of several generations of designers. After all, Giprostroymost was first founded as a specialized design bureau, which was primarily involved in writing up construction master plans.

> *“Creating a bridge is a very complicated and interesting task. A designer is like a movie director at the construction site: he not only determines the shape and parameters of an object, but also the construction master plan. We knew the ropes of construction process; knew the contractors and constantly monitored their work.*
>
> *Yuri Lipkin,*
> *Chairman of the Board of Directors and Financial Director*



The bridge across the Neva River had to be constructed in a very confined area of an existing urban development. And while the first interchange with the Oktyabrskaya Embankment was constructed on a rather empty right bank of the Neva River and took up several hundred square meters, the one on the left bank, with the Obukhovskoy Oborony Avenue, had to be constructed on a small plot between residential buildings. On the plot, there were also a tram line, rail tracks and a network of underground utility lines, including some that were unaccounted for. As a result, the design had to be modified along the process of implementation.

The bridge was constructed from both sides simultaneously. Moreover, different methods were utilized on the opposite sides. In order to reduce the construction time, two primary contractors were engaged: Mostootryad 19 was entrusted with the construction of the pylon and the girder on the left bank of the river, while Mostotryad 114 was in charge of the ones on the right bank.

The construction site on the right bank of the Neva was located right in the river. It took six months to backfill the area and construct a new quay. Elements of the metal structure were supplied by the Voronezhstalmost plant in Voronezh. Pylons were being assembled under the Academician Paton method: vertically placed elements were welded together automatically. All three junction points were welded together in a single go with minimal deformation of the contour.

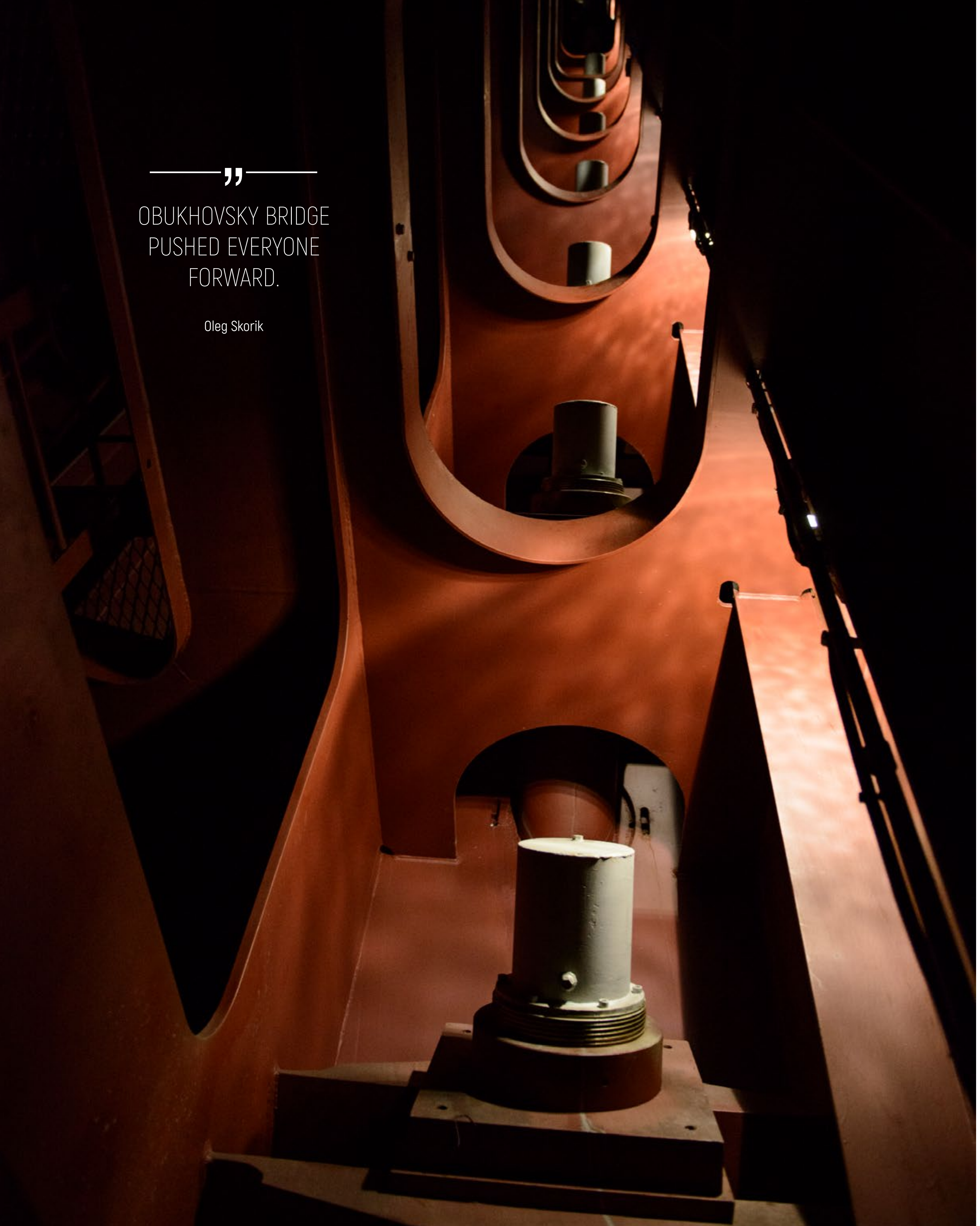
The construction site on the left bank of the river was located in a park between a sports complex and the waterline. Metal structure elements for that site were supplied by another factory, Kurganstalmost. The pylon structural blocks were joined in a special tilting unit, which ensured the welding of all the seams in a horizontal position with semiautomatic equipment. The pylons were gradually topped-up simultaneously on both banks.

Installation of the central span girder was, in a way, a "baptism by fire" for both the construction workers and designers. A 180-ton capacity derrick crane was used to perform those works. Given the tight timeframe, the designers suggested to assemble sections of the central span on the river bank and then float them out to the installation point. As one of the blocks got raised to the 35-m level, it was joined to the previously assembled section of the span and attached to the pylon with cables, placing it into the design position. The Baltic winds did not make constructors' work any easier. At the wind speed of 20–25 m/s, the construction was supposed to be suspended. But unforeseen situations still occurred.

"We have raised one of the central span sections about half-way — to the 18-m level — when suddenly we received a weather alert of an upcoming storm. We had to make a decision: either to raise it further, or to lower it back. We checked the forecasts, quickly pondered the available options and decided that it would be faster to raise the section and lock it in place. Such situations occur quite often. And even though you know that everything has been thought through, the calculations are correct and the structure will hold, you are still worried. What if something fails and the structure would give? Well, it has never failed yet.

Vasily Nikolaev
Chief Project Engineer

Merging the two sides of the central span was a true achievement in its own right. Just before that, both girders had to be aligned by counterweight, balancing the two halves of the span. Successful completion of this unique operation for Russian bridge constructors was celebrated with fireworks. State-of-the-art mechanisms and equipment significantly expedited the construction process. To assemble the 126-m pylon, contractors used a crane with a 400-ton lifting capacity and a 160-m jib. A crawler crane with a 300-ton lifting capacity was also used for construction. Using such powerful heavy machinery allowed workers to assemble the metal structures in larger sections and meet the tight deadlines of the project. The opening ceremony of the first stage of the Bolshoy Obukhovsky Bridge was held on December 15, 2004. Three years later, its cable-stayed twin was completed as well. The second bridge was opened to traffic on October 19, 2007, coinciding with the anniversary of the Tsarskoye Selo Lyceum. A rather elegant coincidence, very much in the St. Petersburg style.



OBUKHOVSKY BRIDGE PUSHED EVERYONE FORWARD.

Oleg Skorik

MONITORING SYSTEM

COLLABORATION

A lot of things happened for the first time on the Bolshoy Obukhovsky Bridge, the first cable-stayed bridge in the history of the Russian engineering school. The cables themselves and the aerodynamic analysis were new; for the first time, special technical requirements were developed in compliance with European standards. Another innovation was the monitoring system applied to the bridge. Specialists used the data from hundreds of gauges and sensors to identify vibrations throughout the construction process and to monitor condition of the two steel pylons. Even after the bridge had been put in operation, those sensors continued monitoring the state of the structure.

A well-respected Finnish company Savcor was the one invited to supply, install and fine-tune the necessary monitoring equipment. The successful collaboration became a beginning of a long-term cooperation that lasted for nigh on 20 years. The Finnish company supplied a turnkey solution of the monitoring system. Just as the construction workers had to work in winter time, the invited experts also had to work in the cold, since sensors had to be installed in the process of assembling spans and steel pylons.

Pekka Toivola
Regional Manager, Savcor, Finland

“It was the first and the most substantial project in our portfolio. Back then, we used to work for two or three weeks, sometimes even up to a month, waiting for the contractor to be ready for us to do our part. Once, we arrived at the construction site to install tension sensors. They had to be welded to the structure with a low-voltage welding machine. But when we arrived, the power was down! The Institute specialists had a special control room set up inside the pylon. There was a voltage regulator. Having reflected on the situation, the experts from St. Petersburg modified the battery array for our welding machine. Everything was ready, but we could only weld two sensors in one go — then, we had to return to the control room to recharge the battery. Nevertheless, the work was done, and I will never forget our cooperation. By the way, the sensors that we installed, with a two-year warranty period, are still working, even though some 16 years have passed since then.

PROJECT SIGNIFICANCE

RESTING ON STAY CABLES

When talking about the significance of the Bolshoy Obukhovsky Bridge, it is difficult to resist the urge to use superlatives. This is the first cable-stayed bridge in Russia, designed and constructed using state-of-the-art technologies and latest scientific advances of the time.

The project design and implementation process encompassed most complicated analysis and aerodynamic tests, the use of the advanced cable-stayed structures and rigging technologies in terms of both manufacturing and assembly. Institute employees developed the engineering design in its entirety, including the design of the primary structures and their construction technology, auxiliary structures and equipment for the bridge, and compiled all the construction master plans. At the time, it was the major cable-stayed bridge construction project in Russia. Such structure would instantly become a hallmark of any design bureau. Having completed the Bolshoy Obukhovsky Bridge, Institute Giprostroymost became one of the most prominent bridge design and construction organizations in the world. Furthermore, the project boosted scientific, technical and creative development of the Institute.

The significance of this bridge for the transport infrastructure of the Northern capital is tremendous: with the second stage of the project completed, now the Ring Road can easily cope with the ever-growing traffic loads of the city. St. Petersburg residents speak fondly of the Cable-Stayed Bridge, as the locals call it, for it allows them to cross the Neva River at any time of day, without having to worry about bridge opening timetables.

Traditionally, the bridges of St. Petersburg are not just a regular link across the river; they are also impressive architectural landmarks. And there are very strong contenders that the Bolshoy Obukhovsky Bridge had to run against, as long before its time, the world-renowned Palace, Troitsky and Liteyny Bridges spanned the Neva River banks. And even though the Bridge never tried to outdo other landmarks, and its pylons do not rise higher than the spire of the Peter and Paul Cathedral, it quickly became a staple of the city landscape. Just as the White Nights are a symbol of St. Petersburg, the Bridge is now a symbol of its constant development.

Yuri Lipkin
Chairman of the Board of Directors
and Financial Director

“ *The Bolshoy Obukhovsky Bridge is a truly unique cable-stayed structure. It was the first bridge in Russia to comply with international standards — in terms of design, metal consumption, analysis and aerodynamic studies. The Obukhovsky Bridge, which we designed from A to Z, allowed us to become contractors for other prominent projects, such as the Russky and Golden Bridges in Vladivostok.*

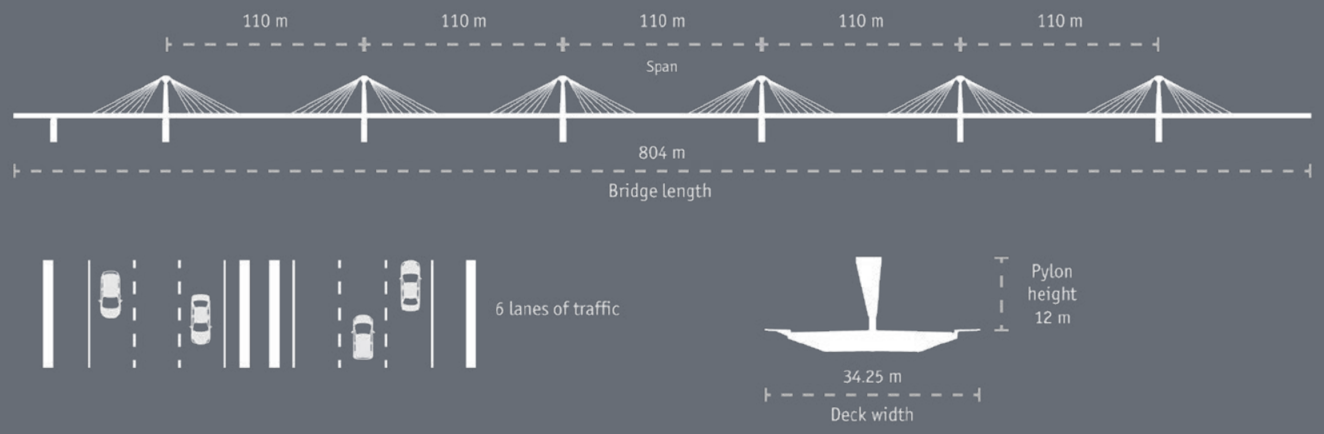
Southern Bridge Riga, Latvia

FIFTH BRIDGE ACROSS THE DAUGAVA RIVER

This is the second extradosed bridge ever constructed in Europe. The most prominent feature of the Southern Bridge is its orange pylons, which are not only a beautiful architectural detail, but also an important structural element.

The Southern Bridge connects the banks of the full-flowing Daugava River in Riga. This is the most recent bridge in the city and the largest construction project in the modern history of Latvia. The total length of the bridge is 804 m. A six-lane roadway, pedestrian walkways and bicycle lanes all fit together on a 34-m wide deck. It was decided to construct the Southern Bridge following the extradosed design.

Extradosed bridges combine advantages of both girder and cable-stayed bridges, which results in a high quality of the ultimate structure and significant reduction of metal consumption. Having opted for the design made in St. Petersburg, approximately 3,000 tons of metal were saved on the construction of the bridge in Riga. For the Institute, the Latvian project became the first step towards recognition in the European Union.



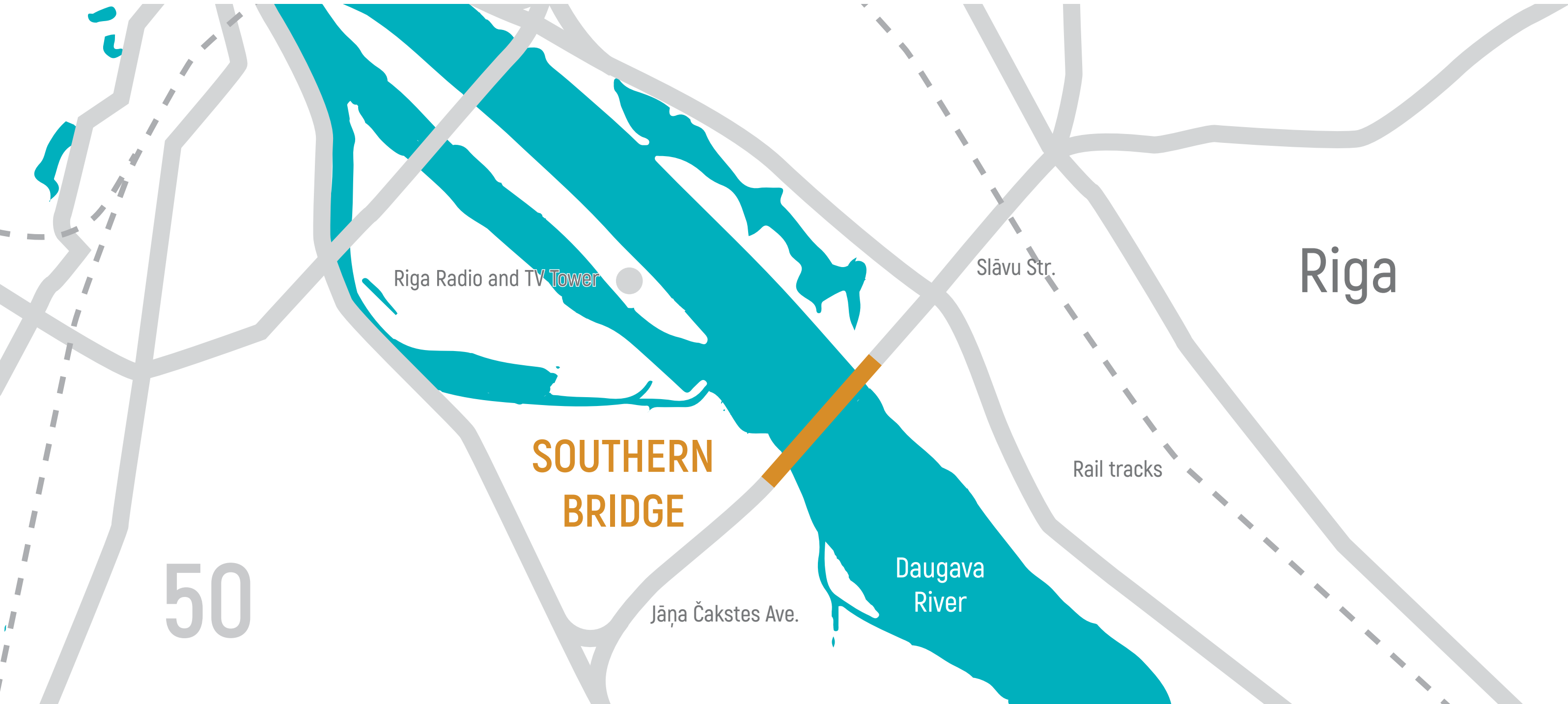
PROJECT BACKGROUND

BRIDGE No.5

There was a saying in the 18th century Riga, 'As impossible, as a bridge across the Daugava River'. The city was founded in 1201, yet the first bridge across the river was constructed only 500 years later. Until then, the city residents had to make do with ferries. Two more centuries had passed until the permanent Iron Bridge was constructed across the main waterway of the Latvian capital. It was first intended for trains, horse-drawn carriages and pedestrians.

Currently, there are approximately 80 various bridges in Riga. Many of these have a thrilling history behind them: as the city grew and traffic loads increased further, bridges would be relocated, taken apart and rebuilt. Before 2008, when the Southern Bridge was completed, four bridges were the main thoroughfares across the Daugava River.

The railway bridge, which was opened in 1914, was badly damaged during the First and Second World Wars. It wasn't until 1951 that it was rebuilt. In essence, it was a new bridge, with a different framework of arches and girders. The Stone Bridge, the first in Riga to connect the historic center with the left bank of the river, was constructed in 1957. Its relatively wide deck (27.5 m) could support all types of transport including trams.



The Island Bridge, which was constructed in 1976, connected both river banks and the islands of Zakusala and Lucavsala. This girder bridge was extremely practical and had rather simple, yet functional design. The Cable-Stayed Bridge was completed in 1981. It now towers above the city with its expressive modern silhouette. The mighty pylon in the shape of a reversed Y stands tall, echoing the spires of the old cathedrals in the historic center.

The Southern Bridge became the fifth crossing on the Daugava River. A new bridge was sorely needed in order to reduce travel times between the left bank and the areas on the right bank which were expanding rapidly. The design tender was announced in 2001. Engineers had to envision a structure that would not get lost among the existing bridges, but instead would further enrich the city landscape and accommodate the ever increasing traffic loads.

PACKAGE OF WORKS ON THE PROJECT

- Conceptual design and detailed design stages
- Execution of design works as the authorized General Designer
- Designing the bridge structures
- Developing construction technologies
- SAC&D (Special Auxiliary Construction & Devices) design
- Development of construction master plan

ARCHITECTURAL CONCEPT

LIKE FLAMES ABOVE THE RIVER

The Southern Bridge remains etched in one's memory for its catching combination of orange pylons and cables. It looks like six torches flaming above the grey concrete framework. Solid piers and spans contrast with 96 light strings of cables. It is a common feature for extradosed structures which combine elements of girder and cable-stayed bridges.

The Daugava River in that area is about 800 m wide. Architects sought to make the structure impressive still without excessive grandeur.

« In Riga, there is a cable-stayed bridge built back in 1981. Our idea was to show the continuity of the outstanding engineering solutions of the past in the present-day structures.

Anton Kuleshov

The Institute specialists were seeking solutions in collaboration with their colleagues from the Architectonica Design Group, Riga who were very scrupulous about the future bridge appearance. It was decided that a girder bridge would be too commonplace. Of course, a girder structure is more reliable and cost-effective but it would be far from an architectural masterpiece. A cable-stayed bridge with a large span and of great dimensions was not a necessity in that area: in 1966, when the Riga Hydro Power Station construction began, heavy vessel navigation down the Daugava River stopped. After lengthy discussions, the specialists opted for a bridge with an 8.5 m clearance and 100-m long spans.

Anton Kuleshov
Chief Project Engineer

« We decided on the extradosed system. In the early 2000s, such structures were quite a novelty. There were mere a dozen bridges built under this technology in the entire world. In Europe, there was only one such bridge — in Switzerland.

The St. Petersburg Institute presented an advanced engineering solution to the Latvian customer, the solution unprecedented both for Russia and Europe. This ingenious design put the Company far ahead of the rest of competitors seeking to obtain the General Designer contract. For Giprostroymost, this type of bridge was a novelty; however, the Institute team was always keen to master new technologies.

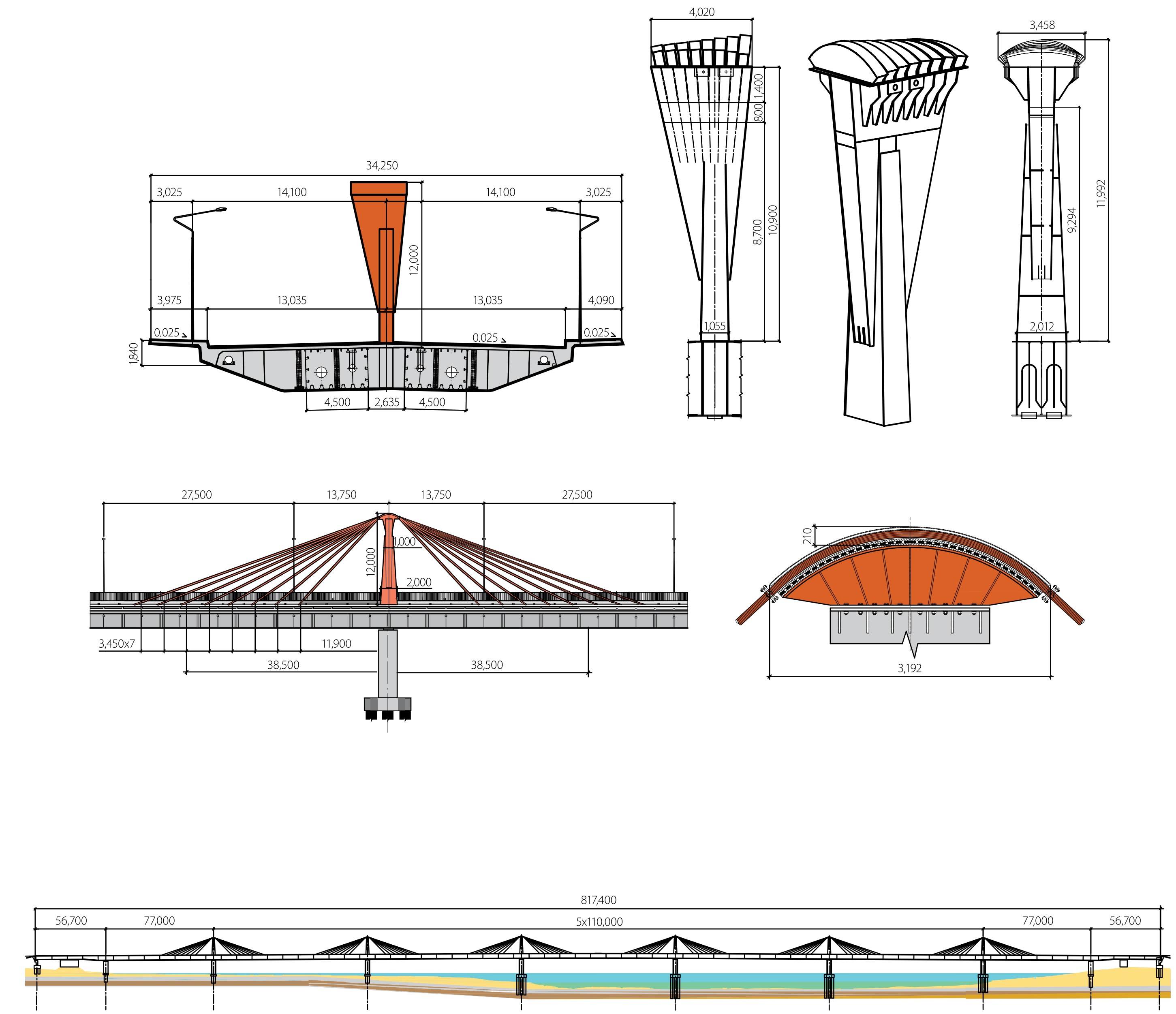
The Southern Bridge's unique appearance fit in harmoniously in the Daugava panorama along with the existing bridges. It was inaugurated right before the Independence Day which symbolized Latvia's European vector of development.

“The Southern Bridge is a well of innovations. It was the first extradosed bridge in Latvia which was a remarkable thing. This structure with pylons of distinctive shape and bright color blended seamlessly into the cityscape. Today, extradosed bridges are quite common; however, at that time the Southern Bridge was an extraordinary project in terms of engineering facilities used for its construction.

Erik Mellier
Director, Major Projects Department,
Freyssinet International & Cie, France

3D model

BRIDGE ELEVATION

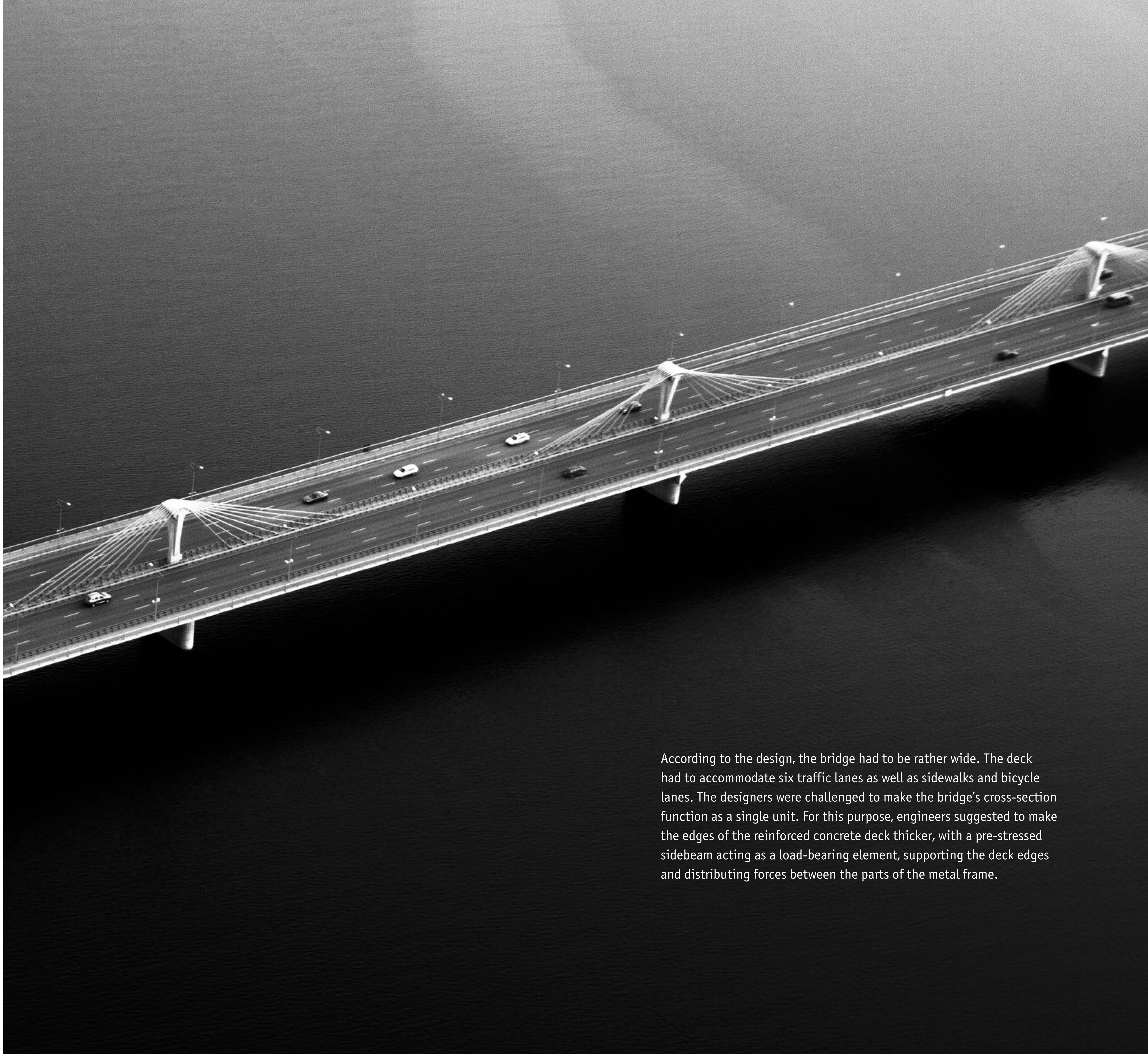


DESIGN SOLUTION

THE OLD NEW TECHNOLOGY

The term 'extradosed' comes from the Latin word *extra* (outer) and the French word *dos* (back). The term explains the concept of external reinforcement in this type of structures. For the first time, the external reinforcement of the tensioned concrete zone was used in construction of the bridge across the Saale River. This way, bridge builders tried to simplify the bridge's further operation. Sixty years later, a French bridge engineer Jacques Mathivat suggested a viaduct design in which pre-stressed elements would be placed above the deck surface running through special "saddles". The first bridge under the extradosed technology was constructed in Japan in 1994. Currently, Japan has the largest number of extradosed structures. Japan also holds the world record: the Kiso Gawa Bridge's span is 275-m long.

The extradosed technology combines the elements of traditional bridges where stiffness is achieved with a proper span girder, and cable-stayed structures where it is the stay pylon that accounts for stiffness. Extradosed bridge looks like a cable-stayed one; however, its static features are closer to those of the girder bridges. Extradosed design has a series of advantages and the major of them is lower metal consumption and higher cost effectiveness. The extradosed technology allows using less steel elements, shorter cables, lower and lighter span girder, as well as shorter pylons. For instance, the pylons of the bridge in Riga are 12-m high while the pylons of the Russky Bridge in Vladivostok surge up to 320 m. Extradosed frame is suited for longer spans with fewer support piers. If not for this system, metal consumption would be 300–350 kg per 1 m^2 of the span. In the Southern Bridge, this parameter is 230 kg/m^2. The city saved almost 3,000 tons of metal. Also, the post-tensioned deck plate is more durable and reliable.



According to the design, the bridge had to be rather wide. The deck had to accommodate six traffic lanes as well as sidewalks and bicycle lanes. The designers were challenged to make the bridge's cross-section function as a single unit. For this purpose, engineers suggested to make the edges of the reinforced concrete deck thicker, with a pre-stressed sidebeam acting as a load-bearing element, supporting the deck edges and distributing forces between the parts of the metal frame.

UNIQUE SOLUTIONS

The Southern Bridge's main girders were to be reinforced with short cables fixed into the girders and rested in the saddles of the pylons erected on the intermediate piers. A combined type bridge's cable-stayed system has a special feature: cables run at a shallow angle. This results in a greater horizontal force and a larger compression of the girder cross-section in the tensioned concrete zone above piers. These effects distinguish extradosed structures from the conventional cable-stayed ones where cables are meant for elastic accommodation of vertical loads.

Designers developed a unique structure to hold the cables bent over the pylons — "saddles". Saddles are metal tubes that keep cables in place and restrain strands from slipping. There are eight saddles on each pylon, one for every two cables. Tubes of complex geometric configuration rest on the support plate through the array of ledges. Each saddle keeps together 37 strands filled with fiber-reinforced concrete*. Never before did anyone apply such solutions to extradosed bridges. This innovation of global significance was developed by the Institute engineers in close collaboration with their French colleagues of the Freyssinet Company.

For the first time, the Cohestrand strands were used on the Southern Bridge with a special system of binding to coating. Each strand consists of seven galvanized wires and has an individual coating. All the strands are bonded in one common high-density polyethylene sheath. Strands then get anchored with jaws** manufactured by the French company Freyssinnet. Jaws get fixed to a block resting on a pivot nut. Anchors are sealed against the stay cables.

The advantage of an extradosed span structure is that stay cables are subject to lower fatigue stress since the value of tension deviation in the stay cable under superimposed loads on the spans remains rather low.

Thus, the design stress cycle for the Southern Bridge is about 36 MPa, while for cable-stayed bridges it normally is 200 to 250 MPa. This is due to the fact that the share of temporary loads carried by stay cables in the extradosed structures is usually below 30 %. Such a low value of stress cycle for extradosed bridges makes it possible to increase cable force up to 60–65 % of the breaking value to improve the cables' economic feasibility.

* Fiber-reinforced concrete is concrete reinforced with fibers.

** Jaw is a clamping fixture in a shape of slotted tensed bush.

USING EUROPEAN STRUCTURAL CODES

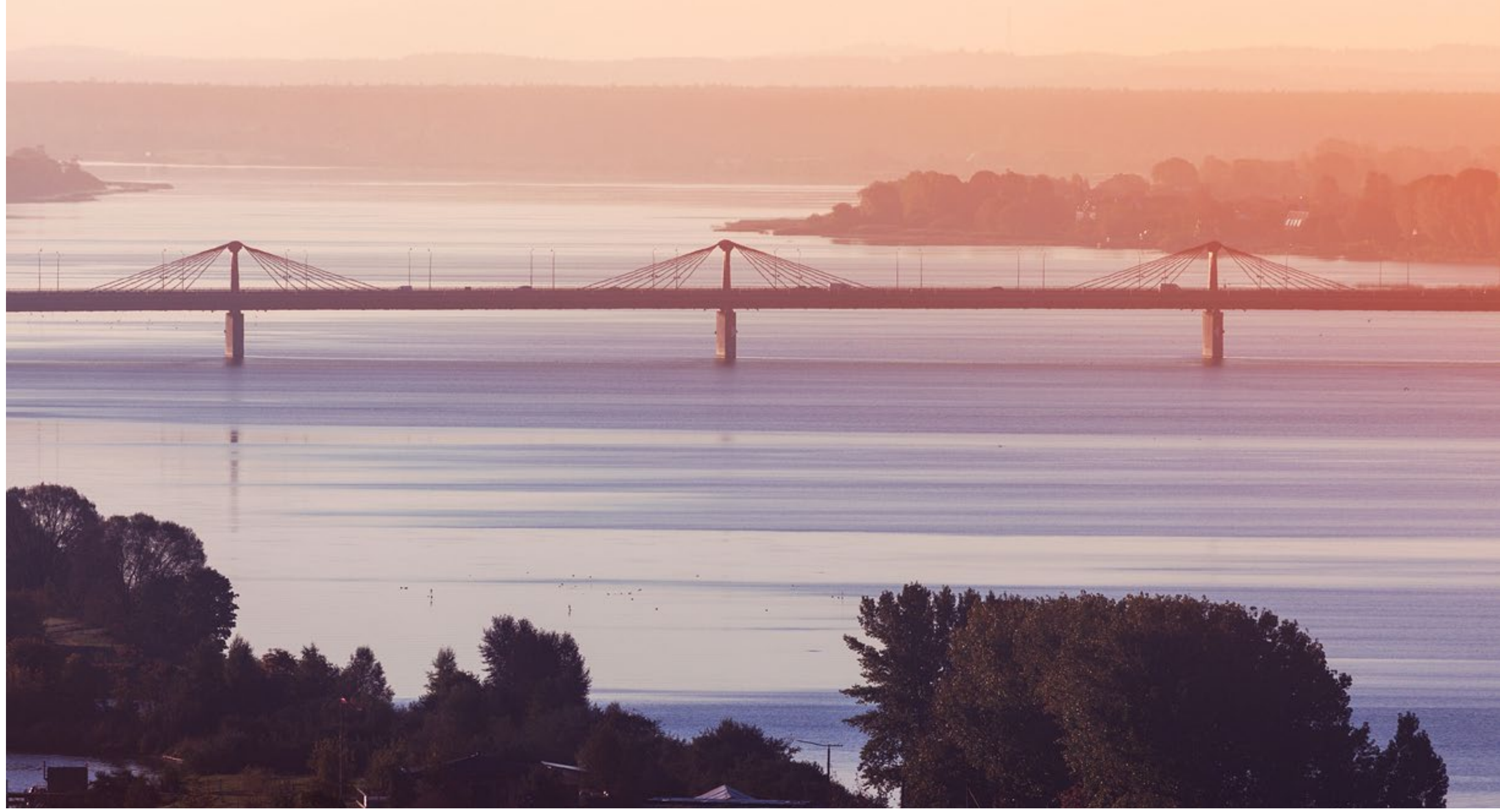
USEFUL EXPERIENCE

The design of the Southern Bridge and of the two interchanges on both its sides was performed in full compliance with the European standards*. Also, the Institute engineers were assigned to make design engineering of the reinforced concrete span of the railway overpass at the Slavu Street in Riga. Design engineering of those major structures required from the engineers to peruse a huge volume of the European standard documentation, in particular EN 1991-2, EN 1992-11, EN 1992-2, EN 1994 2:2005, EN 1993-1-9:2005.

The Institute had the experience in dealing with the European regulations and standards long before the bridge in Riga. Giprostroymost has been involved in international projects since mid-1980s. In 1987, while the documentation was not completed yet, the Institute specialists constructed five bridges across the Keitele-Päijänne canal in Finland. It was then that the bridge specialists from Leningrad — for the first time — faced the need to combine the European and the Soviet standards and codes. In 1995, collaboration with the Finnish company KORTES Ltd. called for using the European standards for design engineering of metal elements of steel-reinforced concrete span structures.

“ *The current European standards are even more strict than the Russian ones when it comes to loads and safety factors. However, in the Western regulations there are numerous sections relating to modern technologies of which the Russian codes do not even mention. At the same time, European standards give customers more freedom in making decisions which implies that they are qualified enough and know how to interpret the standards while being vested with higher responsibility.*

Igor Kolyushev,
Technical Director



The values and analytical methods for cross-sections, limit states, tensions, resistance are quite similar both in Western and in Russian codes. However, when designing a unique structure, it is required to use special sections such as related to aerodynamics, seismics and cable-stayed systems. Here, the European standards are of more use for designers than the Russian ones.

The advantage of the European codes is in the probabilistic method of estimating wind forces. The Russian standards containing estimated ratios are difficult to use in designing unique and complex structures. The European documents contain instructions on how to deal with pulsations, wind load ranges, and turbulence profiles which makes aerodynamic modeling much more precise and reliable, and structural analysis simpler. They also offer models for estimation of vortex shedding and flutter while the Russian codes do not. Neither does the Russian SNiP** regulate stay cable design. All the durability, endurance, water and corrosion resistance estimations are regulated by the European standards EN 10138, EN 1993-1-11:2006, EN 1993-1-11:2006 or SETRA/CIP recommendations.

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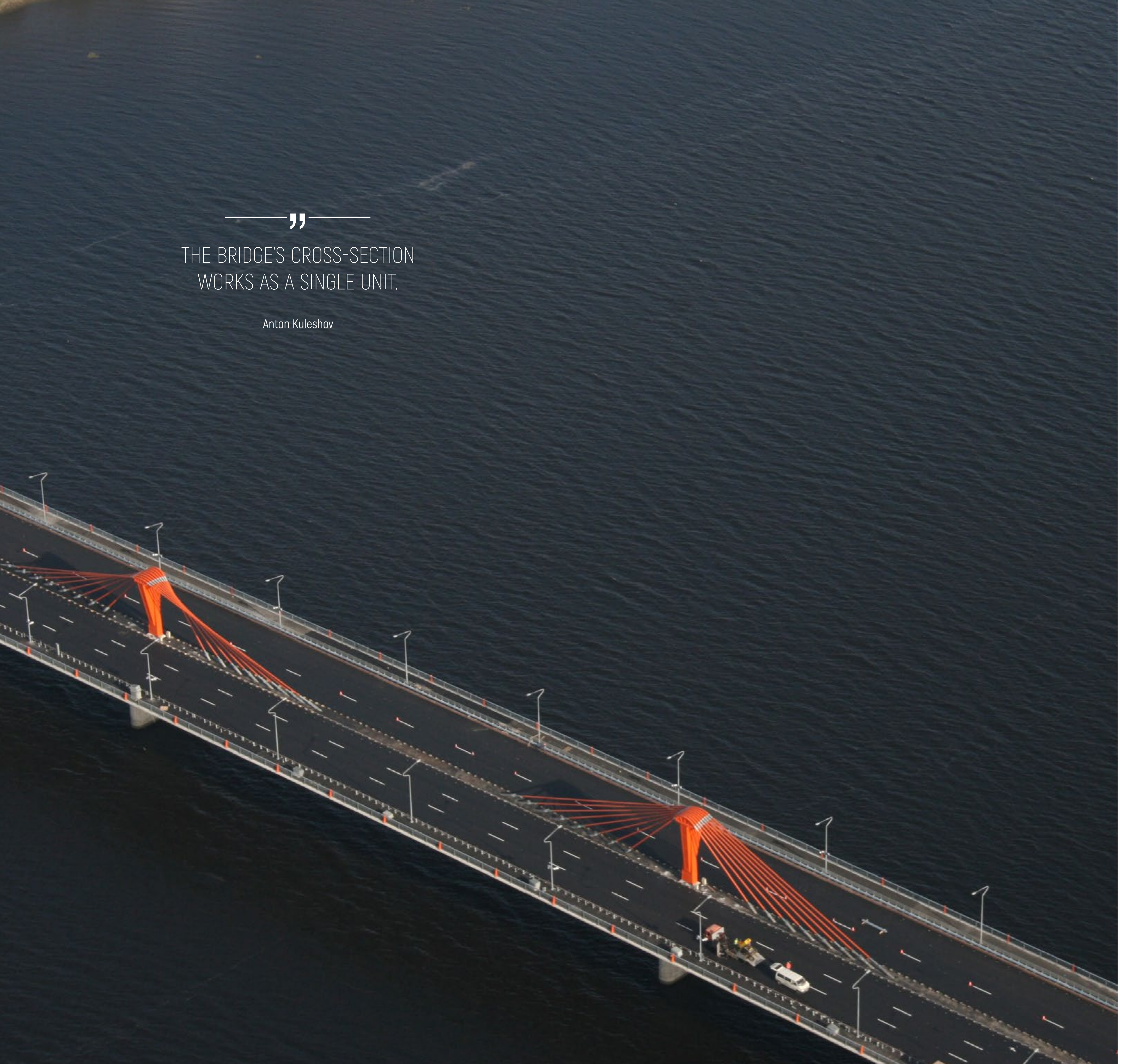
* European standards or Structural Eurocodes is a suite of European standards (hEN) for load-bearing structures design.

** SNiP – Construction Standards and Regulations. A system of regulations in construction in Russia.



> THE BRIDGE'S CROSS-SECTION WORKS AS A SINGLE UNIT.
>
> Anton Kuleshov

CONSTRUCTION PLAN

PERFECT ACCURACY

Under the construction plan developed by the Institute, the bridge's spans were to be assembled on the right bank of the Daugava River and, when ready, launched onto the piers. The entire process took six months from May to December 2006. For this purpose, sliding rails were installed onto the piers; those rails were made of metal plates in fluoroplastic coating with a low friction rate. A length weighing many tons would be pushed with six hydraulic jacks of 100-ton capacity each.

The maximum launching speed was eight meters per hour. The ultimate and the most crucial meters were launched even slower — at two meters per hour rate. Surveyors were monitoring for the slightest deviations from the launch course using special marks on the bridge piers. The massive 804-m long and 27-m wide structure weighing 7,000 tons was placed in the design position. The perfect accuracy of launching came as a result of the meticulously developed construction plan and the seamless actions of the Dienvidu Tilts, the highly experienced construction contractor.

In October 2008, the Southern Bridge passed the durability test which proved that the structure met all the European safety standards. The testing involved 32 trucks with the total weight of 1,280 tons moving on the bridge at different speeds which simulated normal traffic. Distribution of loads on the structures was registered by a vibration meter; after that, the researchers of the Riga Technical University have studied the bridge for potential deformations. The Bridge passed the test with the A mark.

PROJECT SIGNIFICANCE

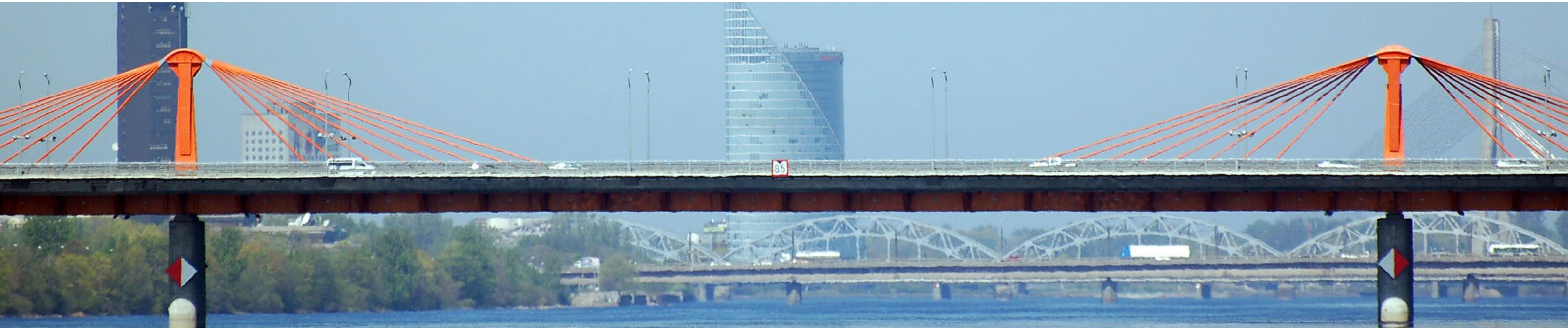
MESSAGE FOR FUTURE GENERATIONS

The Southern Bridge across the Daugava River has become the first significant construction project in Latvia in the 21st century. It is a functional, elegant and hi-tech structure that meets the citizens' expectations. Its off-beat design and innovative solutions perfectly fit into the Riga cityscape. One of the bridge piers contains a message to the future generations from the bridge builders. However, any bridge by itself is a message. The shape of the new bridge in Riga seems to tell: invent, don't be afraid of changes, dare. The bridge across the Daugava designed by the St. Petersburg engineers proved that engineering often has to deliver the solutions that take profound studies, out-of-the-box thinking and non-standard techniques.

This prestigious project became a hallmark for the Institute Giprostroymost – Saint Petersburg in the European Union and an entry-pass to the international professional community. After the Southern Bridge, the Company obtained contracts for designing new objects in the Baltic States — testing bridges and overpasses, complex engineering designs.

Igor Kolyushev
Technical Director

“The work on the Southern Bridge in Riga provided the Institute team with useful experience in interaction and collaboration with the Latvian design, construction and compliance monitoring organizations as well as with authorities.



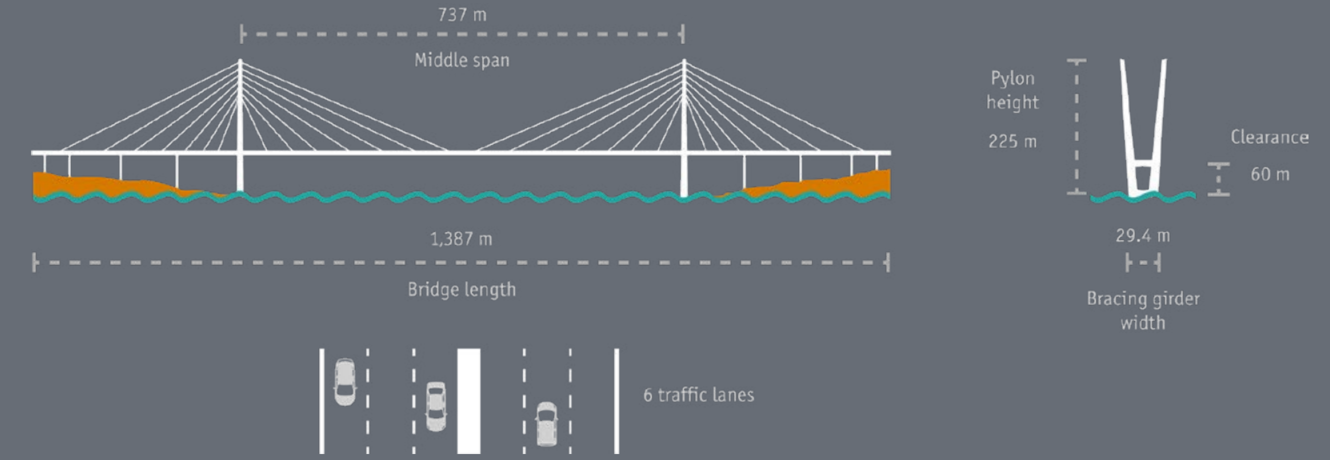
Golden Bridge Vladivostok

THE MODERN SYMBOL OF VLADIVOSTOK

The Golden Bridge is one of the five largest cable-stayed structures on our planet. Its unique V-shaped pylons have no analogues in the world. This man-made miracle of steel and concrete above the bay is worth seeing at least once in a lifetime.

The huge cable-stayed bridge in the center of Vladivostok runs across the Golden Horn Bay and connects the Ussuri federal highway with the Russky Island. Its 737-m-long middle span is one of the longest in the world. The pylons of the Golden Bridge have the shape of the letter V. While working on the design, the Institute engineers have for the first time dared to abandon conventional models and convinced their colleagues of the reliability of this solution.

To the local residents, these supports of unusual shape rising to 225 m above the water surface resemble seagull wings. The Bridge's impressive silhouette has become one of the symbols of Vladivostok. Neat and perfect design and power are clearly felt by anyone looking at the Golden Bridge.



PACKAGE OF WORKS ON THE PROJECT

- General design
- Design of engineering structures as part of the bridge
- Construction Master Plan for the bridge
- Design of major structures
- Developing technology, SAC&D, work design
- Financial estimates
- Designer supervision
- Obtaining General Board of State Expert Review assessment

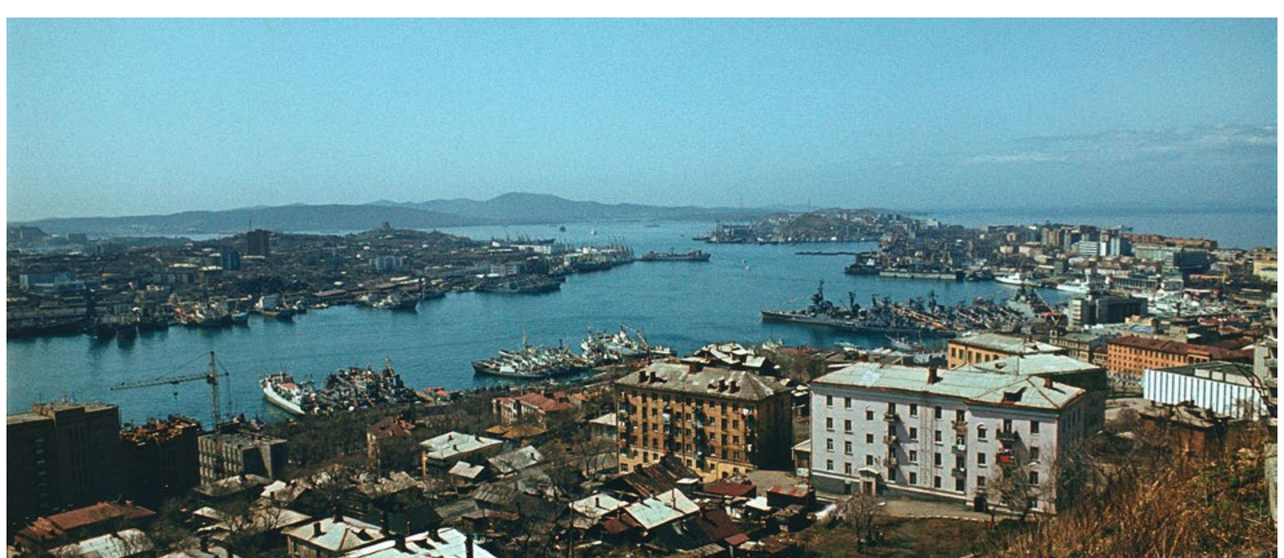
PROJECT BACKGROUND

THE LONGED-FOR BRIDGE

The capital of the Primorye Territory lies at the edge of the continent and is washed by the sea on three sides. The city climbs up the hills and clings to the coast rugged by water and winds. The narrow Golden Horn Bay divides the city into two parts and the locals used to have to make a huge detour to get to the other side. No wonder that the Vladivostok residents were dreaming of a bridge even one hundred years ago.

It was back in the late 19th century that the first bridge across the Bay was intended to be built. In 1903, when the Trans-Siberian Railway was put into operation, the Vladivostok seaport became a connection point for the freight routes between the West and the East; the bridge was to expedite delivery of cargoes. However, wars and revolution in the early 20th century put off the project implementation. In 1960s, the idea of bridges was raised again when Nikita Khrushchev, the First Secretary of the Central Committee of the CPSU visited Vladivostok on his way back from the USA. The Soviet leader was impressed with the picturesque coast of the seaside city and he decided to make it more beautiful than San Francisco. The bridge was included in the 1969 master development plan, however, that time again the plans remained on paper.

The Golden Horn Bay, Vladivostok, 1984



Fifty years later, the strategic decision was made to have three unique bridges — across the Golden Horn Bay, across the Eastern Bosporus Strait and across the Amur Bay — constructed for the 2012 APEC* Summit. In our country, there was no experience of building bridges across sea straits — let alone cable-stayed bridges of such length.

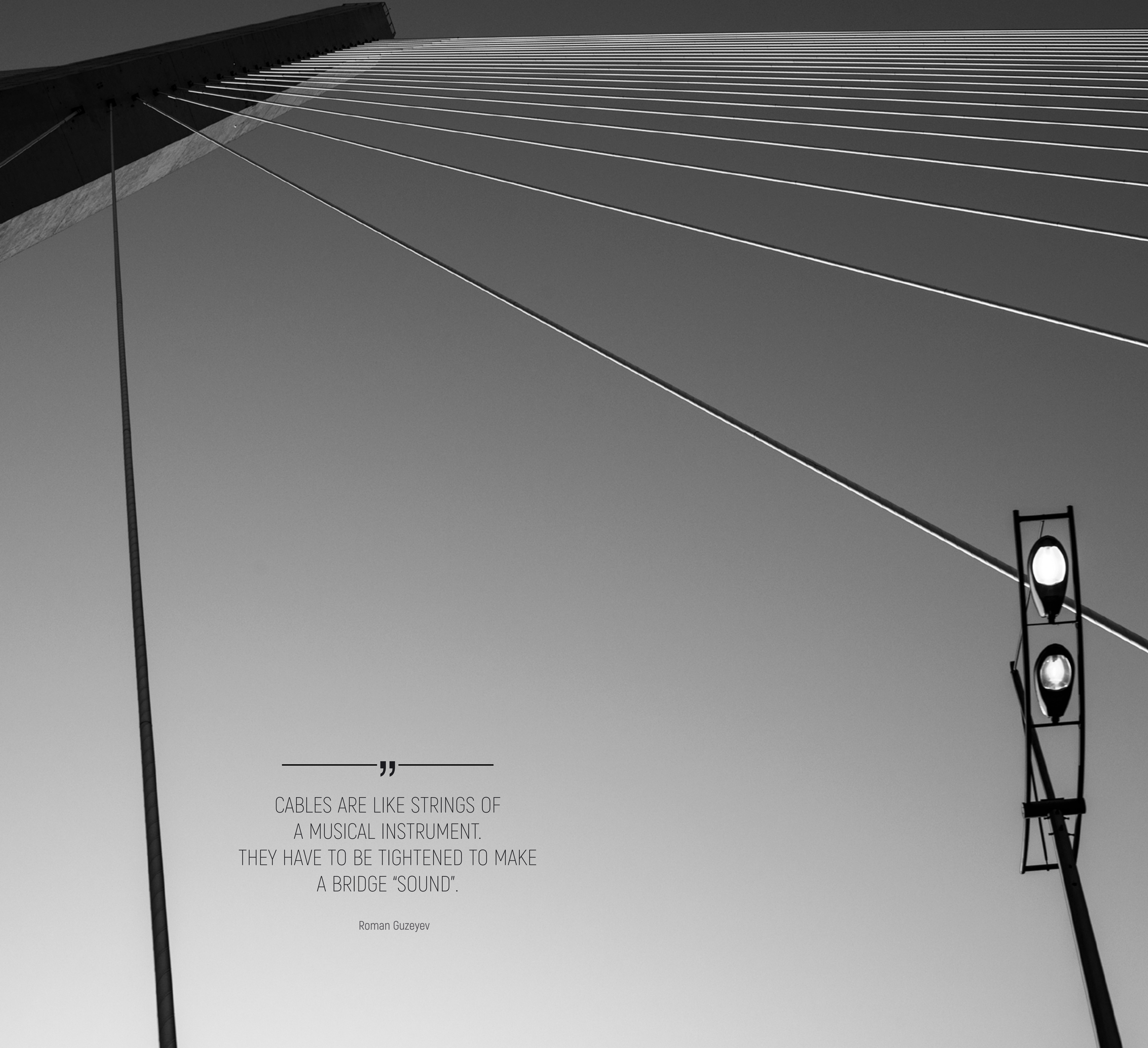
> “ *It was a challenge for our Institute to make the bridge across the Golden Horn Bay stand out from the numerous large cable-stayed structures already existing all over the world. On one hand, we were looking for a shape that would be striking and unique, on the other hand, it had to be technically feasible.*
>
> *Igor Kolyushev,*
> *Technical Director*

”

WE WERE TRYING TO FIND A SHAPE THAT WOULD BE STRIKING AND UNIQUE.

The Institute Giprostroymost – Saint Petersburg was chosen as the General Designer for the bridge across the Golden Horn Bay since by that time, engineers from St. Petersburg accumulated profound experience in designing cable-stayed structures. The Institute team made designs of the Bolshoy Obukhovsky Bridge and of the overpass at the Alexandrovskaya Ferma Ave. in St. Petersburg, designed the extradosed bridge across the Daugava River in Riga, was a partner in joint projects in Moscow and Kazakhstan. No other Russian design bureau could boast such an impressive portfolio. The customer — the Road Facilities Department of the Primorye Territory — appreciated the Institute's expertise in cable-stayed technologies and entrusted the Giprostroymost specialists with this project of national significance. The Golden Bridge design process took five years, from 2006 to 2011.

* APEC – Asia-Pacific Economic Cooperation. International Forum of 21 countries most of which are in the Asia-Pacific region.



> CABLES ARE LIKE STRINGS OF
> A MUSICAL INSTRUMENT.
> THEY HAVE TO BE TIGHTENED TO MAKE
> A BRIDGE "SOUND".
>
> Roman Guzeyev

CABLES STAY. NO OTHER WAY.

What type of design should be chosen for the future bridge in Vladivostok — that was a rhetorical question. From day one it was clear for the designers that it was impossible to put any piers in the bay: on the Southern coast there is an industrial zone with plants, docks and shipyards, large ports and the Pacific Navy base. It meant that a girder bridge was out of the question. The engineers also considered a low bridge with a draw span; however, they realized that there was no point in trying to make the bridge inconspicuous in the existing urban environment. Instead, they decided to make it a grand structure befitting the hills and the bay. Also, it was important to arrange full-scale traffic between the districts of the city of Vladivostok. A low-water design would not meet this objective.

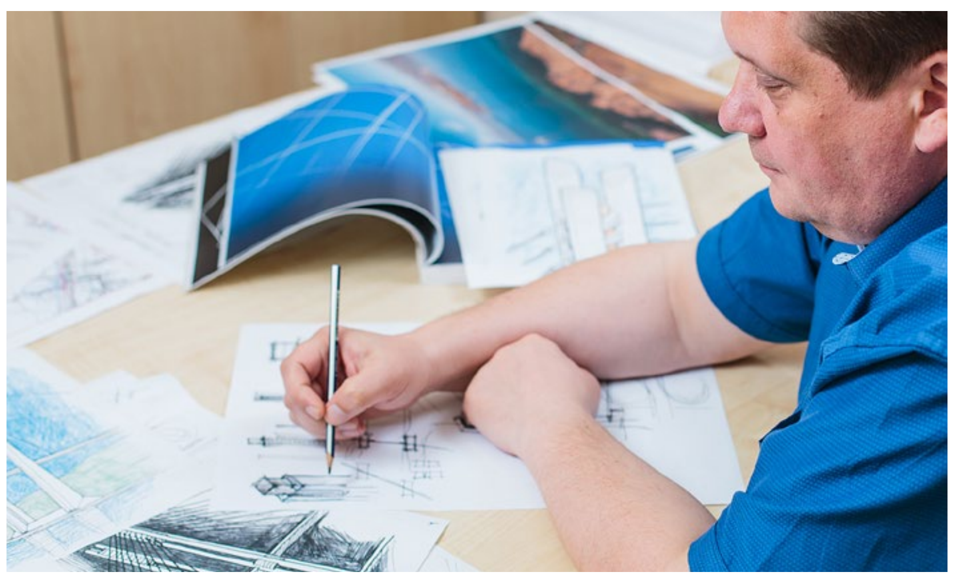
The bay in the area where the bridge was to be constructed is 700 m wide. Only a cable-stayed or a suspension bridge would be able to span such a width "in one go". The suspension bridge option was discussed by designers at the initial stage; however, soon they abandoned it, having agreed that a cable-stayed bridge would be more impressive in terms of architecture.

The choice of the cable-stayed design for the Golden Bridge was, among other things, determined by the challenging terrain: the difference in heights of the two coasts is almost 100 m. The bridge designers and constructors sarcastically dubbed the construction site "ski slope". Another strong argument for stay cables was high seismicity in the construction area. Steel cables ensure not only the structure's stiffness but also its seismic safety.

ARCHITECTURAL CONCEPT

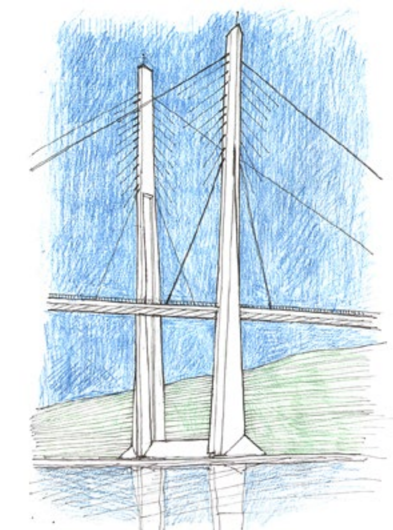
HARP, SAIL OR GULL WING?

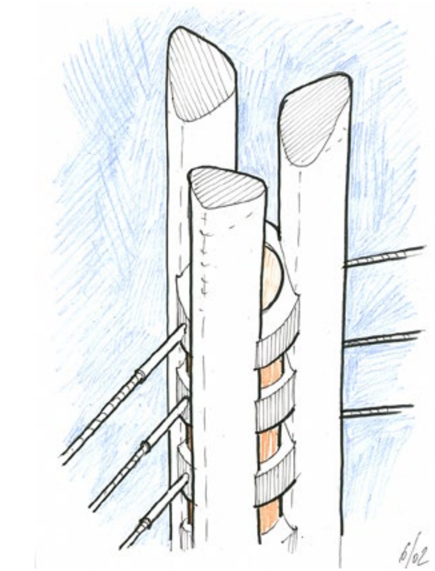
Some people compare the pylons of the Golden Bridge to a harp, others, to a ship’s sail or the letter V for Vladivostok and Victory. The bridge designers themselves compare their creation to the wings of a seagull. They all agree in one thing though: the Golden Bridge is truly unique. Having seen it just once, you would never forget its majestic silhouette, akin to the surrounding peaks, the sea and the sky above. There aren’t many bridges that stir emotions like that.

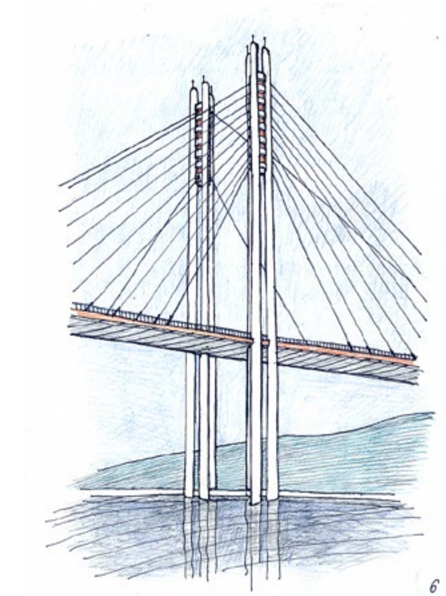


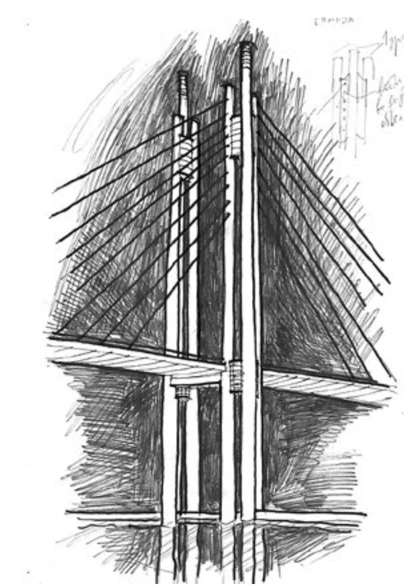
Alexander Malyshev
Chief Architect

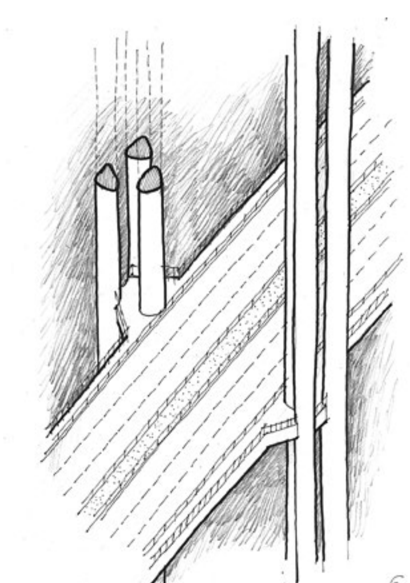
“ We strive to design bridges worthy of global renown not only for their structural solutions, but also for their architectural concept. The Golden Bridge is a unique case when a bridge of this magnitude is constructed in the city downtown area. It radically changed the Vladivostok cityscape. When we started working on the project, it was clear to us that we should not hide the bridge behind any sort of decorations. Look at the surrounding landscape: majestic coniform peaks are reflected in the ocean. Our bridge fit seamlessly into the skyline. It did not push the cityscape into background; instead, it became another landmark, a vector for development.

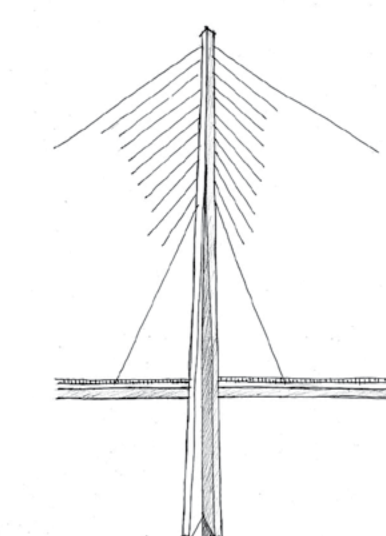












BRIDGE DESIGN PROCESS

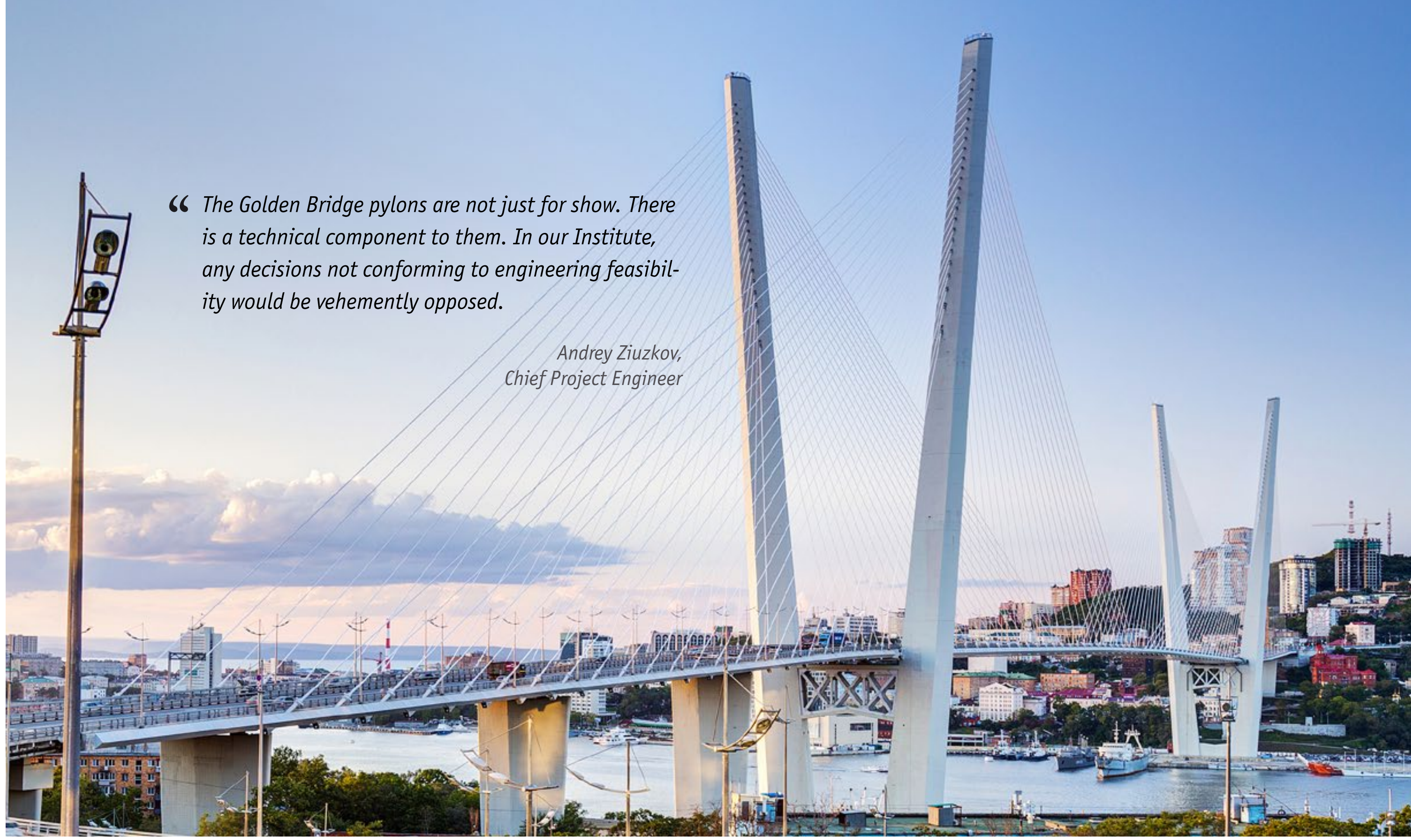
V FOR PYLON

The breathtaking pylons of reinforced concrete that stand on two coasts of the bay are 225 meters tall. Imagine two Peter and Paul Fortresses on the Neva banks standing on top of each other. The size, however, is not what matters most here. The pylons of the Golden Bridge are truly unique elements, something that no one has ever before attempted anywhere in the world. Their unusual configuration attracts not only thousands of tourists, but also global experts in bridge-building.

In pursuit of harmony between dramatic view and technical feasibility, St. Petersburg engineers abandoned the standard pylon shapes looking like letters A, H or inverted Y. At first, the designers looked into a solution with two vertical pylon pillars without a crossbeam at the top. But this would mean that the girder would have had to be made wider, with additional cantilevers for cable joints, which would have been less cost-effective.

Then the Institute engineers suggested a non-standard design of two pillars leaning away from each other without a crossbeam at the top. Given that the pylons had to bear a 737-m central span, the stakes were high. A challenge? Absolutely! Conventional solutions were already tested and trialed both by designers and construction workers. And even though the design of such a unique structure might entail more complicated technologies, the experienced Institute designers accepted the challenge, because they were certain that that solution would not only be feasible, but elegant as well.

In the end, the balance between a spectacular shape and feasibility was successfully achieved. The engineers were able to take advantage of the unique V-shape of the pylons: the weight of the pillars rising at a sharp angle from the base to the top balances out the horizontal component of the cables' load. Detailed trials of the design showed that the optimal balance could be attained when the inclination of the inner face of the pylon pillar equalled 5.8°. Furthermore, the non-rectangular cross-section shape of the pylons reduces the wind loads on these structures. All the analysis and subsequent construction proved that the decision on the engineering design was right.



“The Golden Bridge pylons are not just for show. There is a technical component to them. In our Institute, any decisions not conforming to engineering feasibility would be vehemently opposed.

Andrey Ziuzkov,
Chief Project Engineer

A unique architectural and structural design like this is always a combination of the possible and the impossible. The international bridge-building community speaks highly of this project. The fact that now professional magazines publish European designers' projects influenced by the Golden Bridge design is just another evidence of this recognition. The “gull wings” of Vladivostok fly far and wide across the globe.

Michel Virlogeux
International expert and consultant

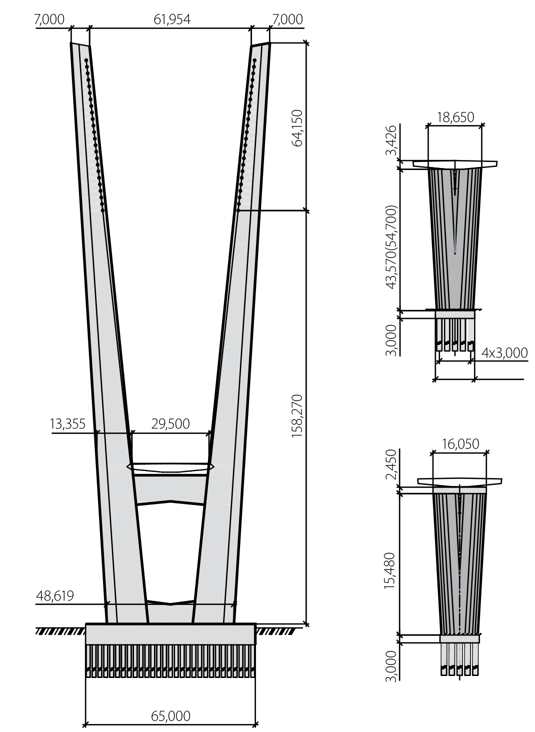
“Any bridge has to be constructed with the end goal in mind. The V-shape of the Golden Bridge pylons makes its structure quite impressive. A crystal clear and neat design would always look better than a cumbersome, excessively intricate project. In reality, engineers today have to seek elegance in their work. Elegance is achieved through simplicity.

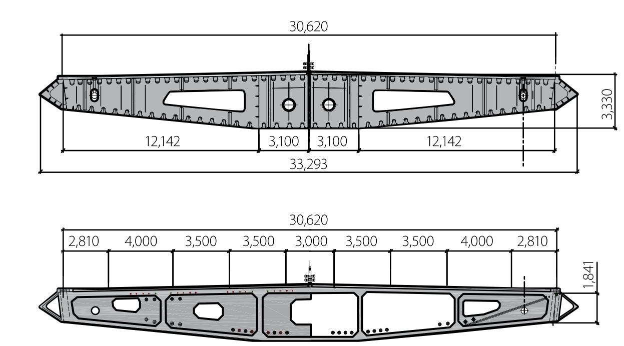
THE BRIDGE DESIGN IS PURE FUNCTIONALITY, SILHOUETTE AND STRUCTURAL SOLUTION.

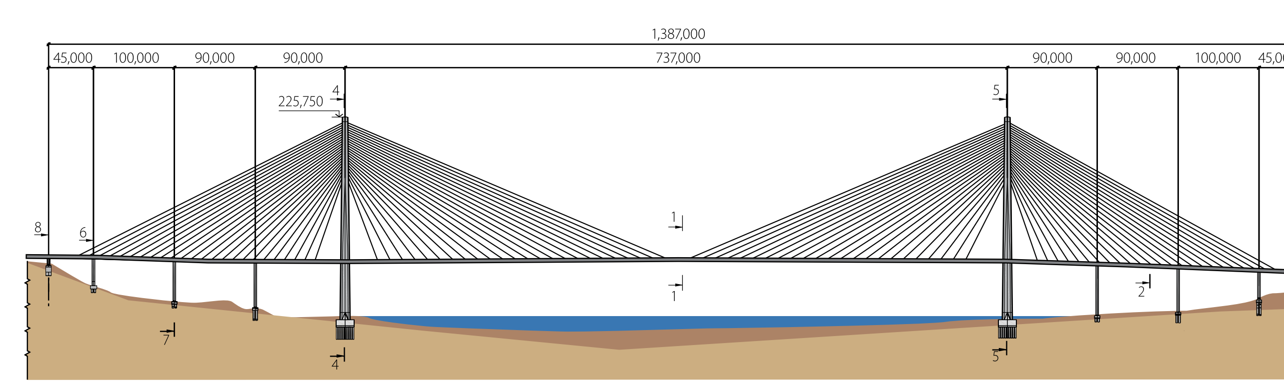
Alexander Malyshev

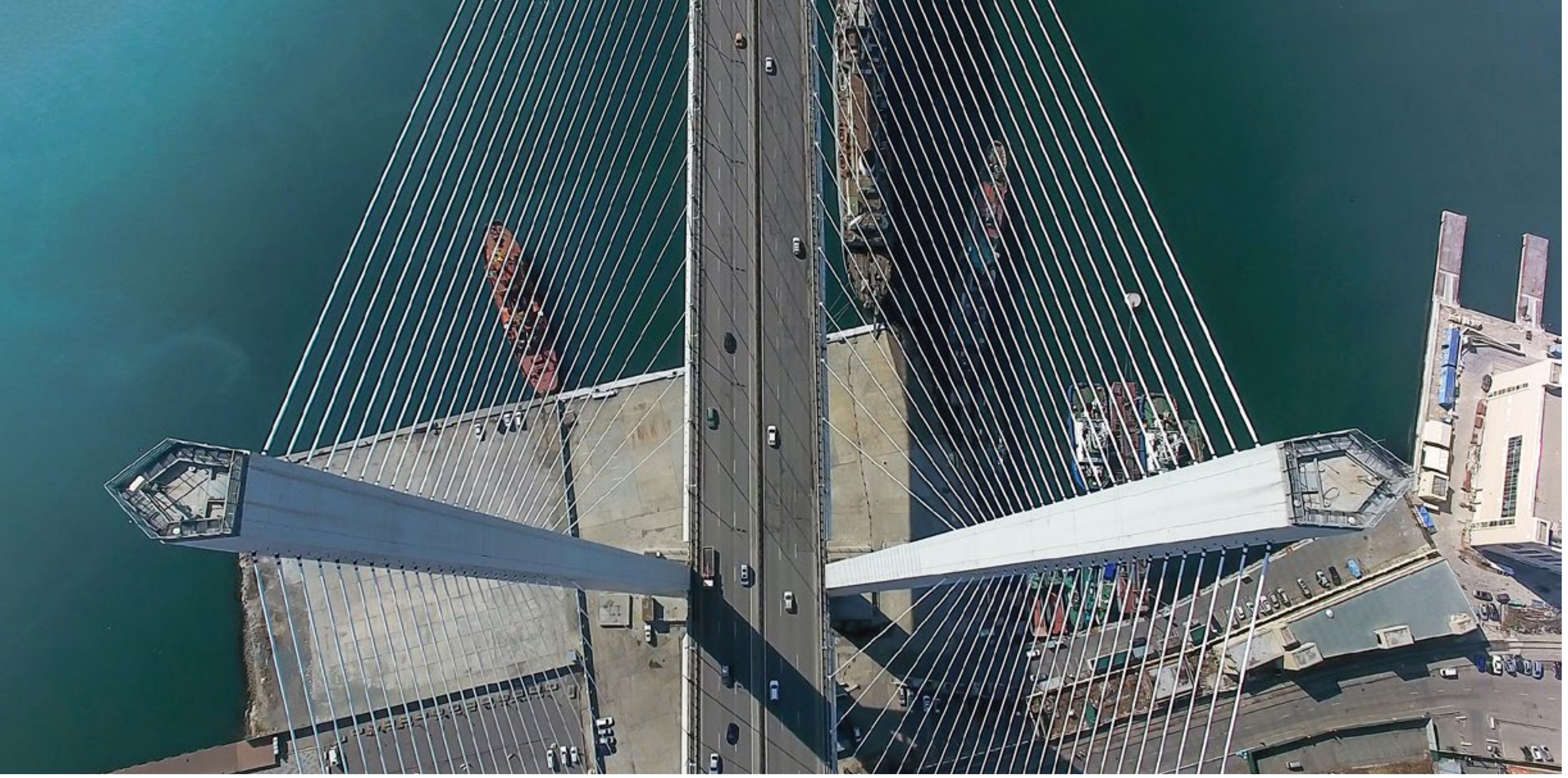
3D
3D model

BRIDGE ELEVATION









DESIGN TRIALS

IN A WIND TUNNEL

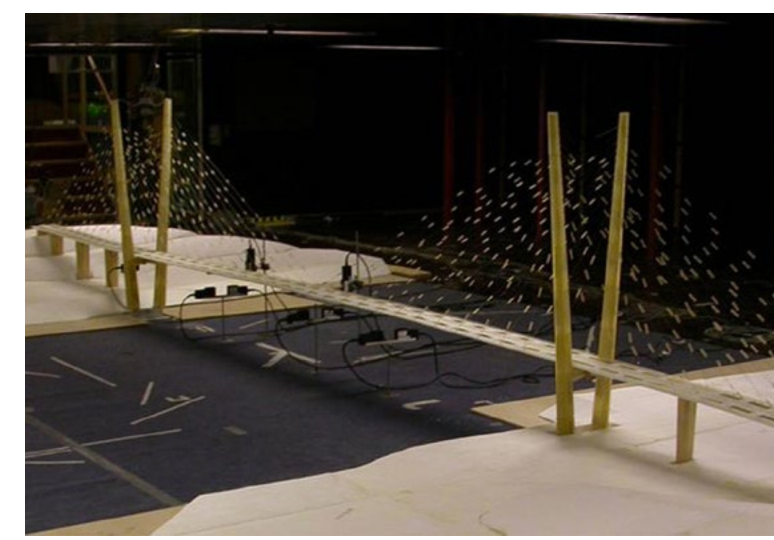
In accordance with the wind action code, the Russian territory is divided into eight regions. The city of Vladivostok lies within the region four: the air currents load on various structures equals 48 kg/m². Vladivostok residents often joke about this, 'The weather is fantastic! Rebars are gently swaying in the light October breeze'.

Wind loads are the determining factor for cable-stayed structures. To figure out whether the wind might cause dangerous vibrations in the bridge during operation, the Institute engineers performed a series of complex aerodynamic analyses. At the next step, a bridge model was trialed in an aerodynamics laboratory. For the first time, similar tests were performed in Russia in the early 21st century when the Institute was working on the design for the Bolshoy Obukhovsky Bridge in St. Petersburg. The first test was performed in the wind tunnel of a reputable Force Technology Institute in Denmark. Several years later, the engineering design of the Golden Bridge was tested in the same Copenhagen laboratory.

The first stage — numerical analysis of the structure — was performed with a computer simulation. Cable-stayed bridges are always designed to withstand significant loads. Wind speeds vary at different heights; that is why it is crucial to determine a critical wind speed threshold above which certain elements of the structure may be subject to negative effects.

At the second stage, specific sections and a full model of the bridge were tested for aerodynamics which required the entire team to be well-versed in various engineering fields. To achieve greater accuracy of the testing results, the Golden Horn Bay landscape was recreated in detail within the wind tunnel. The tests showed that theoretical computations differed from the practical outcome. Analysis of the test results and adjustments of the engineering design were performed at the third and final stage of the bridge aerodynamic testing process.

Aerodynamic tests of a complete model of the bridge



> ANALYSIS OF WIND LOADS REQUIRES AN EXTENSIVE SCIENTIFIC KNOWLEDGEBASE.
>
> Igor Kolyushev

Analytical calculations showed that flutter* may occur at wind speeds of 124 m/s. Testing a bridge section in the wind tunnel revealed a different critical threshold — 144 m/s. The Institute specialists also ascertained the speed at which wind resonance manifests itself.

During the tests, the critical wind speed of 38 m/s was determined for the top section of the 225-m pylon; however, the wind resonance response was rather small — only 7 centimeters. It is important to note that all calculations and tests were performed in compliance with both Russian and European standards and codes.

* Flutter – a combination of self-induced continuous oscillations within a structure.

Igor Kolyushev
Technical Director

“ The Russian engineering school has significant experience in aerodynamic calculations when it comes to aviation. With aircrafts, all the effects occur at very high speeds. With bridges, however, hazardous resonances occur at relatively low speeds combined with certain parameters. From the very start, the Institute engineers realized that the wind load analysis had to be tested and scientifically proven even at the design stage. Aerodynamic behavior of the bridge cannot be fully investigated with simple analytics, which, therefore, calls for a detailed testing of the structure’s to-scale model in a wind tunnel.

“ During the testing of the Golden Bridge model, we had to be very precise in defining the scope of study for our Danish colleagues.
In other words, we had to specify an area for identification of negative aerodynamic phenomena which might occur at the construction or operation stages of the project. The engineers had to mathematically define various potential risks for the central span: namely, frequency parameters of the structure and oscillation amplitudes which should be considered hazardous and non-hazardous. It was important to draw up the testing program correctly: with due consideration for angle of attack, vehicle positioning on the deck and so on. We were thoroughly prepared for the tests, and fully aware of all potential risks and complications even before approaching the wind tunnel. Processing and analysis of the test results was performed in close cooperation with the specialists of the Danish laboratory.

Roman Guzeyev
Head of Bridge Analysis Department

RESPONSE TO EARTHQUAKES

Almost half of the territory of the Far East is located within the earthquake zone. The Primorye Territory is especially notorious for earthquakes of high magnitudes. At present, there are no technologies able to predict a date and place of these natural disasters with 100 % accuracy. It is possible, however, to predict the magnitude of potential earthquakes in a particular area and take these data into consideration at the basic and detailed design stages of a project.

The Golden Bridge is capable of withstanding magnitude 7.6 earthquakes. There are eight shock-transmitting units on its pylons. These steel hydraulic cylinders redistribute seismic shocks. They can be compared to a car seatbelt. These transmitters allow for the bridge spans' "breathing", that is, for free motions at temperature changes. Such motions cannot even be seen by the naked eye. However, during seismic activity, these shock transmitters get activated and redistribute loads from seismic shocks along the bridge pylons. Each of these eight units is capable of bearing up to 1,500 tons of weight. Pistons have a travel limit of approximately 300 mm. This arrangement is activated immediately whenever the bridge span would oscillate at a speed of over 1 mm/s. This part of the design was developed by the Institute engineers in full compliance with the European standards. Shock transmitters were manufactured by an Italian company FIP INDUSTRIALE S.r.L. following the EN 15129 standard. This standard foresees two levels of seismic activity with varying probabilities of occurrence: strength-level events and maximum credible earthquakes. These parameters are not foreseen in the Russian codes.

Designers often refer to cable-stayed bridges as living beings, as they exhibit complicated behavior patterns both during construction and operation. Natural disasters are hard to avert, but engineers have to foresee all the potential risks at the design stage of the project, and ensure its maximum possible safety.

DEVELOPING CONSTRUCTION TECHNOLOGIES

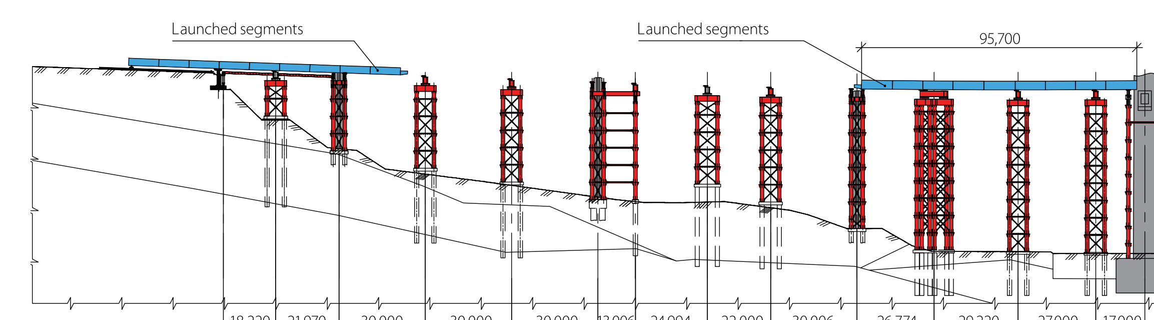
CONSTRUCTION SITE IN THE CITY CENTER

The Golden Bridge seems to soar in the air, revealing new properties of regular construction materials. Steel and reinforced concrete element give the bridge a solid yet dynamic feel. Looking at it, one admires its airy silhouette and cannot fully comprehend the sheer complexity of design and construction of this structure.

The total length of the bridge including approaches, interchanges and a 250-m long tunnel is over three kilometers. The major challenge the project posed was the fact that the construction site was in the city center, amid residential buildings and busy streets.

Vasily Nikolayev
Chief Project Engineer

“There cannot be two identical bridges since every single one is built with specifics of the construction site in mind. In Vladivostok, on one side of the bay there is a seaport, on the other side — a Navy base. There’s a hill to the left and another hill to the right. We had to devise a construction technology so that it would fit in this environment. To create an elegant structure, one has to develop unique technologies and procedures. My colleagues and I have to invent new designs and structures for each specific bridge.



To construct scaffolding* for concreteing sidelong sections of the deck, engineers designed additional temporary bridges on either side of the bridge. They were assembled right above the streets and buildings of the city. First, a platform was built on the hill, from which sections of the scaffolding were launched towards a pylon.

The cranes were unable to reach the assembly area from the bottom, so metal structures had to be assembled in the construction yard; afterwards, each section was first launched laterally then slid transversally. Further, the sections were covered with boards, formwork was put in place, after which the bridge deck was concreted from the scaffolding.

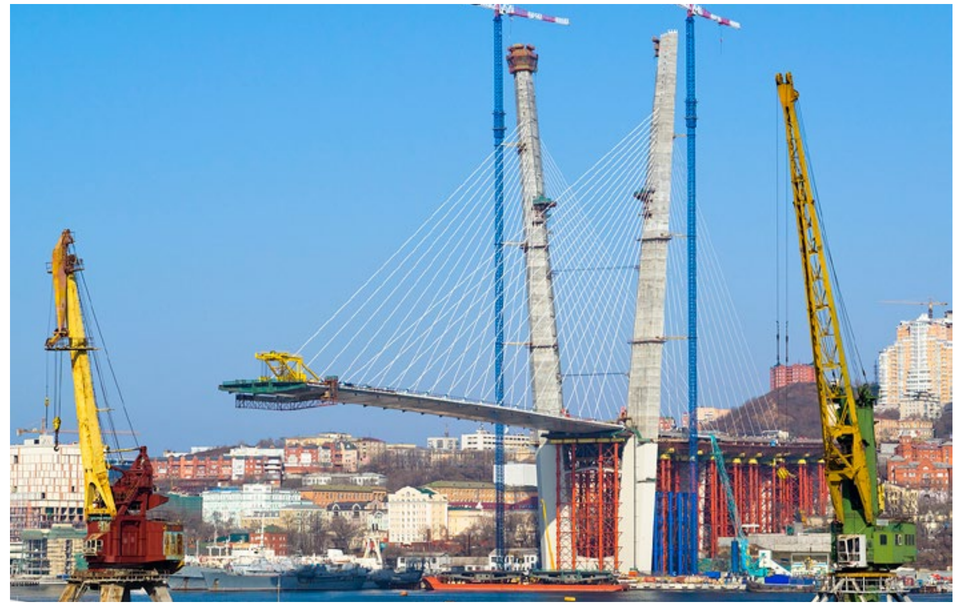
* Scaffolding is a special platform used for assembling bridge span or its sections, which are then launched from this platform to their design position.

Designers always try and find the most feasible solutions. For instance, scaffolding used during the bridge construction first were to be custom made of I-beams.

But the contractor insisted on the beams to be reused after the construction was completed. The Institute engineers complied, and, as a result, typical bridge span sections were used, which could then be reused for other construction projects.

Another remarkable feature of the Vladivostok bridge is that the pile caps* of pylons are made of self-compacting concrete. It has never been used in Russia before this project. Construction work was further complicated by two factors: first, large dimensions of the structure — each pile cap had a height of 8 m and a volume of 10,000 m^3; second, pile cap's high reinforcement density.

* Pile cap is the foundation of the pillar, a concrete mat capping all the piles that support the pylon.



With the help of the Institute specialists, a special mixture has been developed, the work procedure devised, and concrete was continuously poured for days on end. The material was supplied by four different concrete-mixing plants. In total, some 60,000 cubic meters of concrete were used for the pylons and pile caps of the Golden Bridge. To deliver such volumes of concrete, one would have to use a 27-km-long train of 1,950 freight cars!

To balance out the massive inclined pillars of the pylon at the concreting stage, they were braced with bundles of 15-mm flexible steel strands on two different levels. Pylon pillars were divided into 56 sections, each 4 m tall, into which concrete was to be poured. For the pillars, special screw profile rebars were used; instead of welding, these bars were connected to each other with threaded couplings. This technology has significantly expedited the concreting process.

"Gull wings" of the pillars grew day by day. The process was well-documented on countless photographs. Never before were the bridge builders under such scrutiny from both journalists and local residents. Vladivostok citizens watched closely, as the grand concrete pillars gradually were rising above building roofs. The Institute specialists were monitoring the process day and night, observing how pylons reacted to the wind and changes in weather, constantly checking any changes against the design parameters and making amendments to the assembly process whenever needed.

MONITORING THE STRUCTURE

BRIDGE UNDER TIRELESS SCRUTINY

> THE BRIDGES YOU DESIGN ARE NOT JUST FUNCTIONAL, THEY ARE BEAUTIFUL, TOO.
>
> Pekka Toivola

Designers guarantee that the bridge across the Golden Horn Bay will serve people for at least 100 years — almost as long as the city dreamed of it. But even such a colossal structure requires constant attention and maintenance. The Golden Bridge is constantly affected by the nature's destructive forces. Strong winds rock the pylons and the girder, sea mists containing corrosive salts eat away at the metal elements, seismic tremors constantly test the structural strength. But to see the effects of these forces, a simple observation would not suffice. Instead, the bridge's state and behavior are constantly monitored by a special system developed by the Finnish company Savcor.

Hundreds of Futurtec sensors were installed on the cables, pylons and girders of the bridge in order to detect any deformations and to immediately inform operator of the same. These devices monitor tension, inclination, acceleration and control point displacements in real time. They also watch for any changes in weather: speed and direction of sea winds, atmospheric pressure, temperature and humidity.

The monitoring system had been installed by the Western specialists before the construction was completed. Sensors were attached one by one, as the construction progressed. The total length of data transmission cables installed on the bridge — a combination of optical fiber and copper cables leading from each sensor — is almost six kilometers. The bridge across the Golden Horn Bay was a unique project for the Finnish specialists in its own way, as for the first time in their practice they had to work with GLONASS system sensors monitoring displacement of the pylons and bridge span sections.

Pekka Toivola
Head of Structural Health Monitoring Department with the Finnish company Savcor

> *It was an outstanding technological project, as we had to work with a unique system of stay cables and optical fiber cable channels. The monitoring system was installed with the help of the specialists of the Institute Giprostroymost. Our colleagues developed the necessary documentation, which clearly showed where each type of sensor had to be installed. It was not an easy task, as the pylons were 225 m tall, the bridge span was 700 m long, and we had to make sure that every single element of the system worked as intended. We didn't just deliver a box of sensors and electronic equipment to the site. No, we spent nearly a year on-site, monitoring the process closely and making adjustments wherever necessary.*

The Finnish specialists recognize the Russian engineers' lead when it comes to the standards of monitoring systems. Currently, there are no such standards in Europe while the first Chinese edition was issued just in 2018. Our country was ahead of the West and the East in developing those standards and the credit for this should be given to the Institute Giprostroymost – Saint Petersburg. Ambitious projects of the Institute that are among the world's ten largest man-made structures, were created through a dialogue between engineering schools. When designing and constructing bridges, Russian and Western specialists learn from each other and adopt each other's best practices.

PROJECT SIGNIFICANCE

LIFE IS GETTING FASTER

The Golden Bridge changed the life of Vladivostok residents for the better. From the mid-19th century to August 2012, people had to drive along the Golden Horn Bay that cuts the city in two. Mere six years ago, the route from downtown to the Goldobin Peninsula would take at least one hour or even one hour and a half. But now, it's just a short drive by car. A tour of the three bridges designed by the Institute engineers became a must for any visitors who come to the capital of the Russian Far East.

“ *Every year in September, thousands of athletes from Russia and Asian countries participate in a marathon along the Golden and the Russky Bridges. Usually, these bridges are closed for pedestrians. But for the International Vladivostok Marathon the city authorities make an exception. Initially, we even called this run Vladivostok Bridges. Looking weightless from afar and mighty up close, these beautiful bridges are quite a challenge for the athletes. The Marathon route is not easy as it is, with many a climb and dive along the way, but the famous bridges make running even harder. However, runners are quick to forget their hardships as they see the spectacular view that opens up onto the city, the sea and the surrounding hills.*

Hundreds of photos from the Golden and the Russky bridges would be posted online when the race is over. It means that people from across the globe, runners from China, Japan, South Korea, the USA, Thailand and other countries were all impressed with the scope and beauty of these structures. Man-Made Wonders is what tourists call the new bridges in Vladivostok.

Olga Gayeva,
Director, Vladivostok International Marathon

“ *Designing structures like the Golden Bridge immediately moves a design bureau's rank several notches up. In the world, there is only a handful of companies capable of performing engineering design for a bridge of this size. They accumulated vast technical expertise and fundamental knowledge base. Having completed the Golden Bridge project, our Institute joined the ranks of the world-class designers and pushed on to the next level in the design industry.*

Igor Kolyushev,
Technical Director

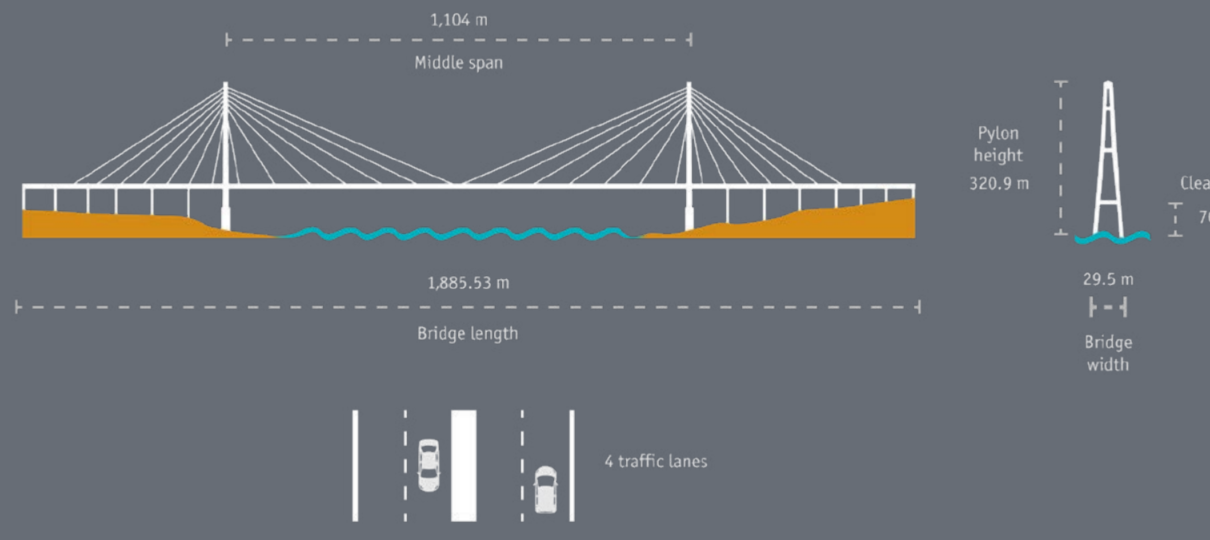
Russky Bridge   Eastern Bosporus Strait, Vladivostok

THE RUSSKY BRIDGE IS A RECORD BREAKER

For the first time, a bridge connected the Russky Island with the mainland. The unique transport infrastructure facility opened new frontiers for the Far East region development.

The 1,104-m-long middle span of the Russky Bridge is the largest in the world for this type of already accomplished projects. The structure that crosses the Eastern Bosporus Strait has the minimum span length-to-width ratio. As of today, it is the longest cable-stayed bridge on the planet. 'Europe took back the world record from Asia!', say the Western designers of the Far East project implying that the Russian and European approaches to engineering are akin.

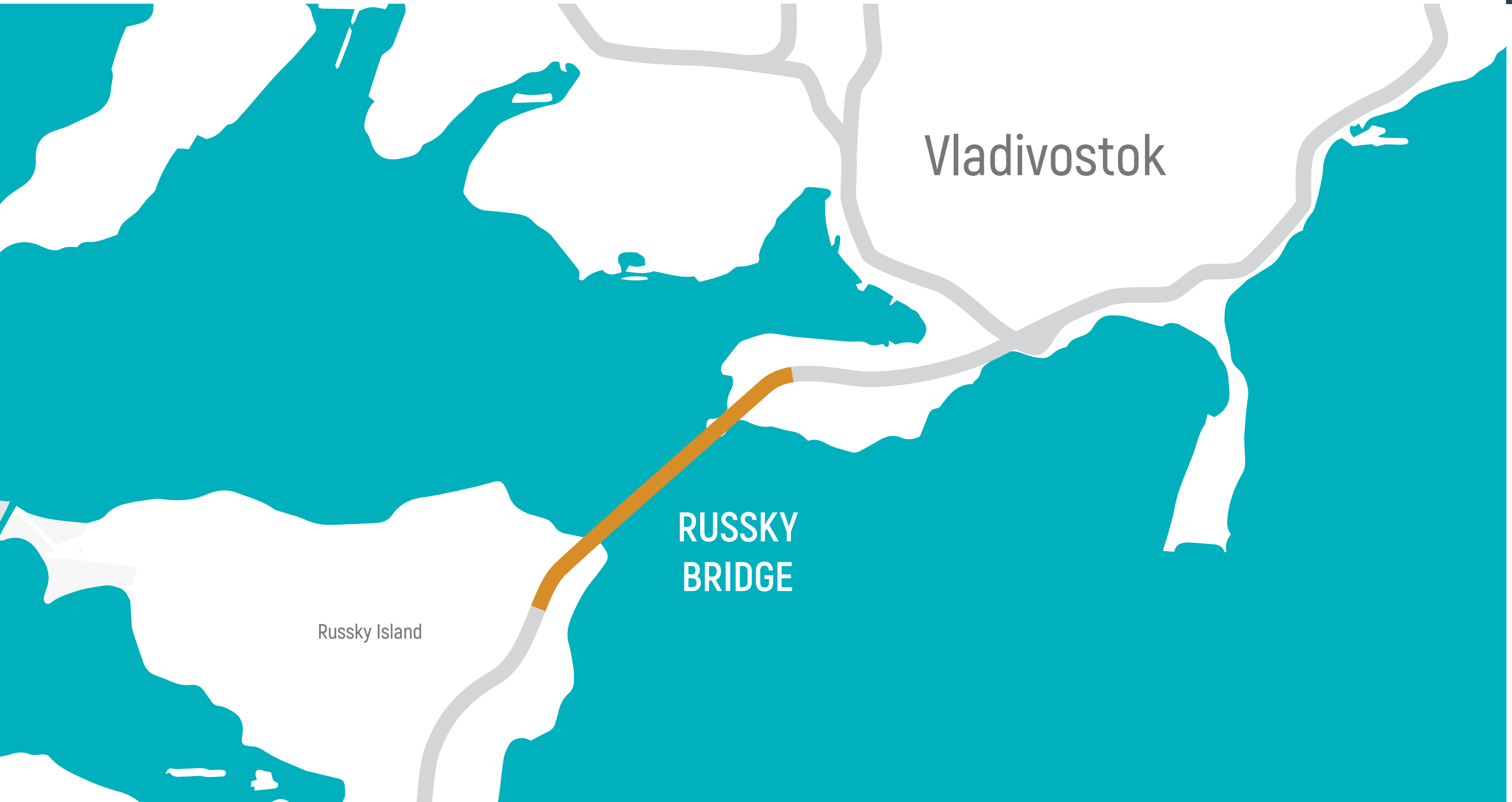
While geographically the Russky Bridge is closer to the Sutong Bridge in China — the second largest in the world — than to the European structures, this project is a quintessence of the European technologies. In the design process, the Institute engineers were drawing on their extensive expertise and experience in creating cable-stayed structures.



PROJECT BACKGROUND

KEY SUMMIT VENUE

The Russky Island is the largest one in the Peter the Great Bay with the area of 97 km². The island was integrated into the Russia's territory in the mid-19th century. It was the first land to greet commercial and naval vessels in the Far East. Having been taken under the supervision of the Chief Naval Base of the Pacific Fleet, the island for many years remained closed to public. In the mid-1990s, having shed the status of a restricted zone, the Russky Island became a popular holiday destination. Vladivostok residents and visitors used ferries to get to the island from the mainland. Sea vessel navigation to a large degree depended on the weather and would often get halted until a weather alert was cleared. The Russky settllement became a part of the City of Vladivostok in 2005. However, the new status did not bring any significant changes. Five thousand residents of the island still had to use the Amur Bay and the Rishko Brigadier ferries to cross the Eastern Bosporus Strait, had it not been for the Asia-Pacific Economic Cooperation Summit to be held in 2012.



The twenty-fourth APEC Summit was to take place in Vladivostok in early September. The International Forum set the vector for further economic development of our country and gave a powerful impetus to the region's economy. Investments into the Forum organization amounted to 600 billion roubles.

Over 50 transport and social infrastructure facilities had to be constructed before the Summit, laying the groundwork for the Far East modernization and innovative development. It was decided that the key events of the Summit were to be held on the Russky Island. A new bridge across the strait had to become the key thoroughfare for the leaders of the Asian-Pacific countries to reach the venue. On August 31, 2008, the President signed a decree for construction of the unique structure across the Eastern Bosporus Strait. Exactly four years and two days separated that date and the Forum opening. Few people believed that a project of this magnitude could be completed in such a short time.

PACKAGE OF WORKS ON THE PROJECT

- The design stages: principal structures, SAC&D (Special Auxiliary Construction & Devices)
- Supervision of engineering solutions
- Engineering design revision
- Aerodynamic tests
- Supervision of main girder construction

THE CHOICE OF STAY CABLES

The choice of the Russky Bridge structural design was based on the combination of the terrain, climate, seismic and geological features of the area encompassing the Nazimov Peninsula and the Novosiltsev Cape. Some of the key factors for making this choice were the navigation conditions in the strait and requirements to the bridge clearance.

Over 250 vessels pass through the Eastern Bosporus Strait every day. Intermediate piers installed in the strait would be an obstacle to the heavy traffic so the engineers had to give up the conventional girder design option. The Eastern Bosporus Strait in the construction area is about 1,400 m wide. Following the international practice of spanning such distances, a suspension bridge would have been an optimal solution. That option was considered efficient enough in terms of all parameters. It was the tight deadline that made the St. Petersburg designers think harder.

> “*We estimated that the construction of a suspension bridge would take longer than that of a cable-stayed bridge. A suspension bridge construction procedure implies that pylons are to be built at the first stage. Next, cables are to be woven. During this process, spans cannot be constructed. Only when the cables are complete, the span would get gradually suspended on them, section by section. Cable weaving for such a huge span would have taken six months at the least. We might have missed the deadline, so we gave up on this option.*

Igor Kolyushev,
Technical Director

A cable-stayed bridge, however, was much more “comfortable” in terms of time as, even before the pylons were complete, constructors could proceed to simultaneous mounting of deck blocks and installation of stay cables. It was the factor that determined the choice of the cable-stayed design. Engineers decided to span the strait in one leap by way of constructing an extra-long span that was to be hung on the pylons standing close to the waterline at shallow depth.

Construction design documentation was developed by three design bureaus: NPO Mostovik from Omsk, Institute Giprostroymost – Saint Petersburg and Institute Giprostroymost, Moscow.

The St. Petersburg engineers were designing the cable-stayed part, revising all the engineering solutions including aerodynamic, static and dynamic analyses. All the key engineering solutions pertaining to structural elements such as spans, pylons, girders, and stay cables were decided on and approved by the St. Petersburg specialists.

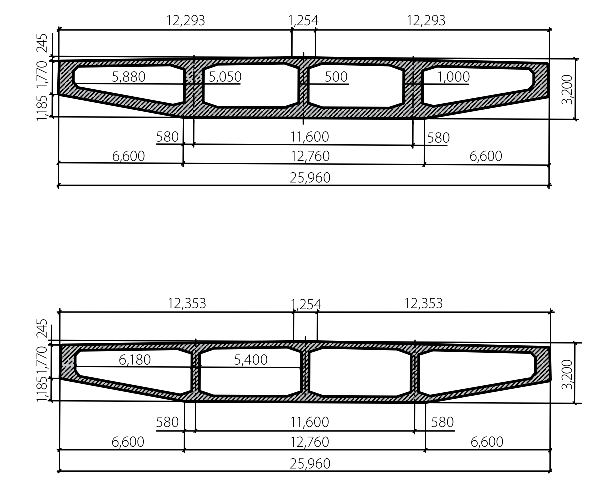
“ The Russky Bridge is the pinnacle of Russian engineering. It was a great success. I always talk about this structure at international conferences. People are not so much impressed by heavy and bulky bridges. The Russky Bridge is huge yet graceful and durable.
To build a beautiful bridge one needs competence, expertise, sense of beauty and vivid imagination.

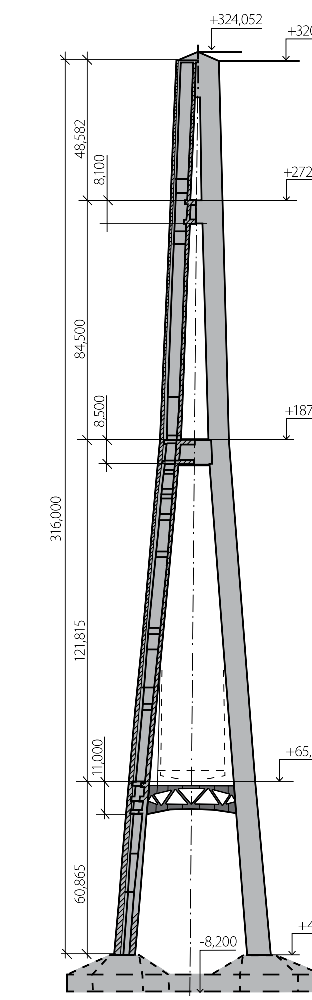
Michel Virlogeux,
International expert and consultant

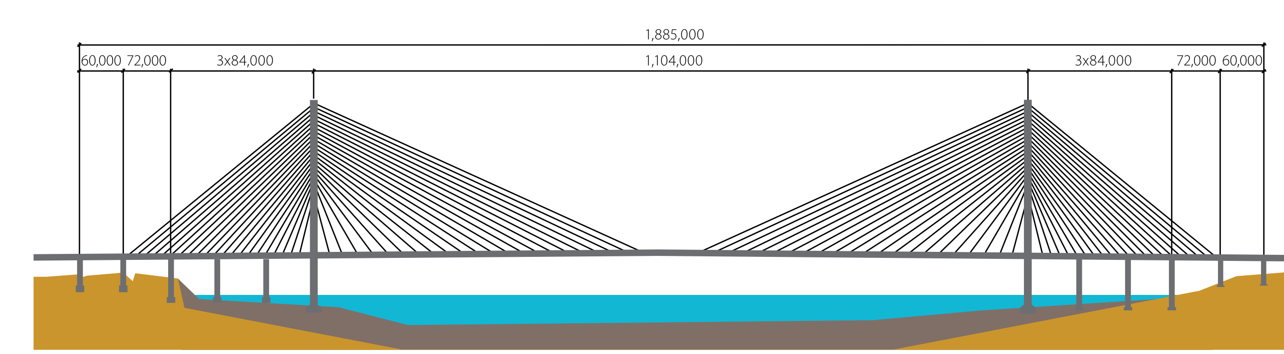
3D

3D model

BRIDGE ELEVATION







ARCHITECTURAL CONCEPT

NEAT AND ROBUST

The bridge that stretched over the strait, with its giant piers, is a product of sheer inspiration. Its lines are clean yet very striking. The credit has to be given to the engineers for making the grand structure look weightless yet well-scaled to the surrounding landscape.

> *“We draw our inspiration from international experience that proves that large structures are mostly neat. Looking at the Russky Bridge one can see pure structural design devoid of any decorations. What matters is making evident the powerful forces distributed along the structural elements. Sticking to minimalism, one still has to demonstrate the structure's might and shift the focus to the incredible so that people wondered how this bridge was even possible.*
>
> *Alexander Malyshev,*
> *Chief Architect*

The Russky Bridge pylons soar 320 m high which is only four meters lower than the Eiffel Tower. There is the law for the cable-stayed structures: the longer the span, the taller the pylons. For this bridge the designers opted for the classical A-shaped pylons. This shape ensures higher transverse stiffness compared to an inverted U-shaped structure. The piers of reinforced concrete are strong enough to carry the weight of the bridge cables and deck. The latter is suspended on 168 cables fixed onto the pylons. The total length of steel “strings” is 55 kilometers.

INNOVATIONS IN DESIGN

A STEP INTO UNCHARTED REALM

The bridge to the Russky Island was meant to become an extension of the A-371 federal highway. A traffic projection showed that four lanes — two lanes in both directions — would suffice. Accordingly, the deck dimensions determined the span width of 24.5 m. With the span width-to-length ratio (24.5 to 1,104 m) the bridge was to become unique, having no precedents in the international bridge engineering. Just compare it to the Sutong Bridge in China whith its middle span 1,088 m long and 41 m wide.

In a storm, wind velocity at the deck level may reach 50 m/s. A wider span responds better to wind loads; however, the St. Petersburg engineers decided not to make the Russky Bridge wider just for the sake of better stability. Also, the wider the deck, the higher construction costs would be.

In search of a perfect solution it was proposed to make the deck more stiff transversely, with holes in it — like with the Stonecutters Bridge in Hong Kong, in the design of which the Giprostroymost engineers participated, too. In that bridge, the deck is divided, spaced out and connected transversely. Eventually, however, the Institute specialists decided to make a narrow bridge. Upon thorough examination of international practice, the engineers became certain they would be able to provide for all the aerodynamic properties even at such a small aspect ratio.

The tests at the Force Technology Institute, Denmark verified the engineering solution. So did the monitoring unit that has been controlling the bridge 24/7 since its commissioning: the extra-long stay cables and the bridge as a whole cope well with hurricane winds. Having undertaken the unique project, the St. Petersburg engineers stepped into an uncharted realm. Neither Russian codes, nor the European standards were able to give answers to all the questions. The engineers had to thoroughly study all the existing cable-stayed technologies and meticulously refine them using advanced techniques.

“ *These parameters reduce the structure’s transverse stiffness and determine many a co-factor. For example, in cross-wind, there would always be a transversal response in a bridge structure. This factor affects a number of parameters — from the deck’s stress to the stay cables’ angle deviations. Wind-induced stay cables’ angle deviations are a specific and very fine parameter that is extremely important for the entire structure, its reliability and durability. Such a narrow bridge with significant transversal response put us in a situation calling for cutting-edge challenges and solutions.*

Igor Kolyushev,
Technical Director

DESIGN TRIALS

PROBLEM WITH MULTIPLE VARIABLES

The unconventional span width-to-length ratio makes the Russky Bridge an extremely sophisticated structure in terms of aerodynamics. The Institute engineers performed analysis of the bridge's aerodynamic and strength behavior, then compared it to the laboratory test results. A seven-meter-long model was tested in the wind tunnel at the Force Technology Institute, Copenhagen. The 1:200-scale model could barely fit in the lab.

Roman Guzeyev
Head of Bridge Analysis Department

“The bridge across the Eastern Bosporus has an unconventional sliding deck that is fixed to the piers with dampers. We calculated the wind loads on those dampers. It was quite a challenge for us and for our Danish colleagues. We were working hard making the structural element models from plates and bearings. It took some time to model longitudinal motion. We struggled for quite a while: six months passed from the time we received the input data to the final result.

The model successfully withstood the hurricane wind velocity of 38.2 m/s. It meant that the real bridge as well would be able to endure winter storms in the Eastern Bosporus Strait.

The decisions on the Russky Bridge design, technology and engineering later were verified by the monitoring system data. Five hundred sensors installed on the pylons, stay cables and the deck constantly monitor the bridge behavior. They provide specialists with the information necessary to control the structure's position and status. Green indicators on the control room displays mean that all the parameters are within normal limits. A yellow indicator would alert of approaching a critical level within a specified range. A red light would send an alarm. Since the Bridge was completed, all the indicators of the monitoring system have always been green. Over the past six years since the bridge completion, the wind velocity in the Eastern Bosporus Strait more than once reached 21–25 m/s. But even with the strongest wind gusts, the structure behavior never came even near the alert threshold.

“ *Imagine that you have an instrument with many strings. At first, it is out of tune and utters hollow notes. A musician has to tune the strings. They may tighten them up applying different forces and set up different cross-sections. Herein lies the freedom: in finding the optimum way to adjust your stay cables. It is an art of a kind. Although there are mathematical formulae for this process, it is up to the engineer to decide how to tune up the structure. Even similar structures with the same stay cables would be tuned differently by different specialists.*

Roman Guzeyev,
Head of Bridge Analysis Department

STAY CABLE TECHNOLOGY

THE ART OF CABLE STRINGS

For designers, stay cables represent a challenge and give freedom at the same time. Using the cables, engineers apply stress to a structure.

The Vladivostok bridges are sporting the French stay cables. Among all the manufacturers in the world, Giprostroymost chose the Freyssinet International & Cie as a partner. The French team built its first cable-stayed bridge back in 1976. The Freyssinet steel cables carry the Millau Viaduct — an engineering miracle designed by Norman Foster and Michel Virlogeux. Those who at least once have been engaged in a great project would forever stay in its orbit. The longest cable-stayed bridge with non-standard pylons constructed in Vladivostok came as a challenge for the experts. An international team of engineers arrived to the Far East region to join the landmark projects.

Stay cables can be made of prefabricated parallel wires — bundled, inserted into protective sheath and delivered to a construction site. The French use a different technology. Stay cables are woven of single strands right on the construction site. The number of strands may vary from dozens to hundreds. The stay cables of the Russky Bridge are made of parallel strands of a 15.7 mm diameter in polyethylene coating. Each strand is woven of seven wires. The wires are galvanized in order to protect the metal from corrosion. The protective coating is made of high-density polyethylene resistant to substantial temperature changes and UV exposure.

For the Russky Bridge, for the first time the cables were used with the strands more compacted within the sheath. It gives a number of advantages. Due to this innovation, the cables' diameter was reduced and, accordingly, the wind load was lowered by 25 to 30 % which is crucial for the bridge stability. At the same time, the cost of pylon, deck and foundation materials went down by 35 to 40 %. Monostrand cables are easier to deliver to the construction site, as separate strands are transported instead of pre-assembled cables. No heavy cranes are required to install them; instead, they are pulled strand by strand with winches and then stressed. What is important, is a possibility to remove and replace any damaged strand from a cable. Pascal Martin-Daguet, Freyssinet Vladivostok Project Manager assures that their cables will serve for 120 years and only in some 60 years some of the elements may have to be replaced.

For the Russky Bridge, the European specialists used a special grade of steel able to withstand extremely low temperatures. The cable assembling and stressing equipment was also adapted to low temperatures.

“ *The cutting-edge technologies were used on the unique structure in Primorye. Along with our Russian partners, we busted the dogma that the stay cable technologies are not suited for giant bridges. The bridge to the Russky Island is a real proof of that.*

Jean-Daniel Lebon,
Asia Region Director, Freyssinet

The cables of the Russky Bridge are of record length. The longest of them is 580 meters long. The total length of strands is almost 3,000 km and their total weight is 3,700 tons. Massive structures are swayed by the sea winds and seismic actions. In order to isolate dangerous vibrations from the bridge, constructors installed semi-active dampers on groups of cables. The hydraulic cylinders with plungers dampen vibrations through the liquid viscosity fluctuation caused by the currents generated by the cables' vibration. Same type of devices was used for the Sutong Bridge. On the longest cables, in addition to internal, external hydraulic pendulum dampers were installed. The Golden Bridge cables are shorter, so the conventional hydraulic devices were installed in the anchorage boxes there.

STRUCTURE DIAGNOSTICS

TESTING IN THE FOG

In bridge-building, technologies do not change as fast as in the IT industry. It may take years for new techniques to be implemented. There is a good reason for such hesitation and the name of the reason is “risks”. Designing a building, a road or a bridge, engineers have to manage risks and bear responsibility for safety. Any structure to be used by thousands of people for a long time shall be tested again and again.

As the Russky Bridge was completed, before its commissioning, it was tested for loads. The endurance trial performed by the diagnostics research institute staff took twenty-four hours. The morning of the trial day was clear and sunny; however, 10 minutes into the trial, a pea-soup fog fell onto the city, the visibility was less than 40 m.

Bad weather did not affect the data accuracy. Using GPS modules, position of each load, span structure and pylon was accurately established. GPS devices were fixed on pylons, in the mid of the main span and in the quarters. As a result, an accurate configuration of the entire system was obtained. Flexometers were fixed on each of the side spans. In addition, 156 Sprut sensors were used; those were registering the bridge behavior in real time. The Russky Bridge passed the test with the A mark. The structure functions as designed and has ample deformation and stress margins. The world-record setter complies with the load classes A14 and H14.

“Nowadays, a bridge-building engineer has to know how to channel everyone’s efforts. Designers have to make all calculations including deck parameters, girder and vehicles weight. One has to make all estimations and establish rapport with contractors. It takes a lot of effort to make the entire process go smoothly. Two cable-stayed bridges in Vladivostok are an evidence that Giprostroymost made a giant leap forward and went global.

Michel Virlogeux,
International expert and consultant

NOVUS INTER PARES

As with any significant engineering masterpiece, the Russky Bridge has many meanings. This is not just the shortest way across the strait. It is also a symbol of overcoming forces of nature, tight deadlines and people's mistrust. The bridge is a testament to the ingenuity and solidarity of the people who created it. The A-371 federal highway serves the residents of the city as a reliable thoroughfare in any weather. Now, the journey from downtown Vladivostok to the Russky Island takes only 20 minutes instead of several hours. The completion of the bridge put an end to ferry service in the city. Snow-white sea gulls, true companions of slow-moving ferries, now follow large ships going out to sea under the bridge. This ambitious project made Primorye the center of bridge-building and gave a new impetus to the development of the island. Currently, the Far Eastern Federal University campus and the Primorsky Oceanarium operate on the island. Once a restricted area, now the Russky Island turned into a land prepared for everything that is to come. With the support of public and private investments, this territory will soon become an international center of science, education and technological innovations.

Jean-Bernard Datry
Director, Setec TPI, France

“When we first started our cooperation on the design of the Russky Bridge, we were pleasantly surprised with the Institute approach to the process — it was very similar to our own. Our Russian colleagues are never satisfied with simple calculations; each of their proposals incorporates both technical and architectural components. It is crucial that the Institute engineers always meticulously analyze all the parameters and conditions that have to be considered when designing a bridge. We were also impressed with the track record of our colleagues from St. Petersburg, as the number of projects they completed speaks for itself.

The Russky Bridge took the top position in the rating of bridges compiled by TripAdvisor.com, having edged out the world-renowned Palace Bridge in St. Petersburg. Among the top ten tourist attractions in Russia are such famous landmarks as the Church of the Savior on Spilled Blood, St. Isaac's Cathedral, St. Basil's Cathedral; yet, the giant bridge in Vladivostok stands alone as the only engineering structure on this list that was constructed in modern days.

2000 NOTE: VLADIVOSTOK

Since the autumn of 2017, the record-breaking bridge can easily fit in your pocket. On the fifth anniversary of the Russky Bridge, its image was printed on the new 2,000 rouble banknotes. The Central Bank organized a public poll for all the Russian citizens. From more than 5,000 landmarks in 1,113 cities, hundreds of thousands of people chose and voted for the Russky Bridge. The new symbol of Vladivostok was the undisputed winner of the poll, and thus became the third Russian bridge to be commemorated on a banknote. The Kommunalny Bridge across the Yenisei River in Krasnoyarsk and a bridge across the Amur River in Khabarovsk were the first two, recognized for their unique architectural and engineering design as well as the cutting-edge technologies used in their construction. The bridge to the Russky Island became the most innovative structure of the three. Thanks to augmented reality technologies, the cable-stayed bridge across the Eastern Bosporus Strait comes to life and stands out of the simple 2D plane of the note.

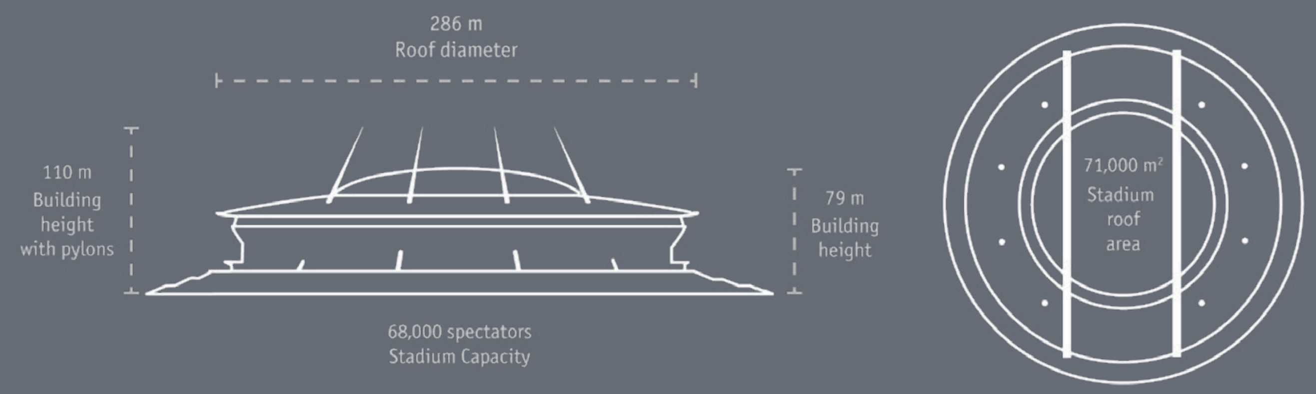
Saint Petersburg Stadium St. Petersburg, Krestovsky Island

STADIUM DOME IN THE NORTHERN CAPITAL

The Saint Petersburg Stadium in the Northern capital of Russia is the largest sports complex in the country. This is the only stadium in Russia, and one of the few across the globe, to have retractable roof and pitch.

The arena was designed by Kisho Kurokawa, a Japanese architect. During construction, the initial design was altered, due to the fact that Russia was chosen to host the XXI Football World Cup. Modifications included the expansion of the stadium grandstand to accommodate up to 68,000 spectators. The retractable roof of the sports complex meant to protect both athletes and fans from rain and snow.

The movable pitch provides a way to transform the playfield into a space for various large-scale events. The Institute specialists designed a truly unique roof structure and a bridge-like grandstand to allow moving the pitch in and out the stadium. The scope of engineering solutions developed by the Institute puts the Saint Petersburg Stadium on par with the best sports complexes around the globe in terms of its technological ingenuity, safety and convenience for spectators.



PROJECT BACKGROUND

NEW TEST OF TIME

For nigh on fifty years stood the Sergey Kirov Stadium on Krestovsky Island. It was there that in 1959, the Soviet record of a football match attendance was set, when 110,000 people came to watch the game between FCs Zenit and Spartak. The giant stadium also hosted some of the competitions during the 1980 Olympics, and was the main sports venue of the 1994 Goodwill Games. Eleven years later, the decision to dismantle the stadium was made; in its place, a new stadium, fully compliant with the sports and technical regulations of international federations, and with additional space for various shops and cafes, was to be constructed. Implementing the same in the old building, with its cramped passages outside the stands would have been impossible.

In 2006, the St. Petersburg Government announced a competition for the architectural design of the stadium. Five companies participated in it: Kisho Kurokawa Architects & Associates from Japan, GMP from Germany, Portuguese Tomas Taveira, and two Russian bureaus — Mosproekt 4 and LenNIIProekt. The Japanese company won the competition. Kisho Kurokawa, the head of the bureau, designed several renowned stadiums. The Asian architect incorporated some of his signature features into the St. Petersburg stadium design. For instance, the Big Eye Stadium in the Japanese city of Oita looks like an otherworldly giant silver hemisphere, very much alike the “flying saucer” on Krestovsky Island. It was the first arena with a retractable roof in the world fit for Olympic competitions. Another sports venue designed by Kurokawa, the Toyota City Stadium, became the prototype for the stadium in St. Petersburg. Its four pointed pylons bear a curved roof with an “accordion”-shaped retractable part.

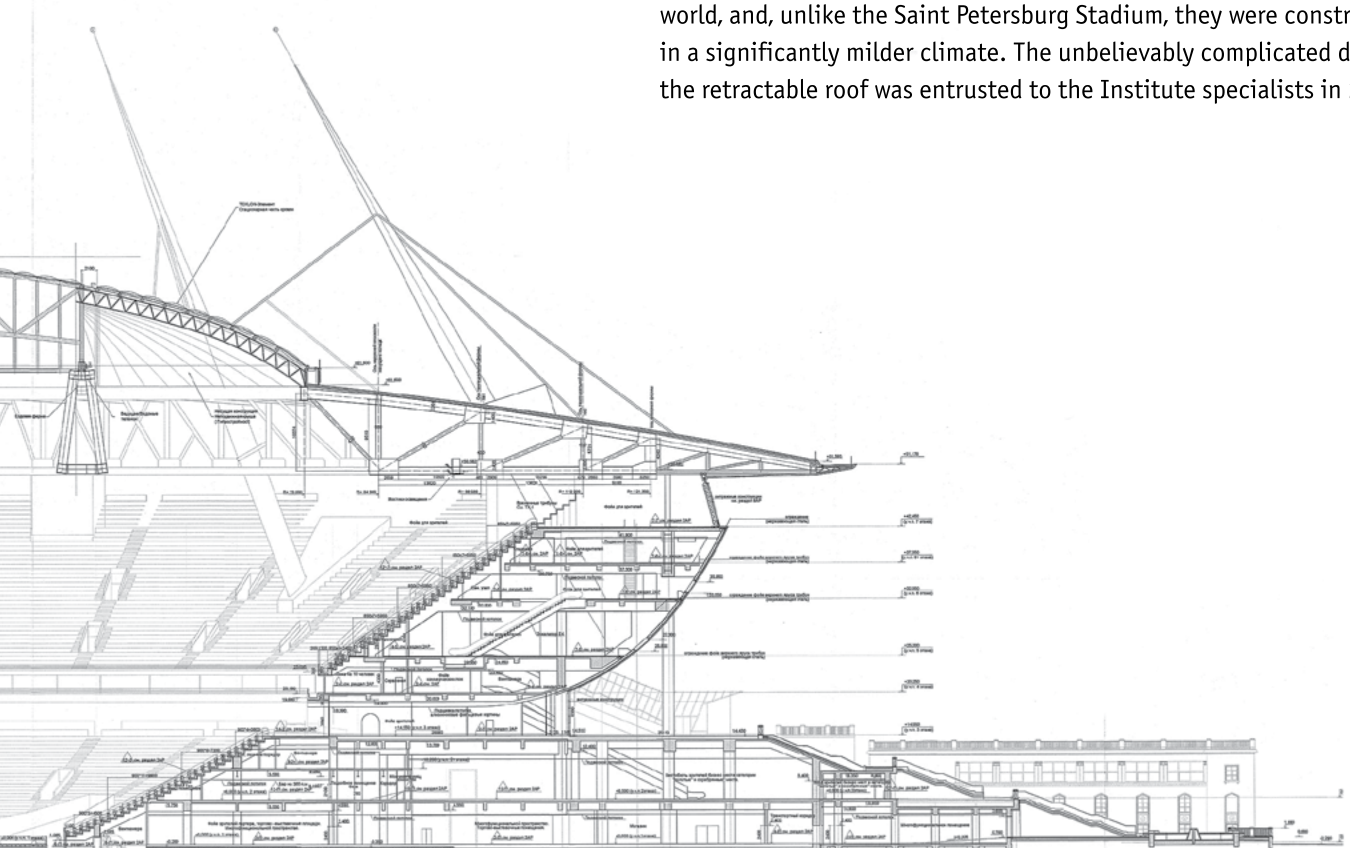
The confirmation that Russia would be hosting the Football World Cup in 2018 came from Zurich on December 2, 2010. The tournament matches were to be held on 12 stadiums in 11 different cities across the country. Saint Petersburg and its “space-faring” arena with magnificent pylons was among the chosen few. When it was decided that the stadium in St. Petersburg was to be the primary venue for the semifinal matches, the facility had to be made compliant with all the applicable standards and international regulations. The arena had to be made more spacious and absolutely safe for tens of thousands of spectators.

DESIGN OBJECTIVES

GREAT CHANGES

Significant changes were made to a number of various aspects of the design. First of all, the stadium dimensions became larger: the number of seats was expanded from 46,000 to 68,000. Layout design had to be changed, too. Various-purpose additional premises were to be foreseen, and their total area increased from 170,000 to 260,000 m².

Key engineering solutions had to be modified as well, and the main change was the decision to use concrete instead of metal for the construction of the stadium bowl. Later on, that decision determined the technology implemented for the roof construction. Major changes were also made to the design of the retractable roof. Engineers had to make sure the structure would remain stable in the event of progressive collapse. At the same time, it was paramount that the approved architectural design complied with the strict safety standards. According to the contract, the basic concept developed by Kurokawa remained unchanged. The dome of the stadium, 295 meters in diameter, is borne by eight pylons, which gives it the appearance of a spaceship that just landed on the shores of the Gulf of Finland. The stadium was destined to become a new landmark of the city, a destination for sports fans from across the globe. There is only a handful of similar structures in the world, and, unlike the Saint Petersburg Stadium, they were constructed in a significantly milder climate. The unbelievably complicated design of the retractable roof was entrusted to the Institute specialists in 2009.



THREE-DIMENSIONAL DOME

PACKAGE OF WORKS ON THE PROJECT

- Amendments to the design
- Performing analysis
- Developing working documentation for main structures
- Designing a bridge-like grandstand above the retractable pitch (Sector G)
- SAC&D (Special Auxiliary Construction & Devices) design
- Computer simulations for the structures of the stationary part of the roof
- Monitoring the structures of the stationary part of the roof during operation and construction

According to the Japanese architect's concept, the dome of the Saint Petersburg Stadium was designed as a three-dimensional structure partially suspended on stay cables. Therefore, Institute Giprostroymost was the obvious choice for the structural design of the roof, since by that time its engineers had already accumulated extensive experience in designing complicated cable-stayed structures.

Back in the early 2000s, those people were the ones to design and oversee construction of the first cable-stayed bridge in the modern history of Russia, the Bolshoy Obukhovsky Bridge, one of the sections of the St. Petersburg Ring Road. While designing the stadium roof, the engineers from St. Petersburg never stopped working on the world-largest cable-stayed bridges for Vladivostok where the latest advances in engineering were implemented.

The Institute specialists were involved in the design of the stationary and retractable sections of the stadium roof, as well as the engineering design of the bridge-like grandstands to be utilized for the retractable pitch of the Saint Petersburg Stadium. Furthermore, the designers were also in charge of the process design for the roof structure assembly, design of special auxiliary systems and devices, as well as specific elements of the master plan for certain installation works.

Georgy Skorik
Chief Project Engineer

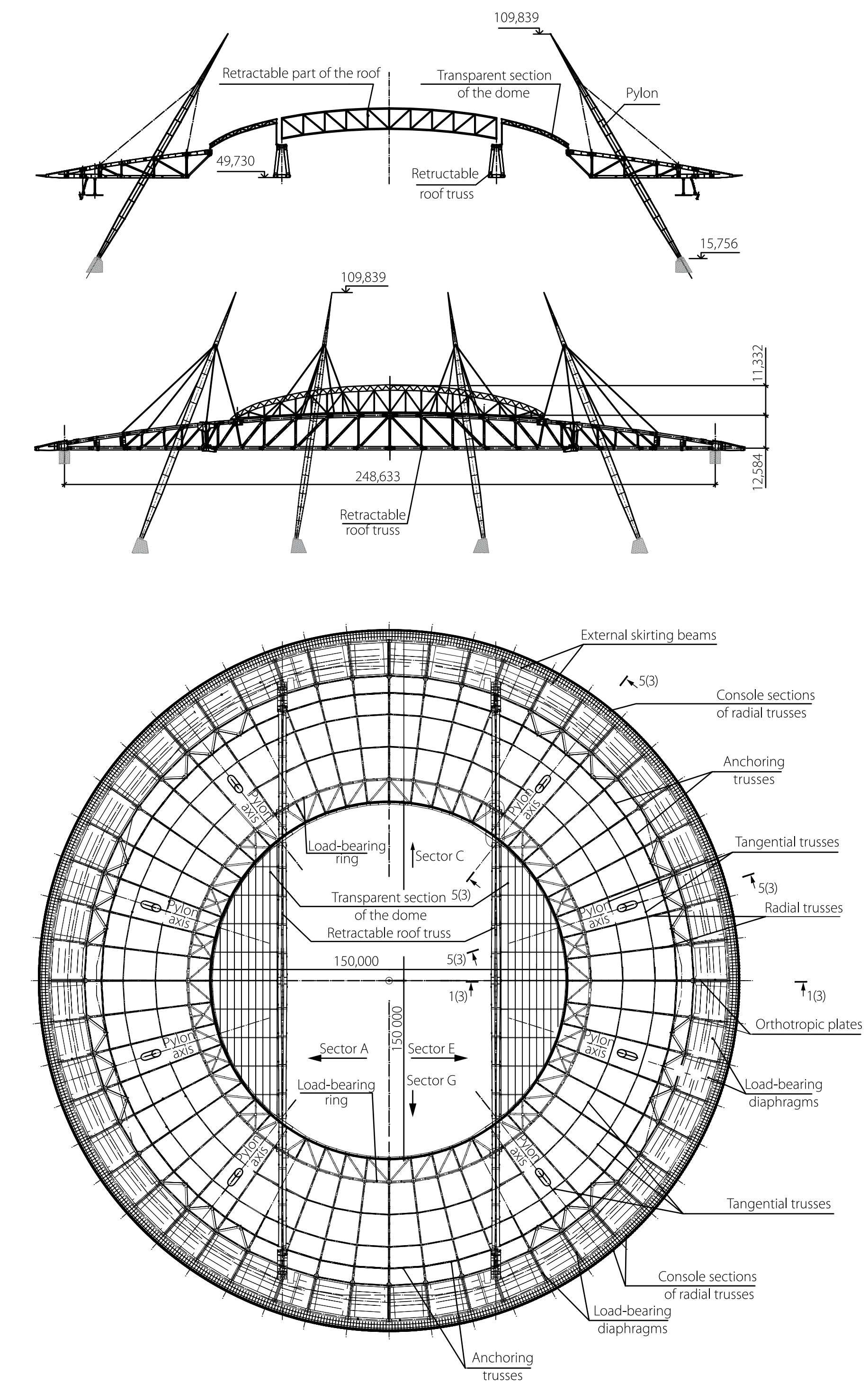
“The lattice of the bridge structure that serves as the roof support, has a span of 90 meters between the tracks and a length of 60 meters. Stay cables are the primary load-bearing elements of the structure, and no one is more experienced in design and assembly of such structures as bridge builders are. It has to be noted that the structure is tremendously heavy. The stationary part alone weighs approximately 15,000 tons, and the whole roof weighs as much as 20,000 tons — on par with a large bridge. Designing, processing and assembling such an amount of metal structures is no small feat; and even though some organizations may be capable of doing it, bridge builders have a natural advantage in the matter.

> *To me, the engineer's talent and skill is determined purely by their ability to combine technologies. If they are capable of constructing a good cable-stayed bridge, they should be capable of utilizing the very same skill set in other projects. For instance, in designing large roofs. This is a true mark of talent and professionalism.*
>
> *Jean-Bernard Datry,*
> *Director, Setec TPI, France*

3D

3D model

ROOF DRAWINGS



SPECIFIED PARAMETERS

DESIGN ADAPTATION

The implementation of this international project was hindered by a number of factors. While the sports complex was being built, several design and construction contractors came and went. As a result of those fluctuations, the project had very tight deadlines and budget. Therefore, the original design of the retractable roof developed by Japanese designers, was no longer feasible within the allotted budget. It became the main issue the Institute had to face while working on the project.

“ The initial design foresaw the use of metal molding. The lower section of the pylon was, basically, a 60-ton metal element. It was nearly impossible to procure such elements in Russia: available steel grades are not proper, and there are no companies to make appropriate molding. Instead of those pylon sections, we opted for shells with 40–50-mm-thick walls. This kit was then assembled like a pyramid, which was a rather complicated technological process. What's more, we managed not to run out the cost estimate, which was not easy to do either.

Georgy Skorik,
Chief Project Engineer

German engineers developed the conceptual design under which structural elements made of German steel and robust moldings* were to be used instead of complicated welded assemblies at the key elements. The necessary grades of steel were not manufactured in Russia, and procuring them in Germany would not fit in the allotted budget. The moldings that were included in the original design would eat off roughly as much as a half of the total cost of the stadium. The Institute specialists had a very short time to adapt the design to the Russian codes and regulations. Giprostroymost lived up to this challenge. Within a limited timeframe, proper steel was found in Russia to replace the one from Germany. Furthermore, engineers proposed to make the key elements of thin-walled pipes. The Institute specialists came up with ingenious structural solutions and a well-thought-out procedure which allowed them to succeed in making the roof lighter and cheaper than the original design by foreign engineers.

* Molding is a metal part of a structure which has been cast as a single element.

Apart from the issue of the materials to be used, the Institute also had to significantly rework the very structural design of the roof, while still remaining within the initial design parameters and cost estimates.

Naturally, the greatest difficulty was the architectural concept. The roof itself is a curved three-dimensional structure with an extremely unusual geometric shape and complicated static load distribution. Furthermore, a large portion of its many elements and nodes is unique.

Andrey Ziuzkov
Chief Project Engineer

“ The dome is unique, because it can be in two states. When open, the roof turns from an ideal saucer into quite another shape. Cables hold the whole structure, and bear and redistribute some of the loads. Without them, the roof would be much more massive.

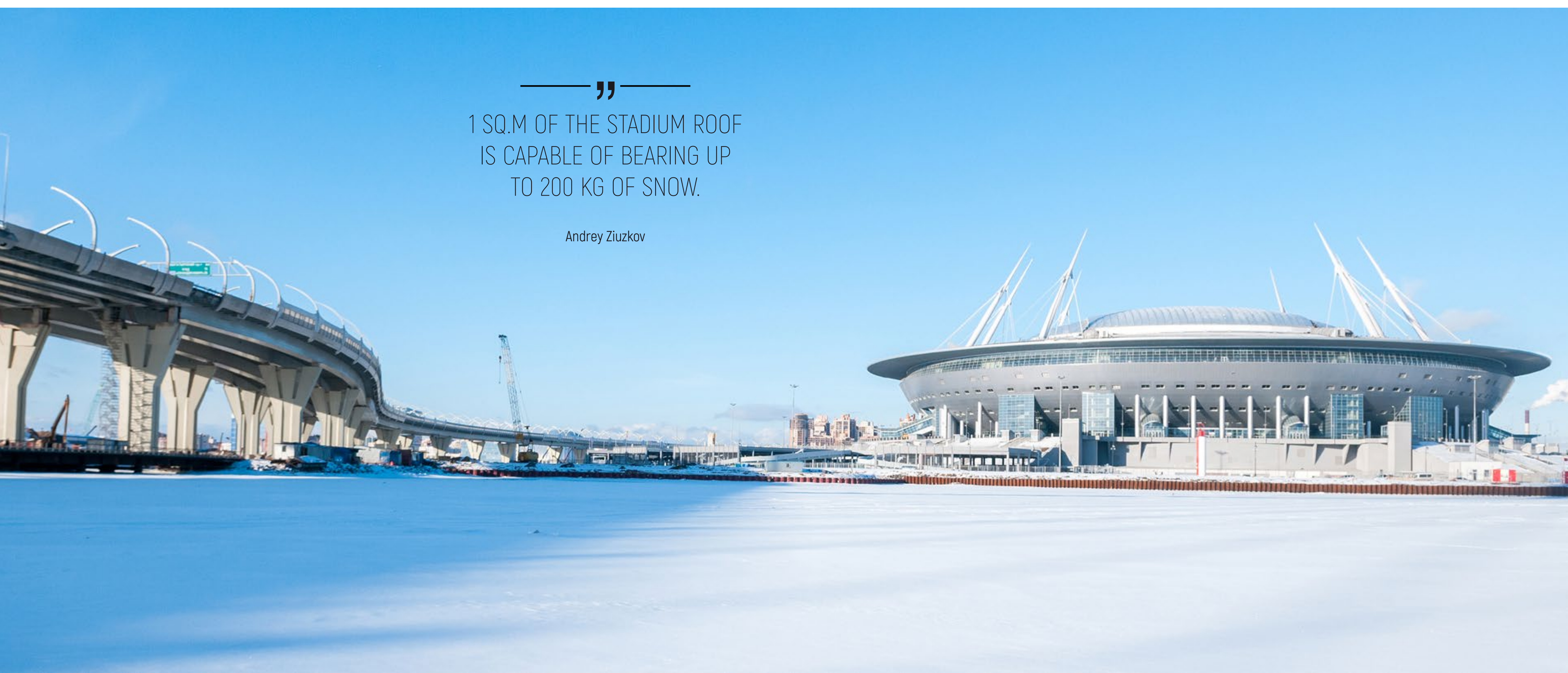
DESIGN SOLUTIONS

THE FIFTH STAY CABLE

The Institute engineers developed design solutions in compliance with the requirements of FIFA as well as natural conditions prevalent in the construction area. One of the primary requirements set forth by the International Federation of Football for any sports venue is that it has to remain stable in the event of the progressive collapse. In other words, the roof has to remain in place even if a stay cable snaps. Given a retractable structure with non-standard design, it is a very complicated engineering task to achieve.

The Giprostroymost specialists found a very elegant solution to this: the designers have added a fifth stay cable to the initially foreseen four per pylon; the total number of cables was increased from 32 to 40. As a result, the stability of the roof improved, too. Now, if one of the stay cables snaps or a pillar collapses, the structure would yield no more than a meter.

Snow loads became the determining factor during the configuration analysis of stationary and retractable sections of the roof, given their tremendous combined area. According to the state codes, Saint Petersburg lies in the 3rd snow belt. This means that the weight of snow banks in this territory is estimated at 180 kg/m². However, special design specifications for this project dictated increasing the estimated snow loads up to 200 kg/m². The Japanese architects first proposed lightweight structures for the stadium in Russia, which had to be implemented differently in terms of engineering. The engineers from St. Petersburg had to develop a sturdier dome which would be able to withstand the whims of the Baltic climate.



“Kurokawa designed the “accordion”-shaped retractable roof made of lighter sections. We had to design a roof that would be capable of withstanding larger snow loads. According to the design, 1 m² of the stadium roof is capable of bearing up to 200 kg of snow. For the spots where snow tends to accumulate, this number was increased to 1,000 kg/m².Thanks to the changes made, the dome is capable of bearing up to 13,500 tons of snow in total. This equals to 1,687 Bronze Horsemen or 60 Statues of Liberty. To avoid accumulation of snow on the roof, a special climate control system was designed. Preheated air is fed into the transparent section of the dome. It makes snow melt and water drain through pipes.

Andrey Ziuzkov,
Chief Project Engineer

TRICKY INCLINE

The roof of the stadium is 295 m in diameter and consists of a stationary and retractable sections. The stationary section protects spectators on the grandstand from sun and rain. Additionally, it also serves as a support for the retractable section which covers the area of 189.6 x 89.8 m above the pitch. The total area of the roof is 71,000 m².

The stationary section is the load-bearing structure that is made up by multiple trusses. When viewed from above, it looks like a circle, its cross-section is shaped as a convex-concave lens with an opening in the center. Along the longer edges of the opening there are tracks — the elements that allow the retractable section of the roof to move. Both sections are borne with a retractable roof by eight inclined steel pylons, each bearing the roof frame through stay cables. Four reinforced concrete columns support the retractable roof tracks.

> “ *Inclined pylons gave rise to a number of challenges. In terms of mechanics, we are talking about additional compression in certain elements of the roof. So, we had to work hard, looking for solutions. We endeavored to give the architectural expression of the stadium a solid and durable shape.*
>
> *Roman Guzeyev,*
> *Head of Bridge Analysis Department*

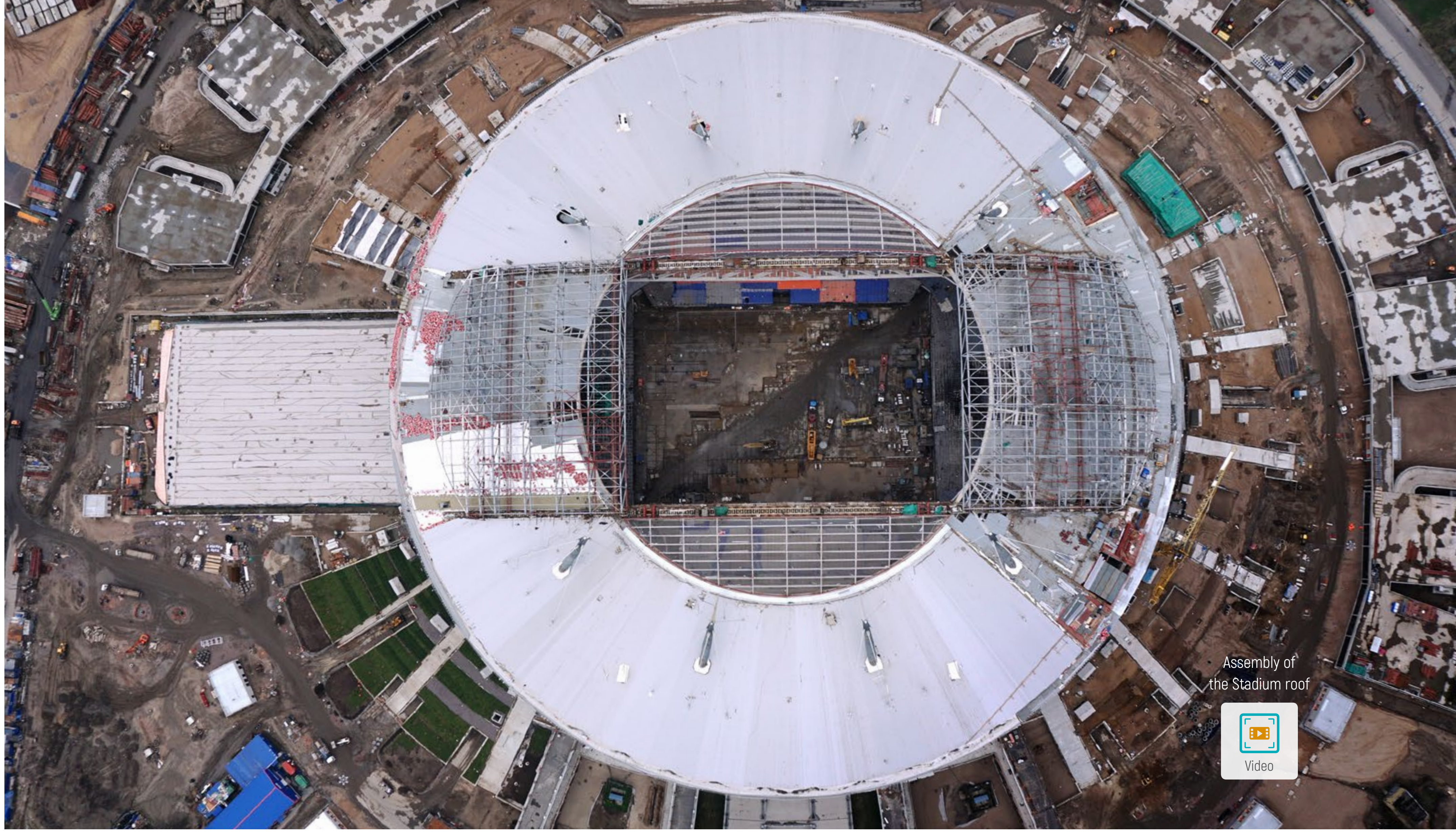
Metal structures designed by the Institute served as the base for the multilayer system of the roof that also provides for insulation and temperature conditions within the arena. The system comprises a vapor seal film, insulation and aluminum seam roofing panels. In winter time, when it rains or snows, the roof is closed above the pitch, and the climate control system maintains comfortable conditions for spectators and athletes within the stadium. Even in the coldest months, the air temperature within the arena is maintained at +7 to +15 °C.

CONSTRUCTION PLAN

MOVING IN CIRCLES

The Institute specialists had to develop the construction master plan at the same time as the roof design. In the process, certain technology modifications had to be made due to the extremely tight deadline. Initially, the project followed a simple sequence where contractors were to install the supports of the roof, then pour concrete to make the monolithic walls of the stadium, and only then were they to finish working on the dome. A similar process was implemented by the Institute specialists for the construction of the Otkritie Arena in Moscow. But the facility in Moscow was designed for 45,000 seats only. Its structural design was simpler; therefore, standard solutions were acceptable.

The situation in St. Petersburg was starkly different. In order to meet the deadline, the roof assembly and concreting had to be performed simultaneously. As a result, it was not possible to put a large number of auxiliary piers inside the arena, as they would have occupied the whole area and hinder certain other works. To avoid cluttering the stadium's interior space, designers suggested constructing scaffolding at the 50-m level from the northern side of the building. The huge structure took up a whole section of the stadium. This platform was used to assemble elements of the stationary roof sections, which were then launched into their design positions along special tracks placed within a 110-m radius. The unique process of radial launching was consistent with the shape of the dome structure itself. To expedite the assembly process, one block was launched from the left, another from the right. Builders were assembling prefabricated elements on the scaffolding, moved the heavy parts along the tracks and then finished the assembly in place. Despite all those difficulties and the tremendous diameter of the roof, tolerances were kept within the 25–30 mm range.



Each part of the retractable section of the roof weighed 1,000 tons. There was an issue to resolve: how to lift 2,000 tons of metal up to the roof level. The Institute engineers suggested dividing the segments into six parts. In the end, 12 blocks weighing more than 160 tons each were designed. Those units were then lifted up to the 62-m level by two cranes with a lifting capacity of 600 and 750 tons. The operation, which greatly depended on weather conditions, took several hours. Then, the formidable elements were placed on special carts and moved with the help of powerful jacks.

Eight inclined pylons presented yet another difficulty, since the angle between the pylon axis and the horizontal surface was approximately 60 degrees. Initially, construction workers were considering using a special anchoring pier about 90 meters tall. But since the concrete was being poured at the same time as the construction of the roof, it was impossible to assemble the pier. Eventually, it was decided that the lower part of the pylon was to be mounted on guiding rails, the "suspended" assembly was to be performed without any additional supports. Once the retractable section of the roof was assembled, the most complicated stage of the Stadium construction was completed. The ground was cleared of towering cranes, and the workers started fine-tuning the retractable pitch system.

KEEPING WINTER OUTSIDE

For the first time, the lace-like shutters of the new Saint Petersburg Stadium have been fully closed on October 3, 2016 during the trial conducted by the Metrostroy Company. At a similar stadium in Germany, over the ten years of operation, its roof has been closed just a few times despite the fact that it was not as heavy as the Russian stadium's dome. The Toyota Stadium, Japan has the roof of a similar "accordion" design; however, it is always kept open due to extra costs for maintenance. In St. Petersburg, where the average year-round temperature is +5.8°C and it is rainy most of the time, the Stadium roof gets regularly moved.

> *This roof cannot be folded and unfolded just like your convertible's, by pushing a button. Due to the heavy weight of the structure, it is an extremely complex and time-consuming process that also involves significant deformation of the roof's stationary part.*
>
> *Igor Kolyushev, Technical Director*

> THE SAINT PETERSBURG STADIUM DOME CAN BE CLOSED WITHIN 15 MINUTES.

Shutters set on special carts slide at the 4-m/min speed upon the tracks that run along the roof edge. There are 14 carts on either side of the roof. Each mechanism has its own drive that is able to produce a 25-ton force. Under the original design, some of the carts were to be passive, without their own engines. For the sake of higher safety, the St. Petersburg engineers equipped each mechanism with an engine. Movements of the roof elements are coordinated by the control room operators.

SIGNIFICANCE OF THE PROJECT

WORLD CLASS STADIUM

The Saint Petersburg Stadium is in the top — the fourth — UEFA stadium category. In the summer 2018, it hosted a number of games of the long-awaited FIFA World Cup. The largest arena in the country welcomed the best football teams and thousands of fans from all over the world. Exactly 448,686 fans have watched the seven games of the World Cup. The Stadium will remain a venue for future major international competitions. The fact that this hi-tech sports complex has been constructed in our country is the evidence that sports and wellness play an important role in our lives and have a positive effect on the construction sector in general.

Conceived as an out-of-category structure*, the Stadium became a new sports symbol of Saint Petersburg. The sports complex can be seen both from the city and from the Gulf of Finland. Its strong retractable roof — the key element and the most complex structure in terms of engineering — is able to endure significant snow loads. Even in the midst of the inclement Baltic winter, people in the Stadium grandstand feel comfortable. Retractability of the dome is a technology that complements the pitch: it lets the sunlight in on the days when the pitch is inside the Stadium.

* Out-of-category structure is a unique and particularly complex structure.

“We are happy to have had an opportunity to contribute to the construction of the structure that is so important for the city and unique in terms of design and construction technology. It was a rewarding experience; we had to perform extremely sophisticated engineering analysis including estimations of snow and wind loads which, given the retractable roof design, required the highest degree of designer expertise. This project was not exactly within our professional domain, although the approaches to designing stay cable systems and structures like this Stadium are similar to a certain degree. In truth, there are not so many organizations in our country having adequate degree of expertise and experience in this field. That is why we were approached and eventually lived up to the challenge.

Igor Kolyushev,
Technical Director

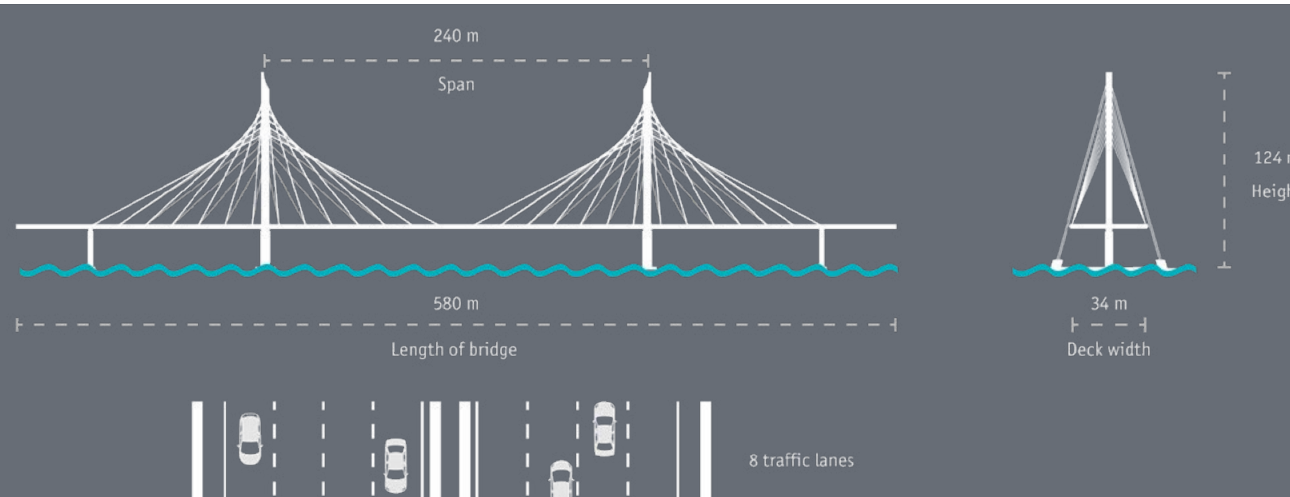
Bridge across the Petrovsky Channel   St. Petersburg

TWO FLUTES HIGH ABOVE THE NEVA

A striking 580-meter-long cable-stayed bridge became a real gem in the crown of St. Petersburg. The Bridge is special for its pylons standing in the middle of the superstructure as well as for an unusual pattern formed by stay cables.

The cable-stayed bridge across the Petrovsky Channel is one of the most beautiful and sophisticated structures within the Western High-Speed Diameter (ZSD). Stay cables run from the pylons to the spans and form fans of a unique shape. The pylons of reinforced concrete rise up to 124 m, competing with the golden spire of the St. Peter and Paul Cathedral. The Bridge across the Petrovsky Channel was constructed under a public-private partnership.

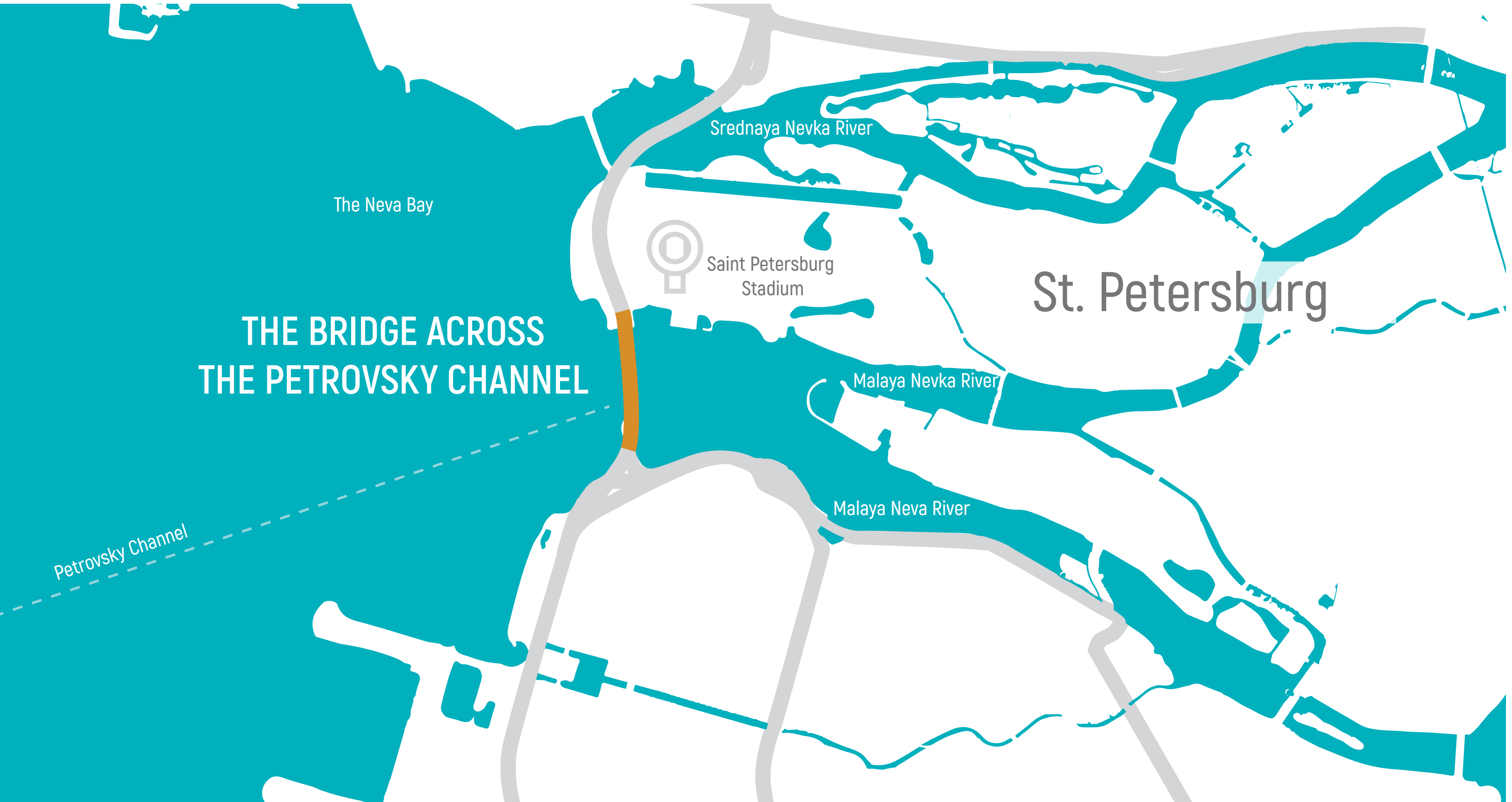
The project was a product of collaboration between the Institute Giprostroymost – Saint Petersburg and the ICA Construction Company which in its turn, was a joint venture by IC Ictas Insaat (Turkey) and Astaldi (Italy). The Turkey–Italy consortium specialists took active part in decision-making and became full-fledged members of the team.



PROJECT BACKGROUND

HIGHWAY ACROSS THE CITY

The Western High-Speed Diameter was put into operation in 2016. The need for a high-speed road that would connect the southern areas of St. Petersburg with Vasilievsky Island and the Primorsky District became evident as early as fifty years back. The city with five-million population has a shape of a horseshoe hugging the Neva Bay. As the southern and northern areas developed and the seaport's freight turnover grew, the traffic on the city roads was getting ever heavier. The 1966 Leningrad Master Development Plan foresaw the shortest possible highway along the seaport that was supposed to connect the city's remote areas. Some thirty years later, a design plan for the first Russian high-speed toll road was approved. The road was named Western High-Speed Diameter (ZSD). The first stage of the expressway construction began in 2005.



The 47-km-long road has three sections: Northern, Southern and Central. Almost half of the road length runs upon bridges, overpasses, and in tunnels. Numerous industrial infrastructure facilities and complex terrain in the areas through which the expressway was to run called for many a man-made structure to be built. The 11.7-km-long Central section of the Diameter was the most complicated of all. For eight kilometers the road runs above water: it crosses the Morskoy and the Korabelny Channels. The Petrovsky Channel, the Sredniaya and the Bolshaya Nevka Rivers were other obstacles to span.

The Gulf of Finland area with its weak soils and heavy ship traffic called for serious preparations on the part of designers and constructors. Giprostroymost, having a vast experience in designing cable-stayed bridges, joined the team that was to design the bridges across the Petrovsky Channel.

JOINT DECISION

PACKAGE OF WORKS ON THE PROJECT

- Defining the bridge concept
- Designing the major bridge structures
- Developing construction technologies
- SAC&D (Special Auxiliary Construction & Devices) design
- Developing Construction Master Plan (CMP)
- Monitoring the cable-stayed bridge structures behavior
- Designer supervision

Eventually, the bridge built across the Petrovsky Channel came out quite different from the initial concept. In 2007, when the Institute just joined the project, engineers had already decided on the extradosed system — a combination of the features of girder and cable-stayed bridges. A similar bridge was designed by the Company for Riga back in the early 2000s. The bridge in St. Petersburg with a 220-m-long main span would have been quite unusual both in terms of its structure and architecture. The design was already approved by Glavgosekspertiza (General Board of State Expert Review).

Later, however, the General Contractor put forward additional requirements to the design. The ICA Construction Company suggested that the bridge's structural elements had to be of reinforced concrete: under the schedule, concreting had to be done in winter time which meant more time and increased costs. This option would not have met the engineering criteria for an extradosed structure; therefore, the Institute specialists came up with an idea to change the bridge concept from the extradosed to the cable-stayed. It meant that the span could be made longer which was essential for the navigable channel; it also allowed making the bridge more expressive in terms of architecture. There was very little time left for developing a new design documentation package. Many people doubted whether it was even possible to develop a new design and to have it approved within a few months.

“ *We were confident of what we were about to do. Within one year, the Institute developed the documentation in compliance with the General Contractor's requirements. Tight deadlines did not affect the design quality. Of course, the Expert Review Board had a number of questions regarding some of the engineering solutions; however, we succeeded in convincing them and gaining their approval. I believe it to be quite an accomplishment of the Institute team.*

Igor Kolyushev,
Technical Director

Ilya Rutman
Director General

“ *The design of the bridge across the Petrovsky Channel involved a series of unique engineering solutions which were worth fighting for at Glavgosekspertiza in Moscow. Our duty was to convince other partners that those were quite feasible things. The bridge's span is not too long; however, the pattern formed by the stay cables, the bridge's architectural design, its integrity with the urban environment are the things to be proud of. Now that the bridge is complete, the view of St. Petersburg from the seaside has changed drastically.*

ARCHITECTURAL CONCEPT

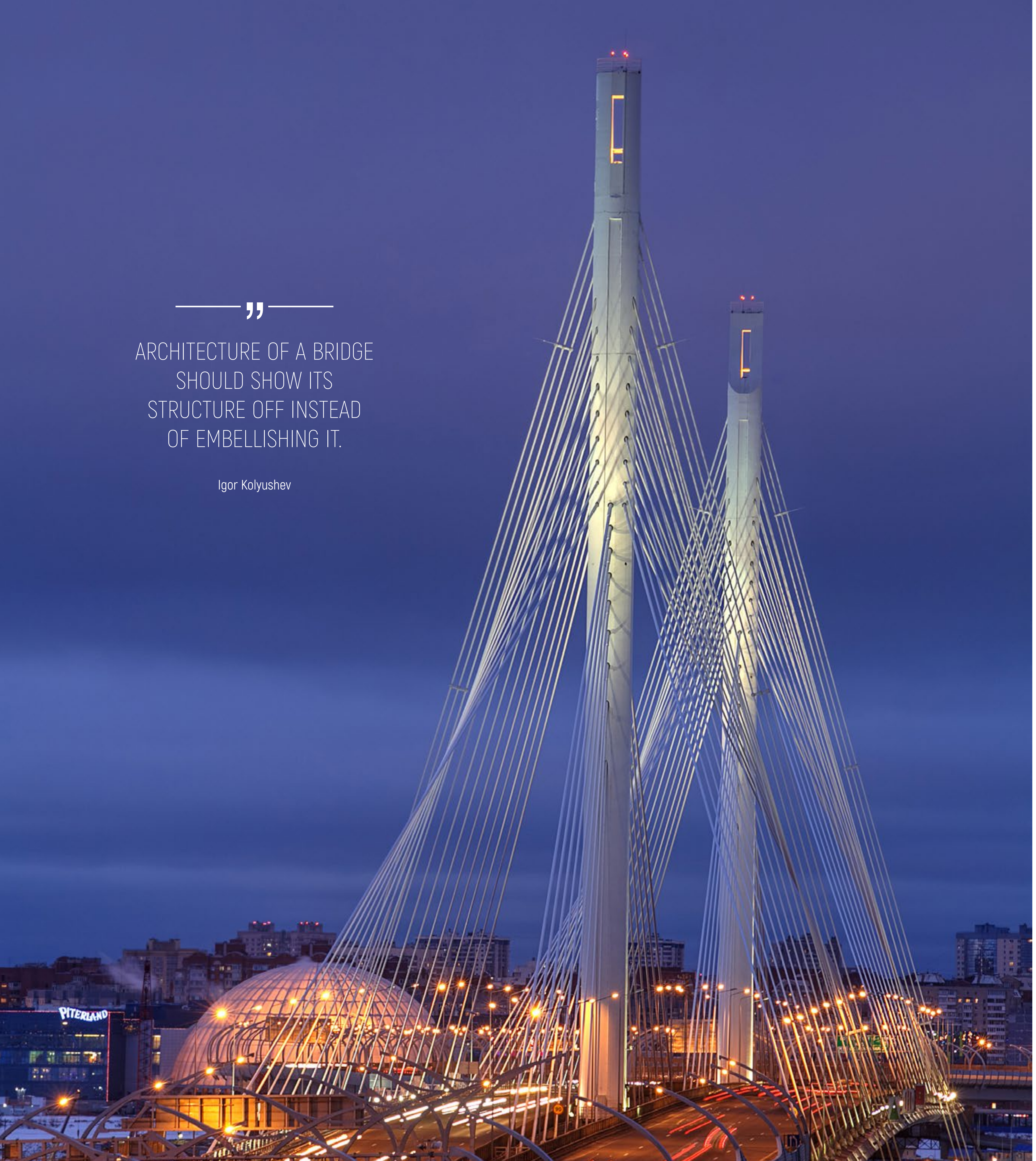
MONOCHROMATIC, LIGHT, AIRY

The new bridge's appearance was of utmost importance since it was one of the first things the cruise ship passengers see in St. Petersburg. The bridge was expected to become a functional art object that would introduce arriving tourists to the classical St. Petersburg. The structure had to be designed in the same style as the rest of the road, yet to become a striking architectural landmark at the waterfront.

The bridge is located at the mouth of the Malaya Neva River and is clearly visible from the Spit of the Vasilievsky Island. The Bridge had to have a slender silhouette that would complement the Neva panorama. Tall pylons were not to clash with elegant spires that for three centuries have been piercing the clouds above the Northern capital.

The Institute specialists consider any bridge architecture as an integral component of the general design process, the primary objective of which is to find a rational engineering solution. Many years of experience in design prove that any structure's beauty lies in its simplicity and clarity.

> *“It was decided to give up any small details in the Petrovsky Bridge design so that it would not look blank against the water and sky. We were seeking to make it monochromatic — an integral object fitting the environment. What we have got now is a slender silhouette with an intricate pattern of cables.*
>
> *Alexander Malyshev,*
> *Chief Architect*



The eye-catching shape came as a result of the elaborate engineering of the structure. The pylons of the bridge rise between the decks, and the snow-white cables are running in different planes. Intricate pattern of the steel threads evokes the image of a sailboat with tall masts.

The shape of side cables came as a result of the elaborate architectural design. Initially, architects were considering a diamond shape. Later, however, the engineers came up with an idea to lower anchors almost to the water level so that the side cables would form triangles which would also make pylons more stable. This solution added stiffness to the side cables and made the construction technology simpler as there were no transverse elements in the bridge. Three planes of cables and several bearing points for the girder enabled making the latter less bulky. Unusual pattern of cables is not only meant to be eye-catching; it is feasible both in terms of engineering and cost effectiveness.

“ *Architectural concept of a bridge is an integral part of the overall design process, primary objective of which is to find a rational engineering solution. Architecture of a bridge should show its structure off instead of embellishing it. The only decorative element of the new bridge is the top of the pylon. What matters most for us in design is the pursuit of the “golden” engineering idea.*

Igor Kolyushev,
Technical Director

The cable-stayed structure above the Petrovsky Channel became another landmark for the city where almost every bridge is an architectural masterpiece. In the company of historical bridges of St. Petersburg the cable-stayed bridge has a special part to play: to enrich the waterfront view and to add to the sober image of St. Petersburg some new lines created with novel, hi-tech and remarkably beautiful techniques.

SPECIAL FEATURES OF THE CABLE-STAYED SYSTEM

3D-EFFECT CABLES

The cables are running in three planes from the pylon to the deck level. Two groups of cables are fixed at the structure edges while the third group is aligned to its axis. Those cables that are closer to the pylon are anchored to its upper part instead of the lower: this solution allows preserving the design dimensions of the deck. In order to make pylons more stable, three anchor cables were installed on either side in the cross-section; they run from the top part of the pylon almost to the water level. The cables' entwined pattern makes the bridge look fresh and airy.

“ *The bridge across the Petrovsky Channel is special for its unique pattern of cables entwined at different levels. A combination of slender pylons and side-cables is another off-beat engineering solution. Steel cables are like ship rigging. A parabolic pattern is breath-taking; it is very sophisticated compared to conventional straight-line cable schemes. The result is an elegant, slender structure that seems to shoot up into the sky.*

Jean-Bernard Datry,
Director, Setec TPI, France

Based on the approved architectural concept, a 3D analytical model of the bridge was made in order to perform static, dynamic and aerodynamic analysis. The obtained data were then used to incorporate the essential engineering solutions in the design. The bridge came out strong and durable, able to withstand the strong Baltic winds.

Ilya Semenov
Project Chief Engineer

“ *The Petrovsky Bridge shape stems from the endeavor to maximize the construction feasibility and to minimize potential risks. The intricate stay cable scheme was conceived in the process of seeking a simple and cost-effective solution for pylon design. As a result, the pylons look like tall slender masts. This design implied that cable anchors could not be installed at one level in the pylon's body cross-section, so we had to find some other combinations. Two options were developed. The first one was a classical case where anchors at outer and inner planes of cables are spaced out at different heights. The second solution — which eventually was realized — suggested the reverse sequence of stay cables.*

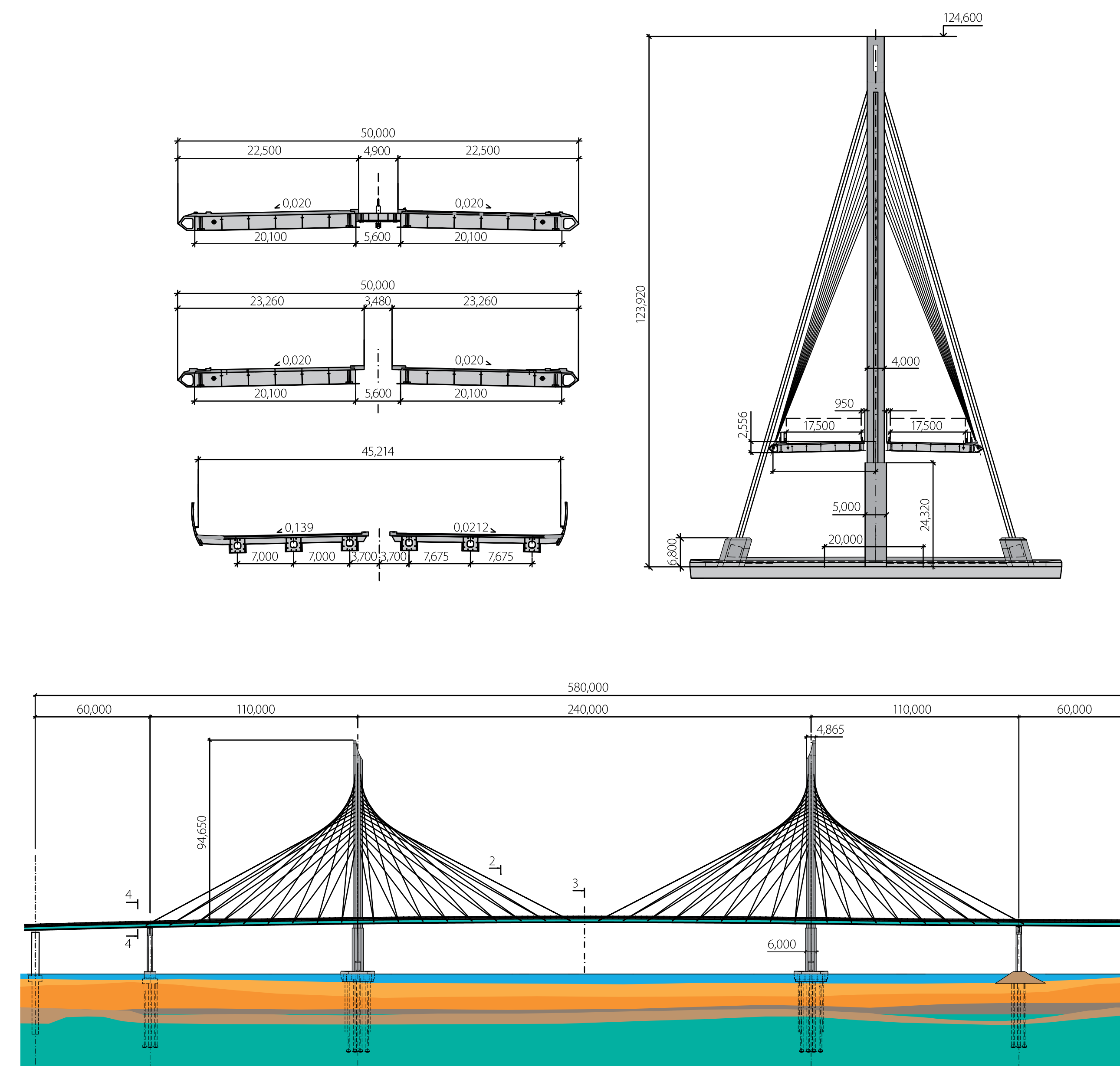
“ The design and concept of the bridge across the Petrovsky Channel were very audacious. Objects like this call for complex and accurate analysis and advanced software. High competence of the Russian colleagues was proven by the fact that all our results were almost fully consistent with the Institute’s data. We were fully satisfied with the quality of their engineering solutions.

Jean-Bernard Datry,
Director, Setec TPI, France

3D

3D model

BRIDGE ELEVATION



CONSTRUCTION PLAN

INNOVATION AS A BASE

Engineers of the Institute Giprostroymost – Saint Petersburg always implement the most advanced Western technologies in the structures they design. Wherever the bridges created by the St. Petersburg specialists are located — in Vladivostok across the Eastern Bosporus Strait or in Riga across the Daugava River — each of them is a unique piece of the art of engineering. It would not be possible if not for the innovation spirit and for the endeavor to expand the horizons.

The bridge across the Petrovsky Channel is not very large compared to the world record holder — the Russky Bridge; however, it is a well of the cutting-edge engineering solutions. It is full of innovations and is second to none in our country. It is a unique cable-stayed structure in Russia, with its steel-reinforced central span encompassing a metal girder and reinforced concrete deck. It was back in 2001, when the Institute came up with this type of structural design for the first time — for the Bolshoy Obukhovsky Bridge; at that time, however, the Russian contractor did not dare to implement an untested technology.

“For this bridge, we had to deal with the steel-reinforced concrete technology for the first time. We were confident that our idea was right. However, idea is one thing, but accomplishing it is quite another. We honed all the intricate aspects and reached a desired result — the design geometry with the cable loads consistent with analysis data. Now we know how to deal with steel-reinforced concrete.

Igor Kolyushev,
Technical Director

Fifteen years later, the international consortium experts endorsed the designers' idea. By that time, steel-reinforced concrete was widely used in the global practice of bridge-building for spans up to 400-m long; this material was considered most cost- and operation-effective compared to metal structures.

The structural design was new for the Russian engineers which made engineering analysis and technology more complex to a certain extent. The assembly process involved additional operations like slabbing, concreting, follow-up cable stressing at each stage. In collaboration with the ICA Construction experts, the Institute specialists developed a mobile unit for installation works. It came as a new and creative experience for the General Contractor as well. Now the colleagues from the West present the bridge across the Petrovsky Channel at various international conferences as an example of a mutually beneficial partnership.

Another structural feature of the bridge is that the deck, instead of being rested on the pylons is suspended on stay cables. This solution was a subject of many a discussion with the foreign partners; eventually it was implemented. Audacious innovations at the core of the design made the bridge across the Petrovsky Channel a new benchmark in the bridge-building industry.

The concreting of the pylons was done using climbing formwork. This technology required advanced equipment, a clear coordination of the process and an uninterrupted concreting process. Step by step, the formwork was moved up with electric and hydraulic mechanisms which allowed building pylons at a speed of 3 m per day. As a result, it took only three months to complete a 124-m pylon. Apart from higher concreting speed, the climbing formwork also provided a way to reduce the number of cold seams. As a result, the monolithic structure is now more durable and reliable.

HIGH-SPEED CONCRETING

When developing the construction master plan, the Institute specialists had to consider not only the structural features of the bridge, but also the capabilities of the contractor, available materials and equipment. The optimal solution for side span construction was the gradual assembly on the scaffolding and incremental launching of the assembled sections. For the central 240-m span, it was decided to construct the section with the use of assembling equipment and watercraft, going from both sides simultaneously.

During the construction of the bridge, several unique design solutions were implemented. For the four assembly sites, master plans were developed which foresaw incremental launching of bridge sections following a curved trajectory. The Institute engineers also made the necessary calculations for lifting 100-m-long metal beams up to the 20-m level and beyond.

Mete Demir
Head of the branch of the Turky-Italy Consortium Içtaş-Astaldi (ICA)

“ I remember the day when the central span of the Petrovsky Bridge was finished, having connected the two sections of the Western High-Speed Diameter. We are truly proud of being the ones who made this project happen. As a result of our cooperation with Igor Kolyushev and his team, we designed and constructed a unique structure — a cable-stayed bridge made of metal. Due to the fact that Russian and European standards are different, we often had certain differences of opinions, but we sat down to discuss those opinions, always staying in touch. Our colleagues were always open to new technologies and processes, and we were able to reach a common ground easily, finding the most feasible solutions that would comply with both the Russian codes and European standards. We came a long way, and found trust between our organizations — this is crucial for our future cooperation.

PROJECT SIGNIFICANCE

LOOKING UP TO THE SKIES

On the night of August 9, 2016, the last metal section of the bridge across the Petrovsky Channel was put in place. The key block was assembled on the bank then loaded onto a barge and delivered to the design location. Powerul hydraulic jacks raised the 20-ton structure from the water surface to the 25-m level. At that point, the Western High-Speed Diameter was closed, forever linking the northern and southern parts of St. Petersburg.

With the opening of the bridge, Vasilievsky Island at last received a permanent link to the mainland. Not only did the bridge across the Petrovsky Channel provide a shortcut for the city residents, it also became a true landmark of the cityscape when looking from the Gulf of Finland. The airy lace of stay cables running from the two pylons firmly hold the wide decks in place.

Another important landmark can be seen from the bridge, the Saint Petersburg Stadium on Krestovsky Island, where the Institute also participated in the construction. Towering 124-m pylons of the bridge visually echo the eight pylons of the sports arena carrying its retractable roof. The conceptually different creations by the St. Petersburg engineers have a lot in common: innovative solutions for structural elements, unique construction processes and shared ideas of the Western engineering school.

Igor Kolyushev
Technical Director

“ *This project is a wonderful example of teamwork, where all members had a common goal. The ZSD Directorate, the Highways of the Northern Capital investment project — the two owners of the project — and the General Contractor, ICA Construction, were all equally interested in the timely completion of the project. Cooperation with the Turky–Italy organization was a very important experience for us. Our colleagues actively participated in the design and decision-making, showing their dedication to the project — in truth, they were invaluable to the process in their own right. They were extremely involved and careful. We had to constantly stand by and substantiate our decisions to them. Acting closely hand in hand is always a right decision, which works for the high quality of the end result.*

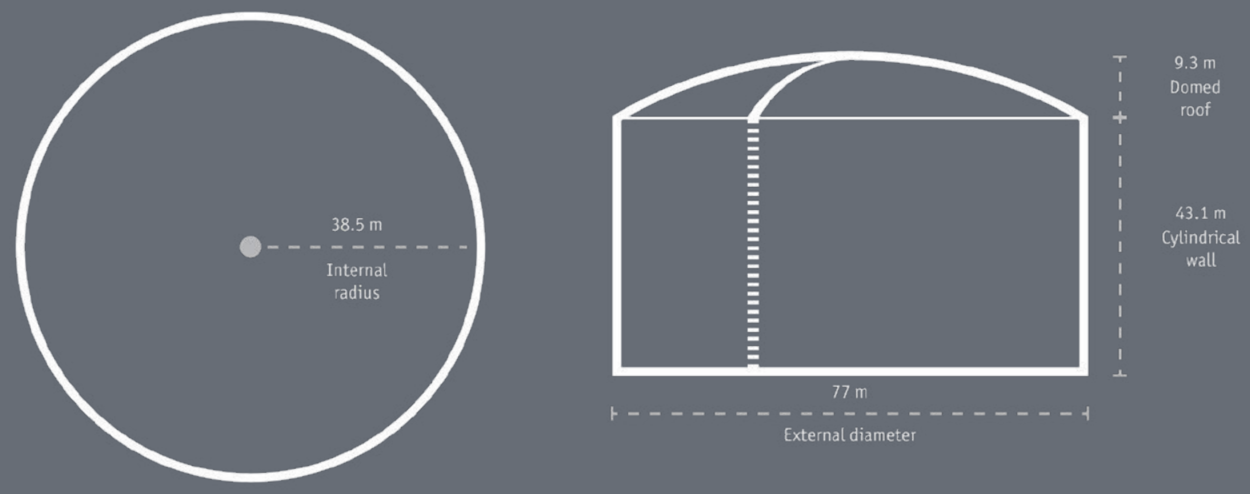
Yamal LNG   Sabetta vil., Yamal Peninsula

HI-TECH PROJECT IN THE ARCTIC REGION

The Yamal LNG plant is an international, fully integrated project for extraction, liquefaction and shipping of natural gas, currently being implemented in the Russian Arctic region.

Utilizing the resource base of the Yuzhno-Tambeyskoye gas field, the Yamal LNG plant is designed to produce approximately 16.5 million tons of liquefied natural gas and up to 1.2 million tons of natural gas liquids annually. The fossil fuels are to be supplied to the countries of the Asia-Pacific region and Europe. The facility is extremely complicated and technology-intensive and is being constructed in inclement climate conditions of the Arctic region.

By the time the plant will have reached its full capacity in 2019, an airport, three LNG production lines with a capacity of 5.5 million tons per annum each, four double-containment cryogenic LNG storage tanks with a capacity of 160,000 cubic meters each, a power plant and a year-round seaport are also to be constructed within the project. The project's location in the Arctic is an advantage, as it allows for higher production volumes in comparison to similar projects in lower latitudes.



PROJECT BACKGROUND

INTERNATIONAL TEAM

The Yamal LNG project may rightly be considered international, since specialists from 15 different countries worked tirelessly on its implementation, while among its shareholders are NOVATEK (Russia), Total S.A. (France), China National Petroleum Corporation (China), Silk Road Fund (China).

Among the companies that joined the project's international team was the French company VINCI Construction Grands Projects that as part of a consortium won the tender for engineering, procurement and construction of double-containment cryogenic storage tanks for liquefied natural gas, including construction of foundations and earthworks.

According to the terms and conditions of the contract, VCGP* had to ensure strict compliance with the Russian legislation as well as regulatory and technical documentation. To this end, the company had to choose a partner; more specifically, a Russian design company which would be able to provide comprehensive support throughout engineering and construction of storage tanks. The cooperation between the European and Russian engineering schools allowed designers to account for the natural and climatic conditions in the region and implement the most advanced LNG** storage technologies.

* VCGP is the VINCI Construction Grands Projects company from France.

** LNG stands for liquefied natural gas.

PACKAGE OF WORKS ON THE PROJECT

- Technical consulting
- Full range of engineering design for the external reinforced concrete shells, earthworks and foundations of LNG storage tanks
- Optimization of design solutions for earthworks and foundations of LNG storage tanks
- Development of detailed design for the external reinforced concrete shells, earthworks and foundations of LNG storage tanks
- Development of working documentation for the external reinforced concrete shells based on the initial structural and technical design of VCGP
- Development of the process, performing field tests of piles and scientific analysis of test results
- Arrangements for scientific and technical support at the design stage and interacting with specialized research institutes engineers

MOMENTOUS DECISION

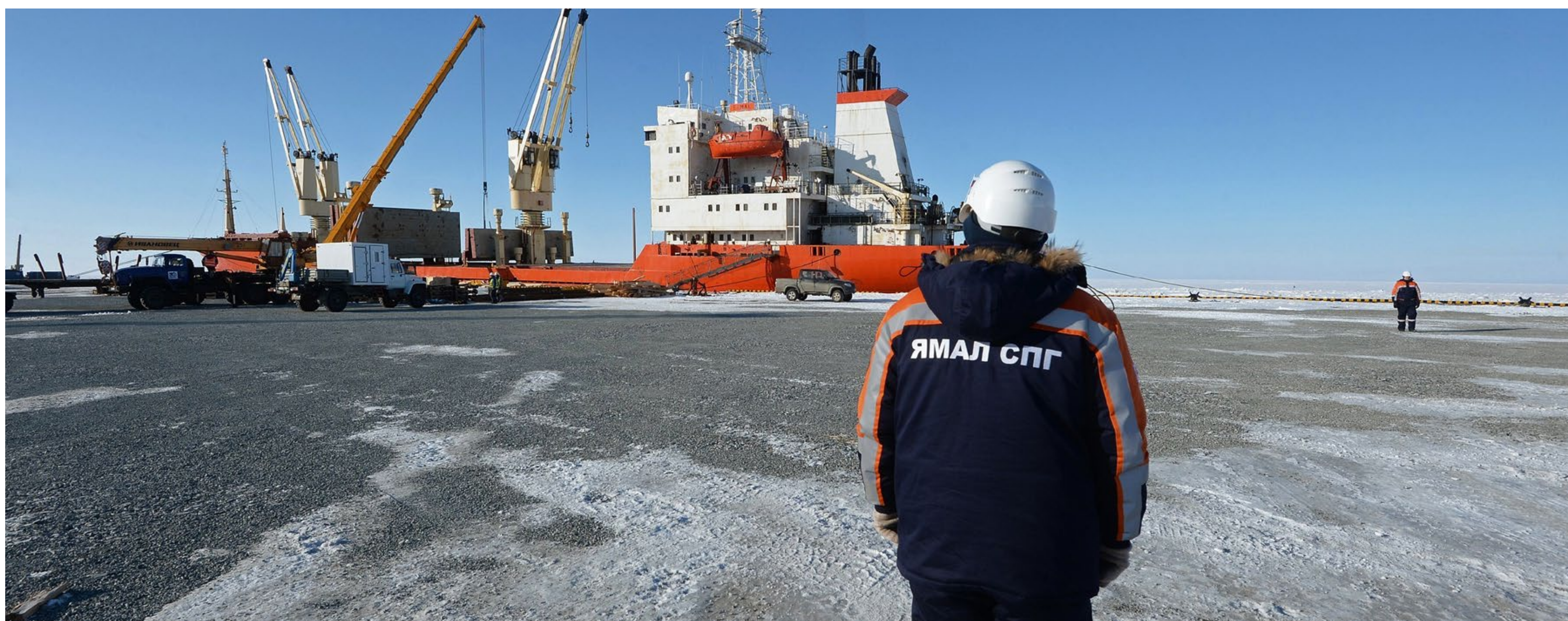
The VCGP company has a century-long history and experience in the construction industry, and over thirty years of experience in engineering and construction of storage tanks for liquefied gases.

VCGP negotiated with various Russian design institutes, having certain criteria for potential partners. The key parameters were: extensive work experience, familiarity with European standards and regulations, and good command of English. Candidates had to have experience in the design of large-span structures of pre-stressed concrete, be well-versed in analysis of structures in the northern climate conditions, as well as earthworks and foundations on permafrost.

Having bid for the tender, Giprostroymost provided convincing evidence of the Institute being one of the leaders in designing structurally challenging and unique projects. The Institute specialists had no difficulties proving that they met all the criteria in terms of technical expertise and English skills. The crucial advantage however, was their extensive design experience and familiarity with the European regulations. In particular, they referred to the construction project of the Southern Bridge in Riga, which was developed by the Institute in full compliance with the European standards. This advantage was the key factor for the foreign colleagues to make the decision in the Institute's favor, since at the LNGT* design stage, engineers were expected to scrupulously cross-check the Russian regulatory and technical base and engineering tradition with the Western designers' solution. Another important criterion for winning the tender, of course, was the human factor. Industry peers familiar with the Institute from their previous joint work on other large-scale projects, strongly recommended the St. Petersburg Institute as a reliable partner.

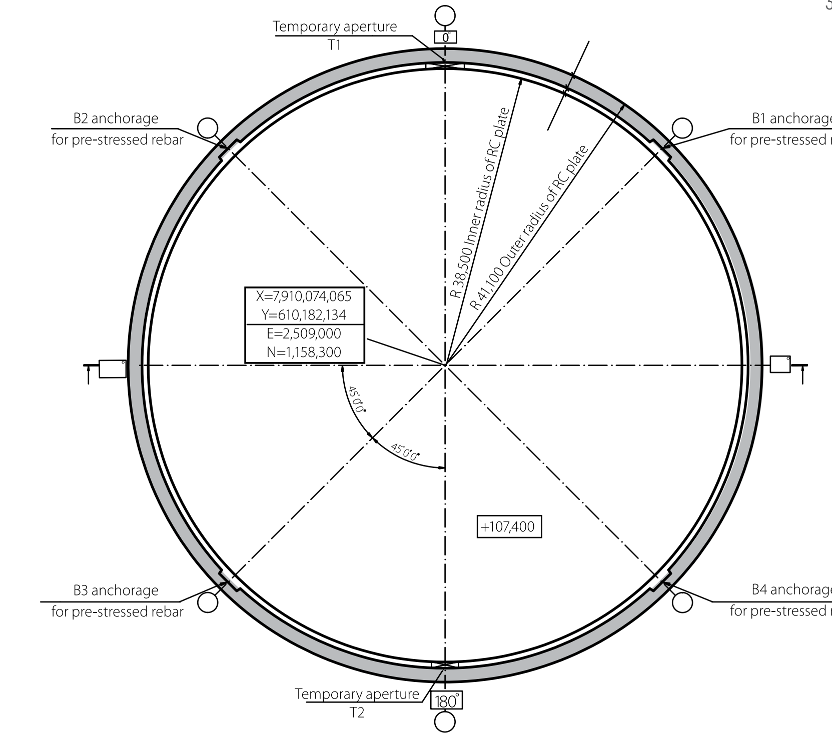
The fair victory gave the Institute an opportunity to participate in a complex, yet exciting project, where the engineers had to show their skills and knowledge accumulated over the decades of successful work.

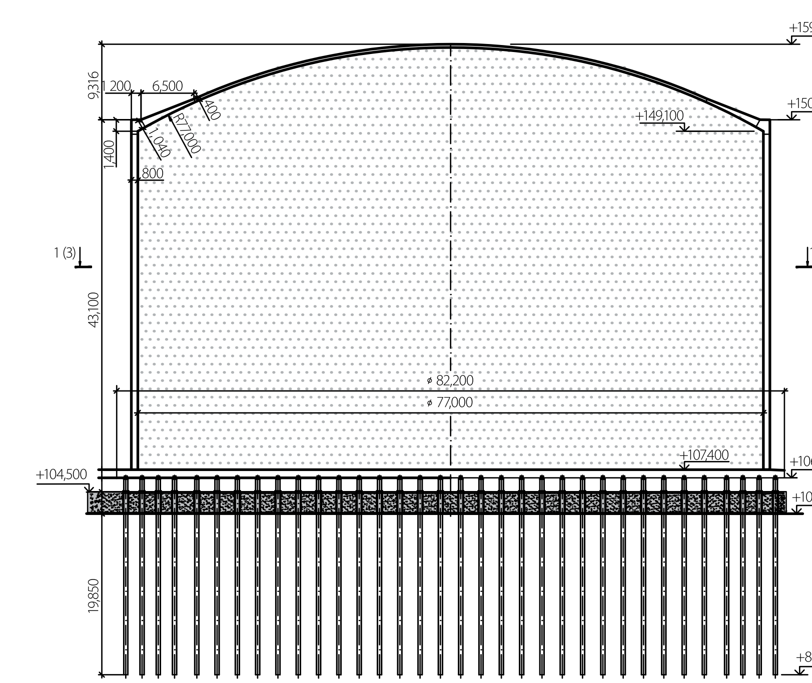
* LNGT stands for liquefied natural gas storage tank.



3D
3D model

STORAGE TANK DRAWING





TECHNICAL CONSULTING

QUICK START

At the early stages of cooperation, the engineers from France and Russia held a series of consultations. At the meetings, colleagues discussed the validity of certain coefficients used in the calculations, determined sources of various formulae and technical requirements. For the project to be a success, the scope of applicability of certain provisions of regulatory and technical documentation had to be determined. Seeking the optimal solutions, specialists studied the best available engineering practices and made sure that the slightest nuances were accounted for, including such mundane things as simple typos in documents.

Anton Polunin
Chief Project Engineer

“ We undertook to guarantee that the constructed facility will comply with all the requirements of the Russian codes. The design was carried out in parallel: our foreign colleagues were making analysis following their codes, while we followed ours. In cases when our French colleagues were not able to achieve a sufficient strength for elements they designed, they had to adhere to the Russian codes. And vice versa, if our norms were not as strict as the European codes, they would opt to follow theirs. Some engineering aspects were not covered by the foreign standards, so we had to take them upon ourselves. We had to discuss every single element of the structure, but, in the end, each piece adhered to the strictest regulations. Codes substantially differ: in some situations, Russian standards require more finesse while in other cases, European codes are much stricter. But in the end, we succeeded in combining the two systems and prepared the amended design package that was approved by Glavgosekspertiza.

Specifics of the Arctic region played their part in the design and construction process: everything had to be done in overdrive. Construction and navigation periods in the Arctic are quite short; thus, failure to meet construction or procurement deadlines might result in serious delays and breaches of the approved construction schedule. To avoid this, design of the structural elements of LNGTs and optimization of earthworks and foundations were performed concurrently.

FIELD TESTS

IN PERMAFROST CONDITIONS

The Yamal LNG plant is extracting resources from the Yuzhno-Tambeyskoye deposit located within the permafrost region. Permafrost, in geology, is the ground with a temperature that remains at or below the freezing point for more than three years. In such soils, inclusions of ice are always present, which act as a binding agent between mineral particles. Torsten Sachs, a German scientist, compared this phenomenon to a giant freezer that occupies almost a quarter of landmass on the planet and some 65 % of the territory of Russia.

Development of copious and hard-to-reach Arctic reserves is always a test of nature's strength. Frozen soil is hard as a rock and may be used as a reliable foundation for buildings and roads. But construction in these latitudes may cause temperature fluctuations and defrosting of soils. This may lead to a drastic change in their properties: the soil can sink or swell, which, in turn, may cause deformation of constructed objects. To avoid deterioration, structures in the Arctic region are often constructed on piles. The LNGT structural design foresaw as many as 948 driven piles to be used as foundation for each of the four double-containment cryogenic storage tanks for liquefied natural gas.

“Testing one pile would take us six months. The pile was submerged, frozen, loaded and then observed. Most of the time was spent waiting for the results. With delivered materials having a +15 °C temperature, soil around a pile would heat up to zero. We had to wait for several months for the soil to freeze again, so we could begin our observations and analysis.

Anton Polunin,
Chief Project Engineer

Structural analysis showed that the engineering solutions for foundations and earthworks of LNGT could be optimized, both in terms of material consumption and the use of load-bearing elements and thermal stabilizers. To develop a solution, unique “predictive” thermal and strength analyses or field tests of piles had to be performed. Empirical calculations are mathematically complex even in the standard conditions of permafrost soils. Additionally, designers did not have sufficient input data to perform the necessary analyses. The final decision was made upon having taken into account the results of surveys that showed that the soils in the construction area were plastic frozen, with marine type of salination, and further encumbered by cryopegs* presence. Given this, field tests of rammed cast-in-situ piles were chosen as a more promising option.

* Cryopeg is saline and brine water in permafrost soils at below-zero temperatures.

In order to develop a comprehensive program of pile field tests and subsequent processing and analysis of the results, the Institute engaged a number of specialists from the Gersevanov Research Institute of Bases and Underground Structures. Not only did the scientists use their achievements from the Soviet era, they also improved upon the approach to engineering design, having used the latest scientific findings of the mechanics of permafrost soils.

After several months, detailed analysis made by the Institute based on the field test data corroborated the initial engineering design for the foundation of the first LNGT, and, later, for the rest of structures.

Specialists offered the customer several effective solutions that eventually reduced the cost of the project and expedited the construction of storage tanks. Excessively sophisticated load-bearing elements were replaced with the hinged fixed ones through a series of special operations aimed at increasing the bending length of piles placed in permafrost soils. Analysis showed that the design length of piles could be decreased from 37 to 24 meters. Predictive thermal analysis of storage tank foundations allowed to substantiate the optimal scheme of thermal stabilizer (SCD)* placement. According to the scheme, the stabilizers were placed evenly over the entire area of the storage tank foundation, with additional zones (foundation sections bearing the highest loads), with increased SCD density.

* Soil thermal stabilizer is a device with a refrigerant that is placed next to the support piles to maintain the required soil temperatures. SCD stands for seasonal cooling device.

INNOVATIONS

"SIBERIAN SOCKS"

THE "SIBERIAN SOCKS" SOLUTION IS A RARITY, EVEN THOUGH IT SEEMS SO OBVIOUS.

Anton Polunin

"Siberian socks" is the moniker given by the French engineers to a jointly developed innovation that ensures temperature stability of the soil and mobility of piles in hard soils. This engineering solution is represented, in essence, by two round pipe segments of different diameters, inserted one into another, with the space between the pipes filled with a special polymer that retains its plasticity even under design winter temperatures. A device fitted in the upper part of the pile provides the necessary flexibility in the frozen soil.

According to the VCGP information, this unique technology received the Vinci Innovation Award–2015 in the Processes & Technologies category.

STRUCTURAL SOLUTION

FUSION OF THEORY AND PRACTICE

Designing the external LNGT shell made of reinforced concrete proved an interesting experience for the Giprostroymost engineers. The four storage tanks hold rectified liquefied gas, which is cooled to −163 °C. The structures themselves are, in essence, barrels of reinforced concrete — 60 meters tall and 82 meters in diameter. The volume of each storage tank is 160,000 cubic meters. Just to make it clear, this volume is enough to fit two Airbus 380 aircrafts within one storage tank. The tanks are equipped with a thermal protection system and are designed to withstand low temperatures of the liquefied gas. The engineers had to design the structures to bear specific loads. Notwithstanding the Institute's extensive experience in the field of reinforced-concrete structure design, many features of this project were new to the experts. They had to analyze various scenarios and determine a structure's behavior should liquefied gas leak from the storage tank, an explosion occur at a nearby structure, a heavy object fall or otherwise impact the tank, or a fire break out. Designing reinforced-concrete structures to withstand these loads and actions is a very complex engineering task; given the exceptional significance of the LNGT project, the Institute specialists had to be extremely careful in their decision-making and attentive to the tiniest of details.

At the time, the Russian codes did not fully cover the needs of the Institute when it came to the design and construction of LNGTs. Specialists had to constantly cross-check foreign publications and standards. This approach was far from optimal, so a specialist from the Gvozdev Research Institute of Concrete and Reinforced Concrete was invited to join the working group. Scientists and engineers summarized foreign publications and standards along with the experimental, regulatory and theoretical knowledge base existent in Russia. As a result, recommendations for the design and construction of LNGTs were developed, which fully complemented the Russian codes. Afterwards, complicated thermal and strength analyses for emergency situations were performed on a supercomputer. Designers analyzed thousands of load combinations for various conditions of construction, tests and regular operation, accounted for unique impact the Arctic climate has on reinforced-concrete structure in their engineering design and prepared several thousand drawings for the working documentation.

PROJECT SIGNIFICANCE

PLANT FOR ENTIRE PLANET

Once the plant will have reached the capacity of 16.5 million tons of natural gas and 1.2 million tons of natural gas liquids per annum, the Yamal Peninsula will become the center of the Russian gas industry for decades to come. The colleagues from the international consortium speak of the construction in the extreme conditions of the Arctic as high as of the humans landing on the moon. Notwithstanding the cold and polar night, the incredible project is well within its timeframes — thanks to the coordinated efforts of all its participants.

Thorough studies conducted at Yamal greatly contributed to the science and further improved Giprostroymost's reputation with the peer community. Few companies would be capable of developing such a hi-tech design. Like the pioneers who had to brace themselves to cross the ice desert, the Institute engineers made a fair share of contribution to the Russian Arctic development.

> *“We have produced a convincing solution for tank foundations which became a key factor for us winning the contract. The innovative approach developed with the Institute Giprostroymost contribution allowed cutting by half the number of foundations required for such special soil as permafrost. Within less than six months the contract was signed, a team formed, foundations designed and built, tank construction completed. It was the first time that we had to work in such hard conditions including permafrost and substantial logistics issues. The Vinci team for the first time experienced what -50 °C feels like. No sunlight in the winter time became another extreme experience for us.*

Hosni Bouzid,
Project Director, LNG STORAGE TANKS

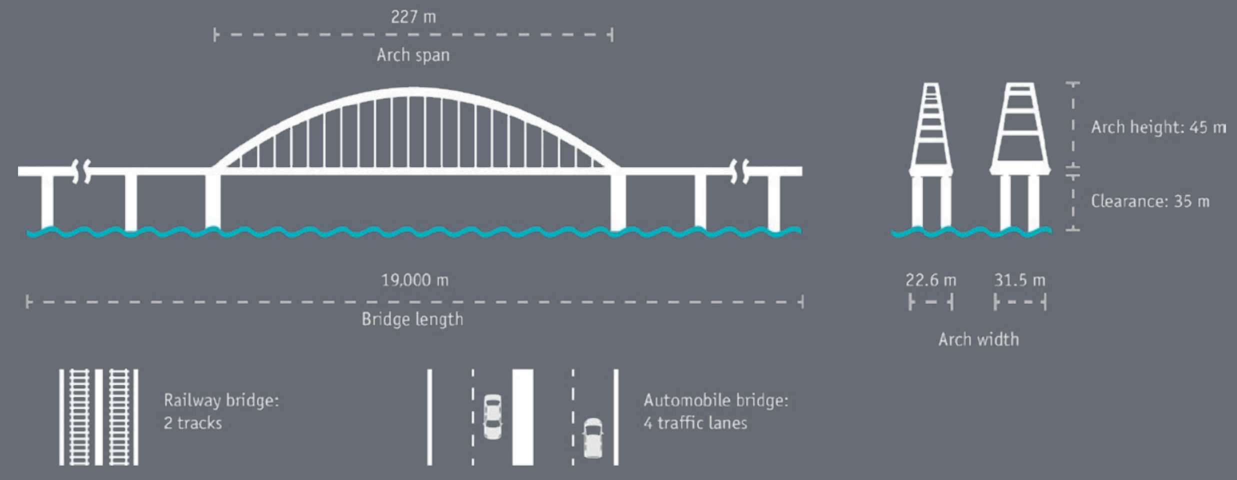
Crimean Bridge Kerch Strait

THE PROJECT OF NATIONAL SIGNIFICANCE

The long-awaited crossing between Crimea and Taman was constructed in the most trying conditions of a sea strait. It has a record length for both Russia and Europe.

The longest bridge in Russia connected the Crimean Peninsula with the Russian mainland. The length of the bridge across the sea strait is 19 kilometers. Complicated geological profile of the Kerch Strait and the tight timeframes predetermined the bridge's unique structural features. Engineers designed two parallel decks: one for automobile traffic, another for railway trains.

Sea vessels pass under the impressive snow-white arches that are visible from afar. In order to let freight ships, tankers and cruisers pass, the Crimean Bridge was elevated 35 m above the water level. There is a good reason for the bridge to be called a "people's project": constructors from dozens of Russian regions were working on it while the rest of the nation was watching the process.



PROJECT BACKGROUND

THE HISTORY OF ATTEMPTS TO SPAN THE SEA STRAIT

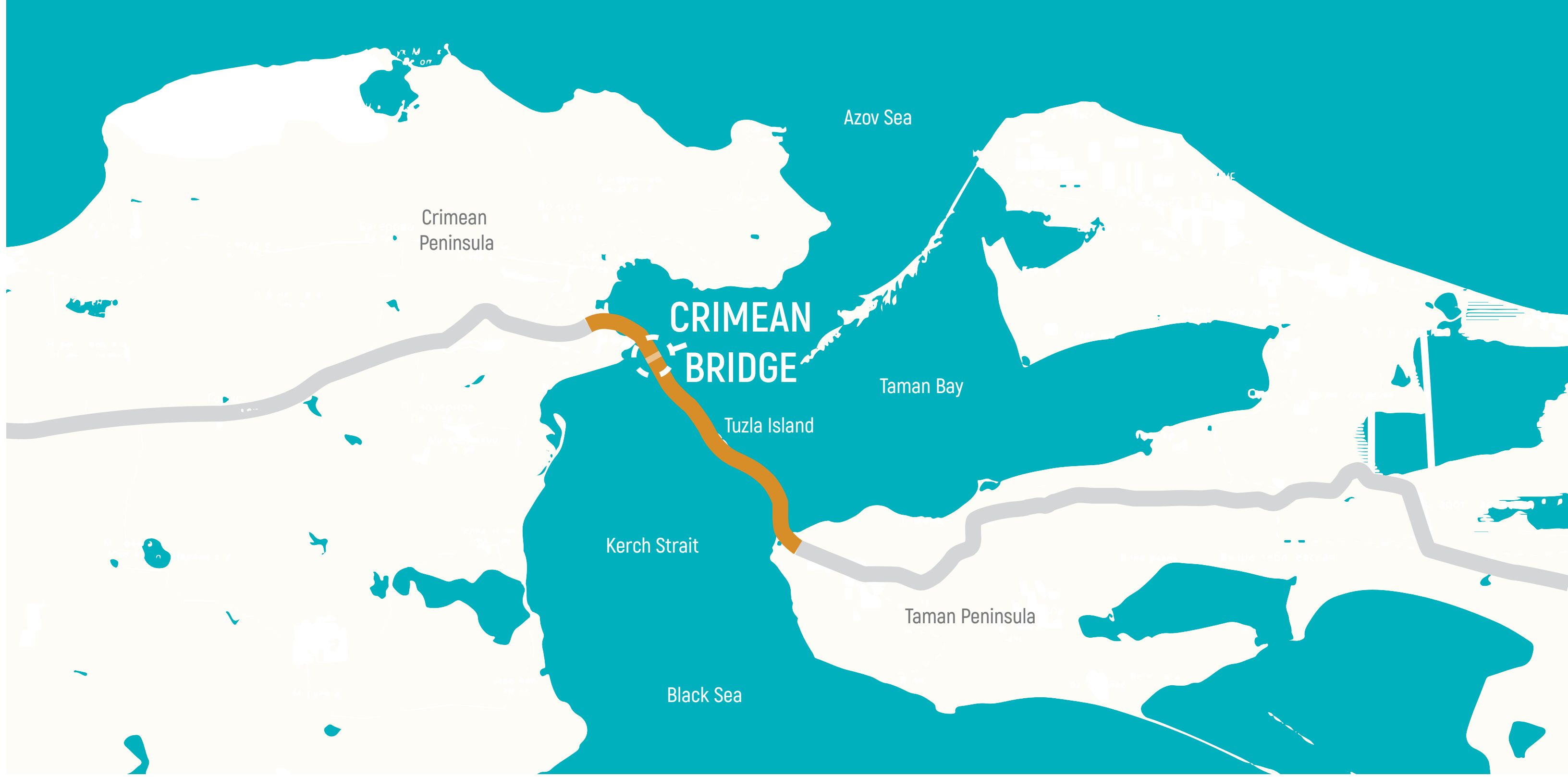
The Crimean Bridge was built mere ten kilometers away from the location of its 1940s predecessor, the construction of which was conceived by the English, started by the Germans and completed by the Soviet engineers.

In the late 19th century, the government of the British Empire was planning to build a direct railroad from London to Delhi. One bridge was to be built across the English Channel, another — across the Kerch Strait. The design was ready by 1901, and soon preparatory works began. Engineers even managed to draw a telegraph line on the Black Sea bottom. However, soon the construction was suspended: the costs of the transcontinental railroad were unaffordable for the British treasury.

Bridge across the Kerch Strait, 1944

The second attempt at constructing a bridge across the Kerch Strait was undertaken by Nicholas II. In 1910, Russian engineers submitted a new design to the Russian Emperor; however, the outbreak of the World War I made everyone forget about it.

It was not until the 1930s when the Soviet engineers resumed designing the bridge. However, the period of peace was too short for the project to be implemented. The World War II began. Crimea was occupied by the Nazis and that time it was the German engineers who started building a bridge for their own needs using their own bridge elements. When they eventually had to retreat, it was decided to blow the bridge up.



The decision to construct a railway bridge across the strait was made on January 25, 1944, three months before Kerch was cleared of the Nazis. Soviet engineers designed a bridge with 115 spans, 27-m-long each. In April 1944, the first piles were rammed in and the first span was completed on May 10.

The new bridge would significantly cut the distance from the Caucasus to Crimea and was vital for the army. The construction took mere 150 days: in November, the first train crossed the Kerch Strait. By January 1945, some of the wooden piles were to be replaced with the metal ones; some ice aprons were to be installed, too. Severe storms broke the bridge builders' plans. Extremely cold weather in the Azov Sea area resulted in a strong ice sheet, and in February great masses of ice piled up upon the bridge piers. Railroad personnel tried to blow up the ice with dynamite sticks; however, people were unable to confront the forces of nature. On February 20, 1945, 42 piers collapsed under the weight of ice. The bridge operated for almost four months, during which time over two thousand trains loaded with military cargoes crossed the bridge. So did the delegates of the famous Yalta Conference.

After the War, engineers developed a new design of a two-level bridge. The would-be Tsar Bridge might become a pinnacle of engineering art of the time. However, the Soviet authorities decided that a railway to Crimea through the South Ukraine and a ferry service would do.

PACKAGE OF WORKS ON THE PROJECT

- General design
- Design of major structures (design and detailed documentation)
- Developing construction technologies
- Design of SAC&D (design and detailed documentation)

EXTRAORDINARY BRIDGE

The Crimean Bridge is special for the following factors: extraordinary length, twin decks, unique construction technologies as well as extremely tight deadlines for design and construction.

Certain Chinese projects are undisputed leaders in terms of the length of bridges. However, in terms of the complex and unique construction technologies, this bridge in on par with the largest structures in the world, while in Russia it is second to none. However, record-setting was not an objective for the Russian bridge builders; instead, they intended to set up a permanent link between Kuban and Crimea.

ARCHITECTURAL CONCEPT

A RIBBON ABOVE THE STRAIT

Perhaps, the mankind's greatest gift is imagination. People use it to transform the world around them. The Crimean Bridge transformed the geopolitical situation, it became a tangible metaphor of reunion. The bridge exhibits confidence; its very shape looks durable and steady, capable of bearing the heavy traffic of motor vehicles and trains.

The Institute team members compare their creation with a ribbon connecting the sea strait's shores. The bridge's architectural concept had the structural design as a core; that is why there is nothing in excess in this ribbon many kilometers long.

Leonid Beliayev
Chief of Visualisation Team

“I remember the day when we started working on the Crimean Bridge design. The spring just came. The spring inspired us to draw something bright and beautiful. In March 2014, I uploaded the area digital model and satellite images, drew an axis, longitudinal profile, set the structure's basic parameters — and there it was, a draft design of the bridge. Further, I pondered over the navigation span more 200 m long — and there it was, an arch. First I put the bridge near the ferry line; however, later I found out that there were tricky currents there and ice was likely to damage the bridge piers in the winter time. So the location was moved but the arch remained. It took its place above the navigable channel. As soon as the bridge “relocated” to the Tuzla Island, a 19-km-long model was designed.

DIGITAL MODELING OF THE BRIDGE

In 2014, a group of architects began the digital modeling of the bridge prototype. The full scale model (BIM) allowed presenting the architectural and structural solutions made by the Institute team.

3D model is good for assessing a structure's design and seeing its minute details: all piles, supports and spans of the 19-km-long route as well as barriers, railings, lighting masts and service walkways were displayed on it. Such visualization allowed to promptly reflect the latest engineering solutions and helped customer and designer in coordinating their actions. It is worth noting that a BIM model was "live": it was constantly updated and promptly — within a few hours — modified in case of any structural changes. Digital modeling never ends until the final design stage.

DESIGN STAGE

IN SEARCH FOR A STRUCTURAL SOLUTION

Before the final design approval, the Crimean Bridge was presented on paper as a tunnel, a combined bridge-cum-embankment, a single two-level structure with a motorway on the top level and tracks on the lower level. Bridges like this are quite common, engineers are used to them, they are time-tested. However, it was the St.Petersburg Institute's draft design that was adopted: parallel twin bridges.

WE PRODUCED A CREDIBLE ENGINEERING SOLUTION.

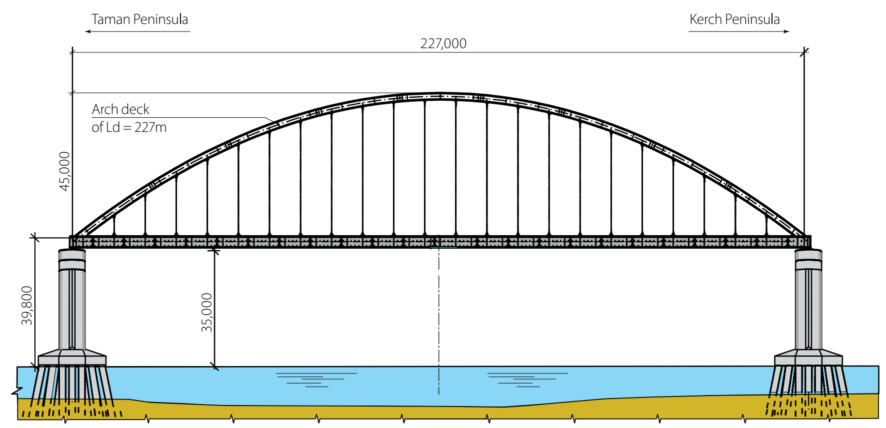
“Dividing the bridge into two — for motor vehicles and trains — meant reducing material consumption. It looked more impressive in terms of construction technologies, too. Most designers offered a combined bridge with tracks on the lower level and a motorway on the top. Such a solution would entail using heavy metal trusses. Our option was less heavy. For an area with high probability of earthquakes it was a great advantage. Also, having divided the bridge into two independent structures, we could meet the deadline. Another advantage of the design would become evident only when in operation. There would be two different organizations to monitor the statuses of the motorway and the tracks; in case of two separate bridges it would be more feasible.

Many strong design companies bid for this project. We produced the engineering solution that was credible. We were able to see the ultimate goal: to design and construct the longest bridge in Russia within three to four years. It meant we had to do what we were capable of. Or something we were to learn to do quickly. The essence of our concept was in simple techniques to be used to connect the Kuban and the Kerch shores as quickly as possible. The bridge's appearance would not be that extraordinary if not for its 277-m-long arches. It was the construction technologies that were most innovative.

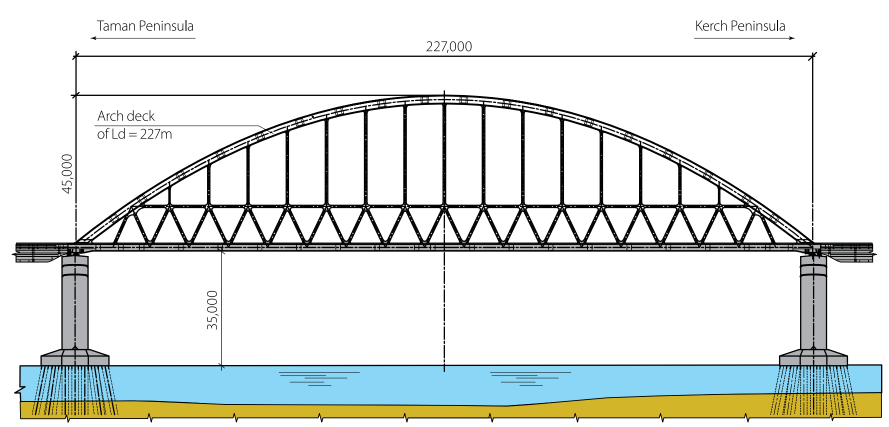
Igor Kolyushev,
Technical Director

BRIDGE ARCHES ELEVATION

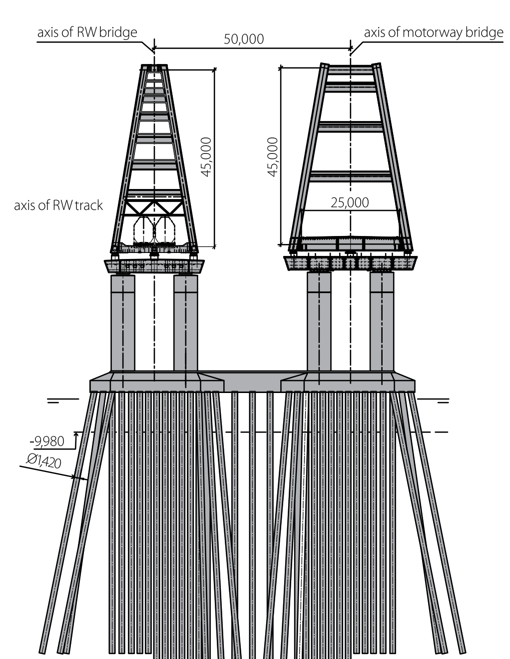
3D
3D model



Arched motorway superstructure



Arched railway superstructure



The structures of piers and spans are different for the railway and the motorway bridges. The reason is that the loads on the railway bridge are higher than those on the motorway which calls for different engineering solutions.

Oleg Skorik
Design Director

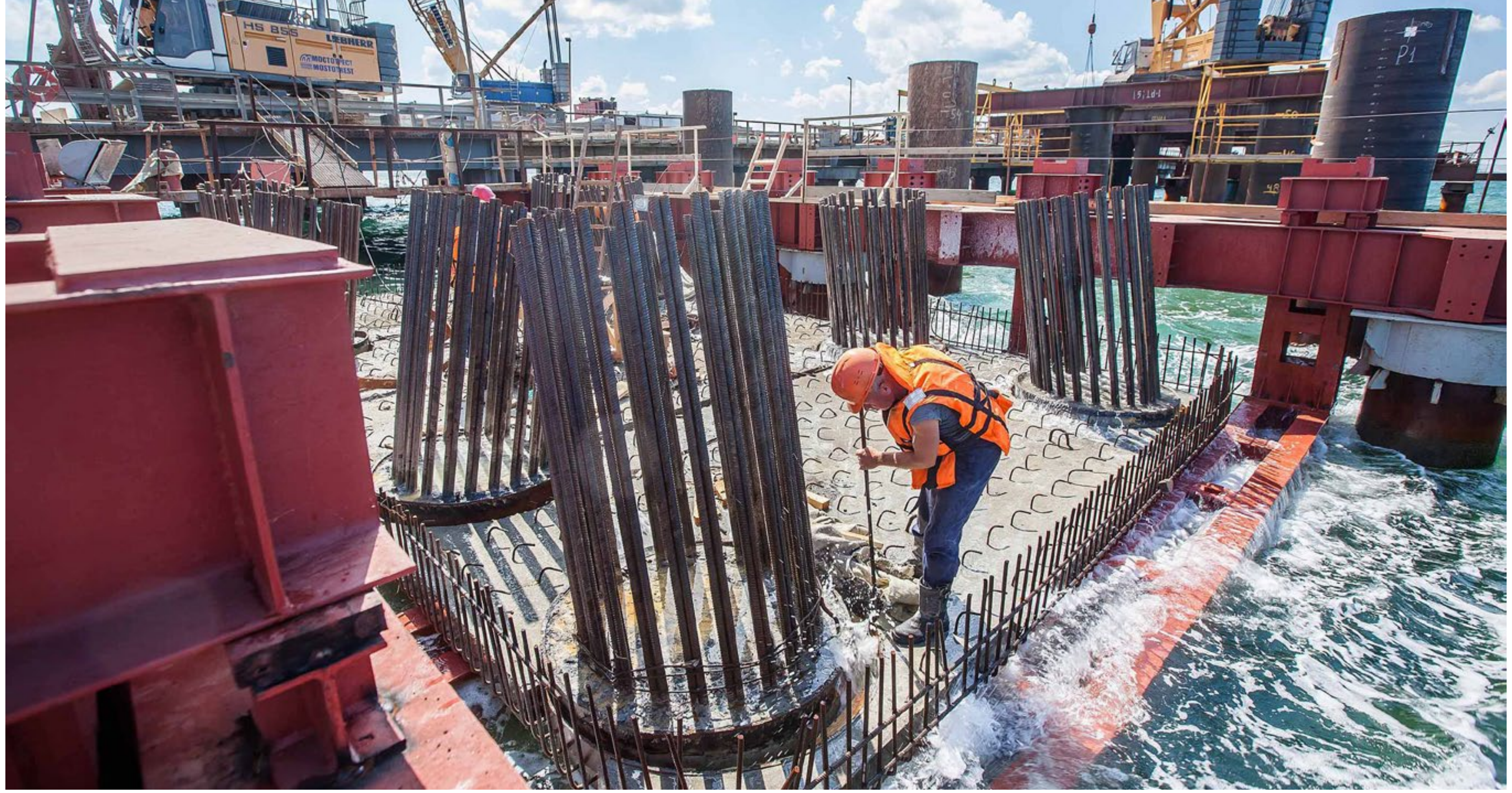
“ We designed independent superstructures for each of the two tracks connected with transverse beams above piers. This was dictated by potential seismic actions. Superstructures were designed discontinuous, made of metal, with an orthotropic plate. The spans are either 55 m (above spits, channels and Tuzla Island) or 63 m long — above the sea. Tracks were to be continuous-welded, laid upon ballast. Pier foundations for both bridges are similar and are made of rammed steel piles. However, there are more piles rammed under the railway tracks and the piers are bulkier there. Longitudinal profiles of the two bridges are significantly different. The incline of the motorway bridge at the approach to the arch is about 40 per mil which allows vehicles to climb as fast as possible. For the railway bridge, such inclines are more than four times flatter — mere nine per mil — which makes the railway bridge’s slope much longer.

DESIGN TRIALS

IN COLLABORATION WITH SCIENTISTS

The more information was obtained of the environmental conditions in the construction area, the more evident it became how complex the upcoming construction works in the Kerch Strait would be. One of the bridge sections of a 7-km length was to run right above the sea water which was quite a challenge for bridge builders. While developing the construction technology, designers were to take into equation the extreme environmental effects: ice, wind, wave loads, high seismicity in combination with weak soils. The Institute engineers drew on scientists' expertise: aerodynamics specialists, seismologists and geologists. The research data were analyzed and incorporated into the bridge concept design, with traditional technologies being adapted to the specific conditions of the sea.

Having drilled a total of 60 km of wells, geologists informed that the top layer of the soil under the bridge was too weak. In the event of seismic shock, sand and clay could get thinned and turn into a "jelly" of a kind. It meant the drilling had to go deeper, down to 65–90 m. Due to the difficult geological conditions designers gave up drilling and opted for rammed steel piles instead. Their advantage was in relatively less time-consuming installation; anything allowing to cut time was welcome.



In order to obtain the data pertaining to seismic actions on the bridge, experts of the Schmidt Institute of Physics of the Earth with the Russian Academy of Sciences were invited to contribute to the project. The experts provided precise information of the region's original seismicity, estimated the value of seismic intensity in the area along the bridge and at each of its sections, taking into account their particular features. According to the data obtained from the scholars, the current normal situation for Crimea is 70 to 80 shocks of various intensity per year. The maximum intensity the Crimean Bridge would be capable of withstanding is a magnitude 9 earthquake. The probability of such a disaster is very low but it could not be ignored.

Earthquake protection solutions to a large degree affected the bridge's structural design. The St. Petersburg engineers foresaw relatively short spans of 55 to 63 m and a large number of piers: 288 for the motorway bridge and 307 for the railway bridge. This solution allowed lowering the loads on the piers: a lightweight structure would be better prepared for seismic shocks. Inclined piles were used to better withstand seismic shocks and ice impact.

The main element of the earthquake protection is shock-transmitting units installed between the piers and deck of the motorway bridge. About 800 hydraulic devices distributing seismic shocks were to be installed on the bridge. For the railway bridge, the earthquake protective span-bearing system was designed as a combination of stationary and linearly shifting units which allowed distributing seismic shocks between piers. The arches spanning the sea channel are fixed onto the piers with special movable abutment shears capable of enduring a magnitude 9 earthquake.

The combination of earthquake protection solutions incorporated in the Crimean Bridge design provides for its high reliability and stability in the seismic events.

Andrey Ziuzkov
Chief Project Engineer

JOINT WORK WITH THE KRYLOV RESEARCH CENTER

Aerodynamic and ice studies of the bridge models and piers were performed at the experimental facilities of the Krylov State Research Center, St. Petersburg.

Before 2014, when the Krylov State Research Center launched its own wind tunnel, any large-scale aerodynamic tests of bridge models had to be performed at foreign laboratories. The Krylov Center specialists in collaboration with other St. Petersburg engineers designed a hi-tech landscape wind tunnel. Up to that point, Russia had no wind tunnels suited for full-scale bridge models while there were tunnels for aircrafts and ships.

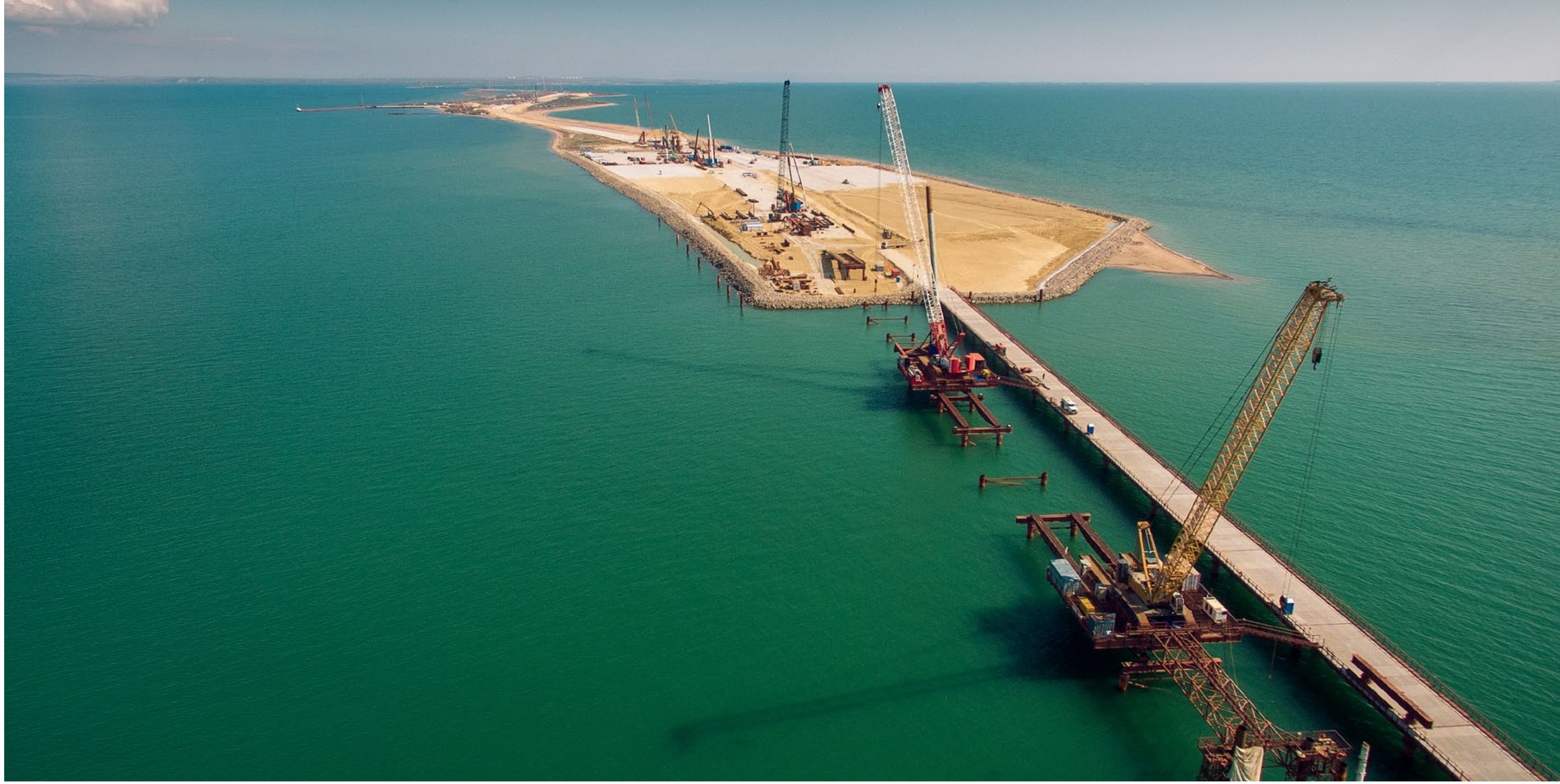
The Crimean Bridge's piers studies in the ice basin were a unique experience determined by the climate in the region. According to meteorologists, ice in the Kerch Strait can get as thick as 70 cm. In February and March, ice blocks of dimensions and weight hazardous for the bridge stability can come from the Azov Sea. In order to verify numerical simulations of ice loads, the Institute specialists conducted a series of studies at the Krylov State Research Center. The 1:237-scale pier models were immersed into the 100-m-long ice basin where the spring-time ice drift conditions were simulated.

“ *One may say, 'Crimea is a subtropical resort, what ice are you talking about?' But just recently the Kerch Strait got frozen so that people might cross it on ice while navigation had to be stopped. Ice from the Azov Sea advances towards our "ribbon" bridge that spans the strait. We conducted the unique studies along with the Krylov Research Center experts. I never heard of anyone in Russia who ever tested a bridge piers' behavior in an ice basin. Our scaled-down model withstood the impact of 3-cm-thick ice blocks which, when scaled up, correlated to 72-cm-thick ice. We made conclusions of the load values and incorporated them in the engineering design.*

Two parallel bridges with 277-m-long arches are complex structures in terms of aerodynamics as well. Wind loads were studied in the landscape wind tunnel at the Krylov Center. For the trials, a 1:60-scale detailed model was printed on a 3D printer and exposed to strong wind flows. Designers studied the way the bridge would behave in a storm wind at the 40 m/s velocity. The maximum velocity to which the Crimean Bridge model was exposed was 56 m/s. Although such strong hurricane winds occur in the Kerch Strait only once in 100 years, the bridge had to be prepared for any extreme loads.

DEVELOPING CONSTRUCTION TECHNOLOGIES

GOING BY LEAPS AND BOUNDS



1 **March 2014**
The decision to construct a bridge across the Kerch Strait is made.

2 **April 2015**
A temporary bridge for the delivery of equipment and materials is finished.

3 **February 2016**
The Glavgosekspertiza's approval of the bridge design developed by Institute Giprostroymost is obtained.

4 **Spring 2016**
The first pile is rammed.

5 **August 2017**
The railway bridge arch is installed in place.

6 **October 2017**
The automobile bridge arch is installed in place.

7 **May 2018**
The bridge is opened for motor vehicles traffic.

Such was the timeline of this ambitious project. It's clearly obvious that the project progressed by leaps and bounds. Fundamental intelligent decisions were a key for avoiding excessive stress and for meeting tight deadlines. Institute engineers accumulated extensive experience in design and construction technologies. It allowed them to design a structure and clearly understand the specifics of its assembly. Given the tight deadlines, the bridge had to be constructed at the least possible financial costs and with minimum efforts.

“Designing a bridge like this usually takes at least two years, and no less than three years to construct it. So, all in all, constructing a large bridge takes around five years, and, in some cases, up to six or even seven years. There are exceptions, of course. Plans for the construction of the Crimean Bridge are ambitious, no doubt, but feasible nevertheless. I worked closely with a large Russian company, Institute Giprostroymost. I was invited to participate in two projects for the construction of cable-stayed bridges: one across the Golden Horn Bay, another to Russky Island. My role there was limited to consulting; all the analyses and drawings were made by my Russian colleagues. They are outstanding specialists in their field, I have no doubt about that.

Holger Svensson,
Professor at Dresden Technical University, bridge construction engineer, renowned specialist in cable-stayed bridges

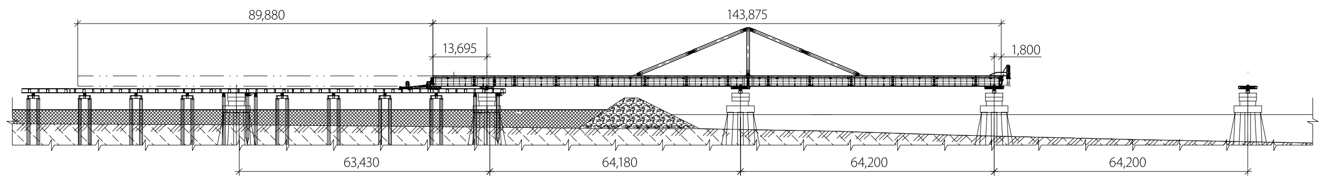
The success of the construction was secured back in 2014 and 2015. It was then that the designers made the key decisions that allowed the contractors to work ahead of schedule.

1 Decision number one: the construction sites had to be prepared on both shores in advance. A temporary bridge between the Tuzla Spit and Island was built a year before the design got approved. As soon as the first draft of the working documentation was completed, contractors started the construction. The fact that the usual gap between design and construction was eliminated saved a considerable amount of time. The public contract was concluded with the sole contractor, Stroygazmontazh company.

2 Decision number two: the construction had to be in process along the entire length of the bridge. Usually, bridges are constructed either from one bank, or from two sides simultaneously. In the case of the bridge across the Kerch Strait, a different solution was found that expedited the construction process: the bridge was growing in multiple directions at the same time. Nineteen kilometers of its length were divided into eight sections. At each of them, contractors concurrently performed various works: piles were rammed, piers erected and span sections assembled. Construction progressed at a high pace with virtually no stops, apart from sea storms.

3 Decision number three: to use domestically produced metal pipes for some of the foundations; those pipes of 1.4 m diameter were significantly cheaper than their imported counterparts of larger diameter. This decision allowed contractors to save on materials and reduce the construction time for bridge piers. Given the great depths and weak soils in the construction area, bored piles presented significant difficulties in terms of construction technology.

4 Decision number four was not to build the bridge from the water surface. With frequent strong storms from October to March, shallow depths of the sea and high rental costs of construction vessels, it was more feasible to erect temporary bridges and berths. This decision meant that the delivery of materials and assembly of structures were less dependent on the weather. For instance, in February of 2017, a storm on the sea lasted for 250 hours, so that any works on the water surface were suspended for nearly a fortnight. Piles were rammed from mobile platforms that rested above the sea level on special piles. Pile caps and intermediate piers were constructed off-shore using the platforms attached to temporary bridges. Bridge spans were assembled on-shore atop special scaffolding and then incrementally launched along constructed piers into their design positions.



Stage 2. Launching

“Designing the construction technology is often more difficult than designing the bridge itself. Even back in the Soviet times, our Institute was designing new technologies and we were always dealing with highly complicated non-standard structures. Throughout our 50-year history, we accumulated a vast experience. Many of our specialists were previously involved in construction projects. Having combined our knowledge, we learned to design structures and technologies simultaneously. Few designers can boast such skills. And this is, without a doubt, our competitive advantage.

Igor Kolyushev,
Technical Director

STEEL PILLARS UNDER THE SEA

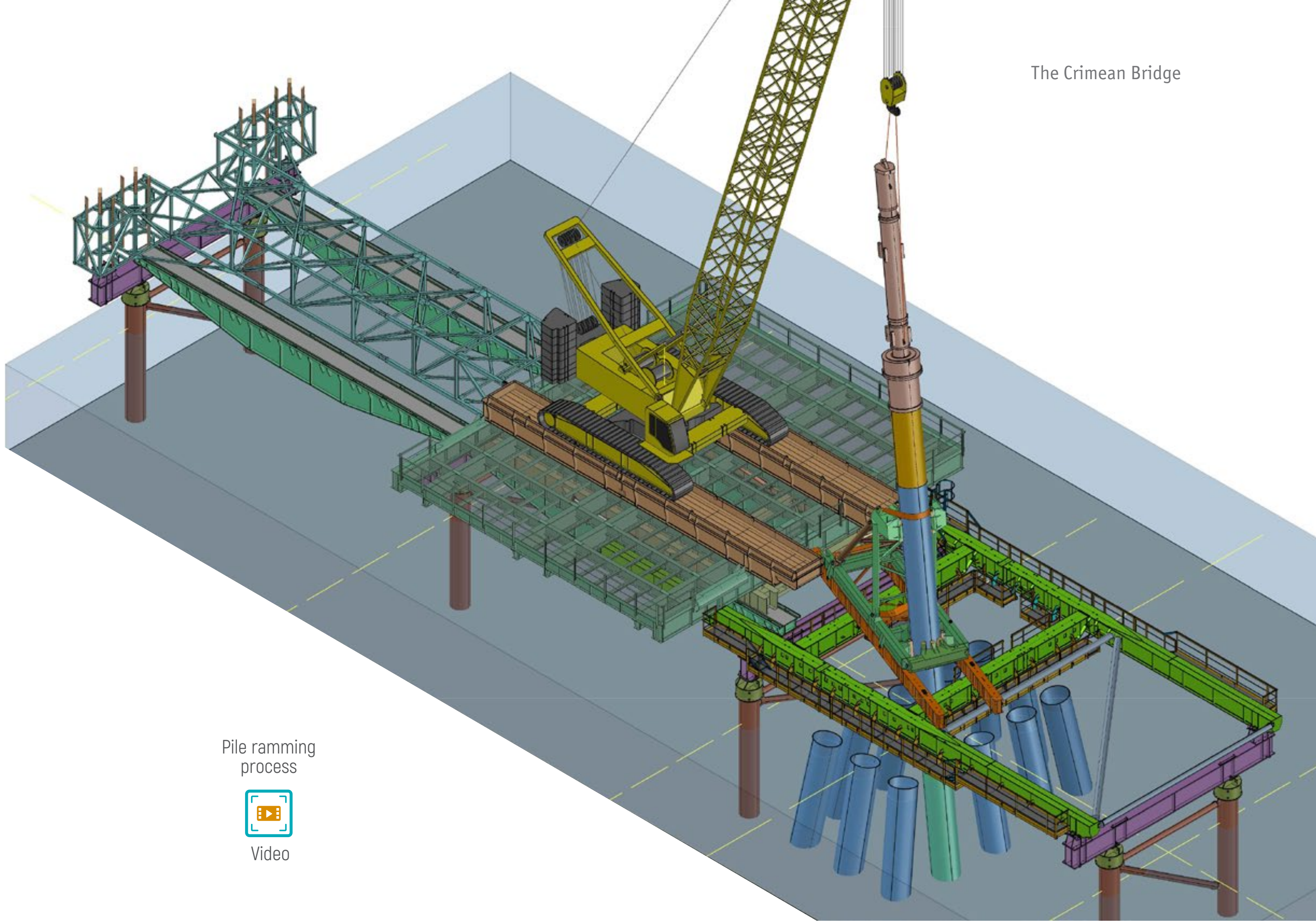
The Crimean Bridge rests atop 595 piers: 288 of them support the motorway bridge, and 307 carry its railway twin. Beneath the railway tracks, the structures are bulkier, able to hold the weight of heavy trains. The most formidable piers carry the arches, which mark the navigable channel. More than 100 tubular piles with a concrete core form foundation of these piers. For other sections where loads are lighter, fewer metal pipes were used: 8 to 16 piles per pier. Steel pipes pass through the mass of weak soils, reaching as deep as 102 meters, where solid Sarmatian clays are located. They serve as the bed that holds the piles firmly in place.

Never before in the practice of Russian bridge-building were the inclined piles used in such numbers and at such depths. Before submerging the piles into the aggressive corrosive seawater environment, they were coated and treated to withstand its effects. In view of the tight deadlines, piles had to be sumberged quickly. Having studied the global experience of oil and gas rig construction, engineers decided to set up a welding site to assemble pile sections 24 or 36 meters long from 12-meter pipes 1,420 millimeters in diameter. Those sections were then assembled further on-site into a longer pile up to 90 meters long.

"

WE FOUND A WAY TO CONSTRUCT THE BRIDGE QUICKLY AND SMARTLY.

Igor Kolyushev



Pile ramming process

Video

To submerge the metal piles to such depths, the Saint Petersburg engineers developed a technology that allowed construction workers to ram those long pipes from the water surface without using construction vessels. Following the Institute design, special mobile platforms were built that supported heavy-duty cranes, movable track frames and a powerful hydraulic hammer. This invention allowed workers to carry on with the construction regardless of weather, moving the platform along special supports and ramming piles at different inclines.

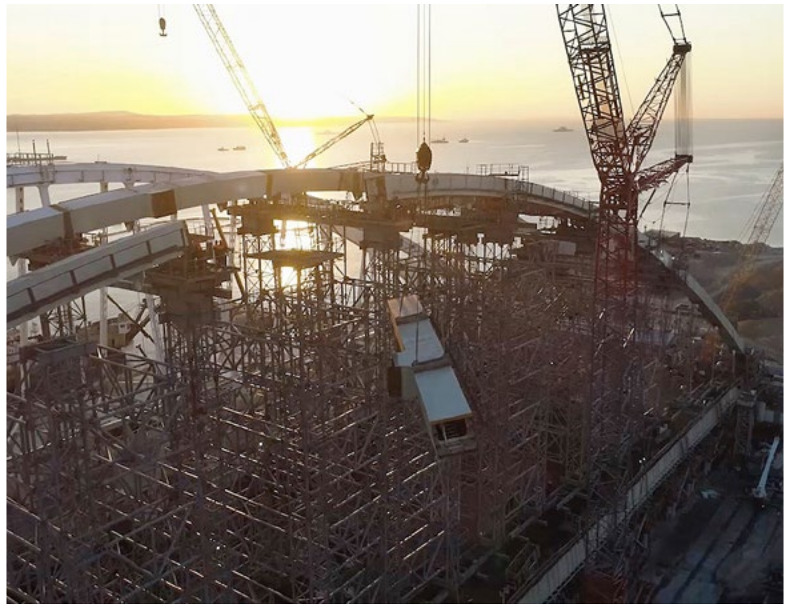
The pipes were rammed into the seabed by a 28-ton hydraulic hammer. At first, submerging would take up to a week, but with time going, bridge builders mastered the equipment so that one pile took them no more than 36 hours. Each pile had many sensors on it, so that the workers could monitor the submerging process in real time. Once rammed into the soil, a pile was partially filled with concrete, covered with a pile cap and used as a foundation for the bridge piers. In total, 6,700 piles were rammed into the seabed on Tuzla Island and off-shore. Builders used three types of piles: metal, bored and prismatic. The process of erecting 595 massive piers took a very long time. The last one was completed in September 2018.

INSTALLING ARCHES
IN THE OPEN SEA

TRIUMPHANT ARCHES ABOVE THE STRAIT

Bridges not only make people's lives easier, they also complement surrounding landscapes. The snow-white arches of the Crimean Bridge are a perfect example of this. The lace-like structures, rising 35 meters above the sea surface, catch the eye of tourists and locals. This is a new landmark of the Kerch Strait and at the same time a key link of a permanent crossing to the Crimean Peninsula.

Installation of the arches of the railway and motorway bridges was to be the most difficult stage of construction, and preparations took several months. At the stage of arches installation, bridge builders set a new record: they transported, raised from the water surface and assembled structures weighing 10,000 tons in total. Operations like this were performed in Russia before, but the weight and scale make the Crimean Bridge unrivaled.



Some 5,500 tons of metal was used to make the railway bridge arch, and 4,500 — for the motorway bridge. The length of each span is equal to the length of two football fields — 227 meters, with arches 45 meters tall. For almost a year, the arch structures were being assembled on a special site on the Kerch shore from hundreds of elements manufactured on Russian plants.

The arches were installed during the peak tourist season, from August to October 2017, when the sea was calm. On August 28, the railway arch was the first to travel into the Kerch Strait. The 54-hour-long operation was preceded by ten months of preparations.

On October 11, 2017, the operation for transportation and subsequent installation of the motorway bridge arch above the channel began. The giant span was moved from the construction yard on land onto pontoons. The floating platform carrying a massive 6,000-ton arch was transported to the design location by tug boats. The enormous structure was to travel a three-kilometer distance across the strait. In order to avoid interference with the transportation and installation processes, navigation in the strait was suspended for three days.

“ *Transportation technology that was developed by the Institute was a truly unique operation at sea. Our engineers assessed and calculated all potential risks. The course of this complex and, to some extent, risky operation could be affected by weather: wind gusts and waves could easily rock this giant structure on the floating platform.*

Igor Kolyushev,
Technical Director

ALL INVOLVED WERE PREPARING FOR THIS MOMENT AS IF FOR A NAVAL OPERATION.

The second stage of the operation was to raise the arch to its design position. It took twelve powerful jacks six hours to raise the giant structure from the water surface. The installation was performed at the pace of 5 meters per hour under the scrutiny of hundreds of specialists and close supervision by the comprehensive automatic monitoring system.

It was for the first time in the history of Russian bridge-building that such a massive structure was raised above the water surface. A hi-tech process like this has never been perpormed before in Russia or the Soviet Union. Designers clearly understood there was no room for mistakes. Any contingency would mean failing to meet the construction deadline.

“ *Everyone who was involved prepared for this construction stage as if for a naval operation, since there was no way back. This was an extremely complicated technological process with potentially irreversible consequences!*

Igor Kolyushev,
Technical Director

Special sensors were installed on the arches: they were monitoring the strain-stress state of the structure and allowed observing the arch span behavior in real time. Crossing 3 km in the channel took several hours. Then, with the help of winches, the arch was pulled in place between the piers. This process demanded the highest level of coordination between all parties involved. With its impressive dimensions, the distance between the 227-meter arch span and bridge piers had to be no more than 65 centimeters.

On the morning of October 15, the arch took its design position atop the piers at the 35-m level, next to its railway twin. The arch was raised with the utmost positioning precision. The unprecedented operation of transportation and installation of the motorway bridge span above the channel was successfully completed.

The installation of arch spans of the two bridges in the Kerch Strait is an indisputable accomplishment of the Russian engineering science that was made possible by the synergy of innovation technologies, state-of-the-art analytical methods and bold design ideas.

PROJECT SIGNIFICANCE

A WORLD OF OPPORTUNITIES

After numerous acceptance trials, as well as static and dynamic tests, the Crimean Bridge was opened for motor vehicles traffic on May 16, 2018. It happened six months ahead of the schedule foreseen by the public contract.

The Crimean Bridge became a firm link between the ancient peninsula and the mainland. Now, traffic on the A-290 federal highway no longer depends on any whims of weather, strong winds and storms; thousands of vehicles will no longer be stuck at the ferry crossing while valuable cargoes will always be delivered on time. The bridge has a design capacity of 40,000 cars and buses per day.

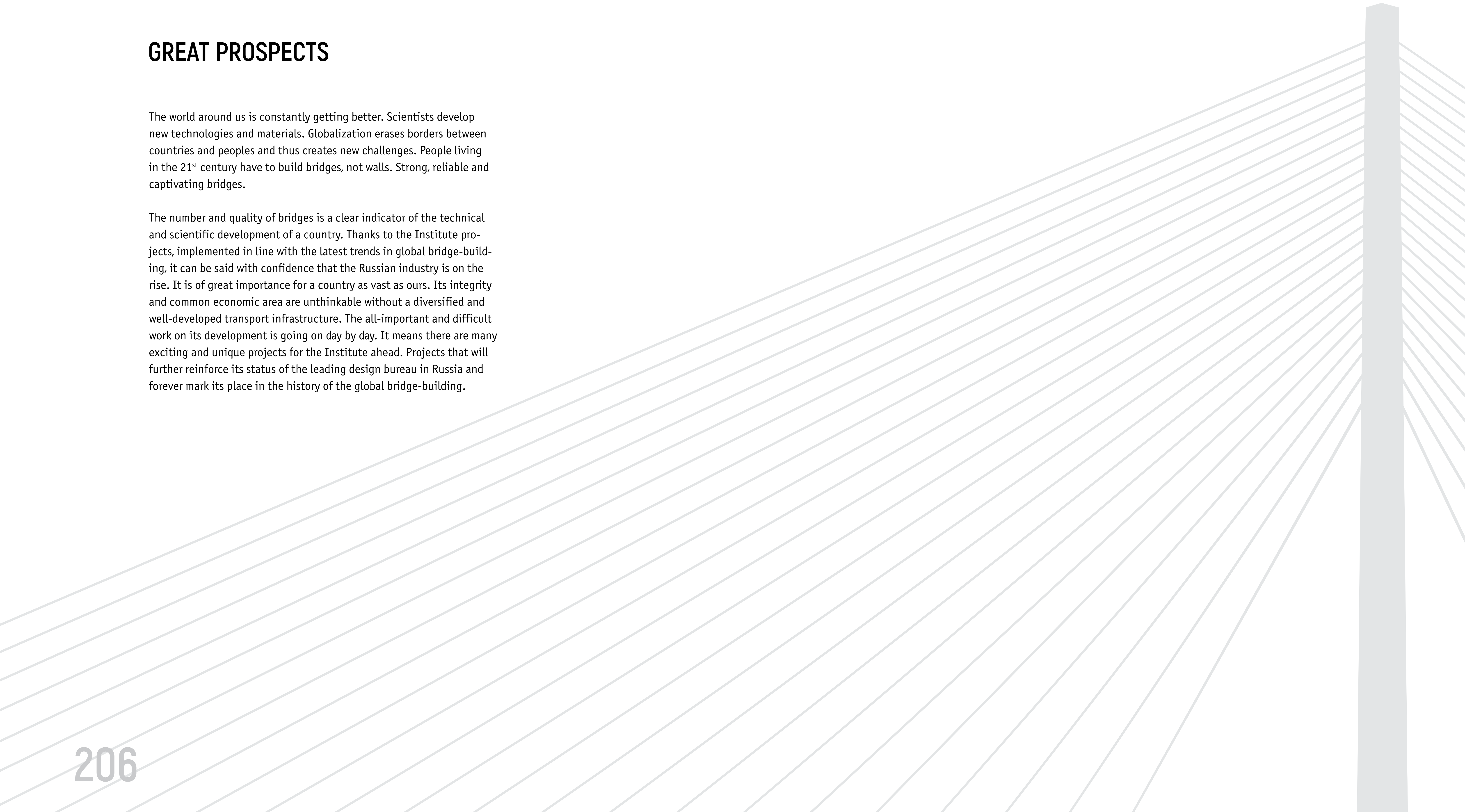
First and foremost, the changes affected the residents of the Temryuk District and the city of Kerch. 270,000 people live in the area, and from now on, they are able to travel across the record-breaking bridge every day. With the opening of the railway crossing, the passenger flow to the peninsula will undoubtedly grow. There will be trains carrying thousands of tourists and millions of tons of various cargoes to Crimea and Kuban. Reliable logistics in the region will improve the investment attractiveness, create new opportunities for local businesses and give a new impetus for further development of the Crimean Peninsula and the South of Russia as a whole.

> THE CRIMEAN BRIDGE IS NOT ONLY A SYMBOL OF THE NEW RUSSIA, BUT ALSO OF OUR ABILITY TO COMPLETE LARGE-SCALE ENGINEERING PROJECTS.
>
> Ivan Andriyevsky,
> First Vice President of the Russian Union of Engineers

GREAT PROSPECTS

The world around us is constantly getting better. Scientists develop new technologies and materials. Globalization erases borders between countries and peoples and thus creates new challenges. People living in the 21st century have to build bridges, not walls. Strong, reliable and captivating bridges.

The number and quality of bridges is a clear indicator of the technical and scientific development of a country. Thanks to the Institute projects, implemented in line with the latest trends in global bridge-building, it can be said with confidence that the Russian industry is on the rise. It is of great importance for a country as vast as ours. Its integrity and common economic area are unthinkable without a diversified and well-developed transport infrastructure. The all-important and difficult work on its development is going on day by day. It means there are many exciting and unique projects for the Institute ahead. Projects that will further reinforce its status of the leading design bureau in Russia and forever mark its place in the history of the global bridge-building.



THIS BOOK HAS BEEN PREPARED FOR THE 50TH ANNIVERSARY
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