The Pelješac Bridge

Road Connection
to Southern Dalmatia

HRVATSKE CESTE

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to Southern Dalmatia

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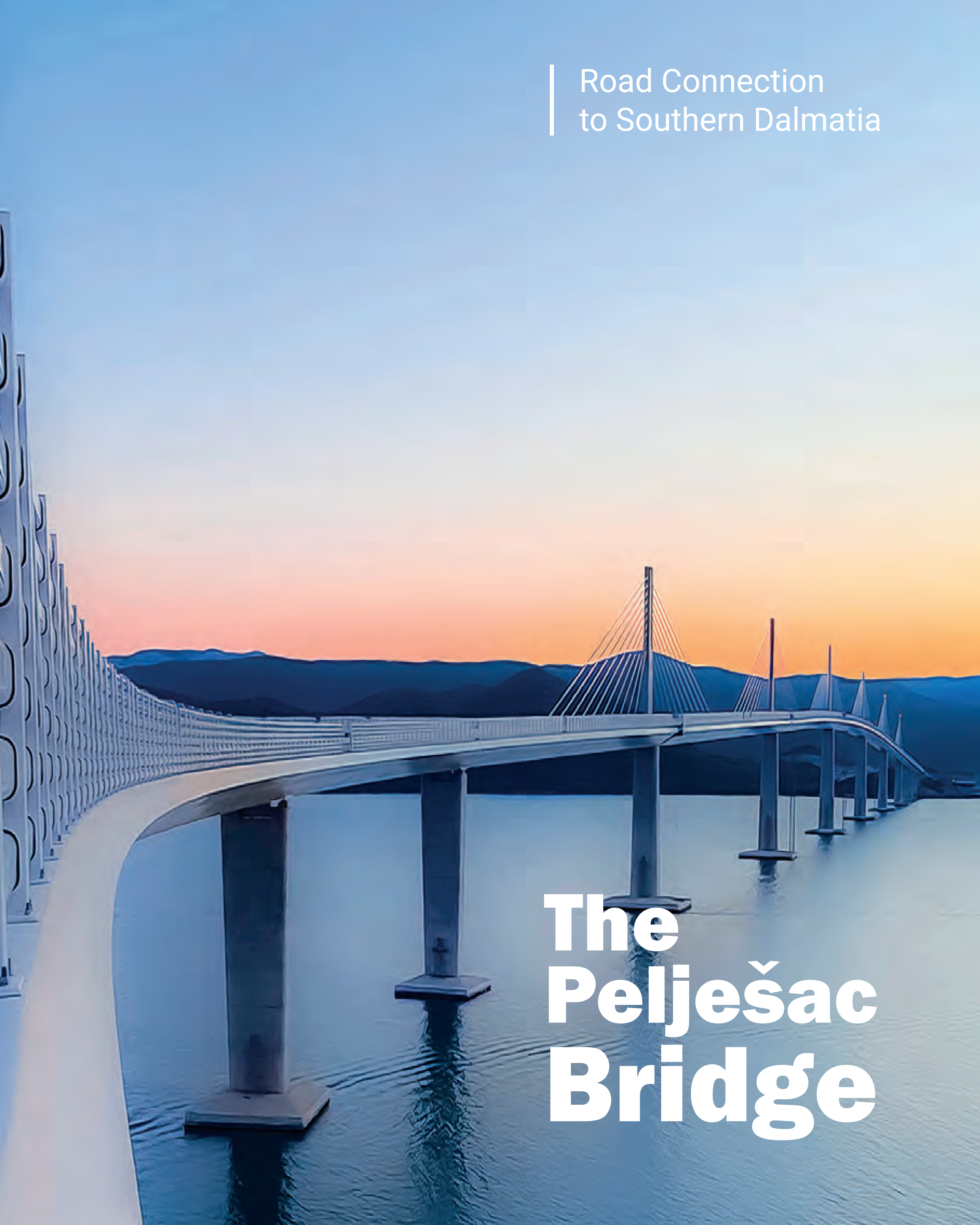

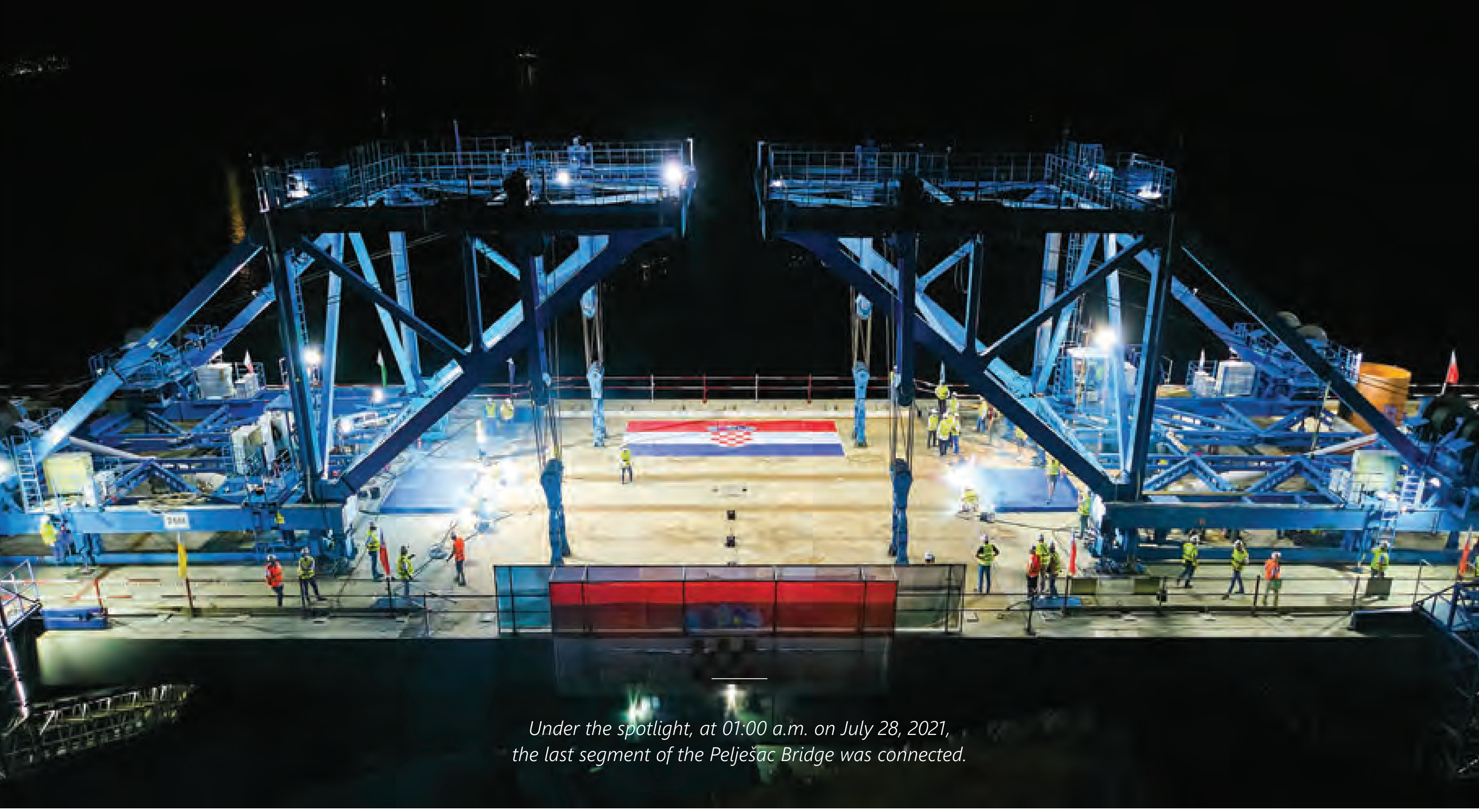

Under the spotlight, at 01:00 a.m. on July 28, 2021, the last segment of the Pelješac Bridge was connected.

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CONTENTS

1. FOREWORD

Foreword of the Prime Minister of the Government of the Republic of Croatia

ANDREJ PLENKOVIĆ

Over the past thirty years, Croatia has had a number of projects that were strategic in terms of transport, economic and social development of certain parts of the country. The construction of the Zagreb – Split motorway and of the Sveti Rok tunnel were such a huge step forward that brought the mainland and Dalmatia closer together. Numerous other projects have also been realized – roads, bridges, viaducts, tunnels and other infrastructure projects that strengthened the potential of the country's development. Croatia is a Mediterranean and Pannonian country, and its entire transport infrastructure – airports, seaports and river ports as well as railway infrastructure – represents the lifeblood of our country and its economy. Transport connections, especially to European transport corridors, provide important support for the economy, and also contribute to a higher quality of life for the local population, regardless of where they live, either in urban or rural areas of our homeland.

For our generation, and for our Government, which has invested over HRK 20 billion in the transport infrastructure development projects in the past six years, one of the most important projects is the realization of the road connection with south Dalmatia, which includes the long-awaited and finally built Pelješac Bridge. It is one of the largest transport projects in Croatia, worth more than EUR 500 million, of which EUR 357 million from European funds, owing to the well-prepared project documentation. Hence, I feel extremely proud to be at the head of the Government that managed to realize this important project, the project that will remain a legacy for future generations.

The Pelješac Bridge, 2.4 kilometres long and 55 meters high, together with access roads, has multiple meanings for Croatia. First, it is important for the Croatian sovereignty because, after more than three centuries it connects the south with the rest of the country by road. As a result, the Croatian coast mainland are finally fully connected.

Secondly, it is important for the Dubrovnik-Neretva County, which will be completely integrated with the rest of the country in terms of traffic and economy from July 26 this year.

Thirdly, it is a geostrategic project for Croatia that will ensure greater security of the common European border, especially after we enter the Schengen area. In addition, this project is a symbol and legacy of the first ten years of membership in the European Union, and as such is a visible and tangible testimony of the benefits that this membership brings.

And finally, the project is evidence that in international cooperation, in this case with the Chinese company China Road and Bridge Corporation, Croatia has high-quality companies, competent engineers and capable workers, who can plan and realize contemporary construction projects, assisted by the leadership of the Government, the competent ministry and Hrvatske ceste. I sincerely thank and congratulate everyone who contributed!

After we open the Pelješac Bridge, there will be several projects left that will additionally connect Croatia and strategically strongly encourage the development of certain parts of the country. Completion of the pan-European corridor Vc, the full profile of the Istrian Y route and the second tube of the Učka tunnel, the Zagreb – Sisak motorway and other expressways and bypasses of various cities and municipalities, as well as the further strengthening of the Port of Rijeka. These are all projects that, along with the Pelješac Bridge, will be realized with the same objective – balanced regional development of the country, demographic revitalization and economic strengthening of Croatia in a time full of challenges, but also new opportunities.

Prime Minister of the Government of the Republic of Croatia

Foreword
of the Minister of the Sea, Transport and Infrastructure of the Republic of Croatia

OLEG BUTKOVIĆ

Capital transport

infrastructure – basis for development

A career in politics gets its full meaning when the visions on which we build the community future and prosperity are realized. As the Minister of Transport, the department in which some of the largest infrastructure projects are being built today, I can say that the projects we are building are not ends in themselves. One of the most important contributions of transport and transport infrastructure construction is precisely to be the driver of economic growth in every region involved.

The Pelješac Bridge is an excellent example of this: a fascinating structure that represents the realization of the vision of a connected Croatia. Furthermore, the construction of the Pelješac Bridge marked an important step not only on the path to better transport connections, but also to the new development upswing of the south of Croatia and a new motif for postcards of the Dubrovnik region.

Therefore, I am proud of the fact that the bridge with access roads was built during my ministerial mandate, as a project largely co-financed from EU funds. With my associates from the Ministry, I advocated for the project to be recognized as European, since it is such, to ensure finances and remove potential obstacles to its realization.

After the project application, the tender for the construction works was conducted in two stages. It was a transparent international public tender that successfully passed the procedures of the European Union that follow the implementation of large co-financed projects.

About a year and a half after the start of work, when the Chinese contractor successfully completed the foundation works, the corona virus pandemic occurred and threatened to halt the supply of materials and the arrival of workers. Just like the rest of the world, Croatia faced problems with border closures. Perhaps the biggest challenge was the impossibility of supervising engineers to go to China to inspect the steel structure of the bridge, but the trust in the contractor proved to be justified, so this problem was solved.

The bridge was completed without delay, despite the difficulties that are inevitable when building a bridge with foundations a hundred meters below the seabed and piers a hundred meters above the sea surface. Today, we are witnessing its completion, but perhaps we are not fully aware of its true significance. The Pelješac Bridge will mark a new page in the life of the people in the Dubrovnik-Neretva area.

With the implementation of this project, we will not abandon our efforts to ensure a better life for all citizens and to encourage economic development by means of connecting all Croatian regions, since this is indeed the true purpose of transport and politics that fully considers the future.

The Ministry that I am in charge of, headed by the Government, strongly supports infrastructure investments. Furthermore, over the past decade, the greatest infrastructure projects have been realized with the help of EU funds.

Less than ten years after full membership in the Union, we can see which projects are being co-financed from

Minister of the Sea, Transport and Infrastructure of the Republic of Croatia at the construction site of the Pelješac Bridge in 2021

European funds. From the road infrastructure construction in the context of increased safety to the construction of airport infrastructure, along with investments in seaports that are by far the greatest ever, and also development of broadband Internet access infrastructure which will enable fast internet access in all parts of Croatia. Finally, there is also the construction of railway infrastructure, which will be in the spotlight in the following period.

All this is happening in a complex and challenging business environment, where it was necessary to implement structural reforms of individual sectors, adjust regulations and find ways to optimally include private capital in investments of national importance. There have been certain setbacks and temptations on the path to major projects, from financial market disruptions to the global corona virus pandemic, but today we can proudly say that the greatest part of the problems is behind us.

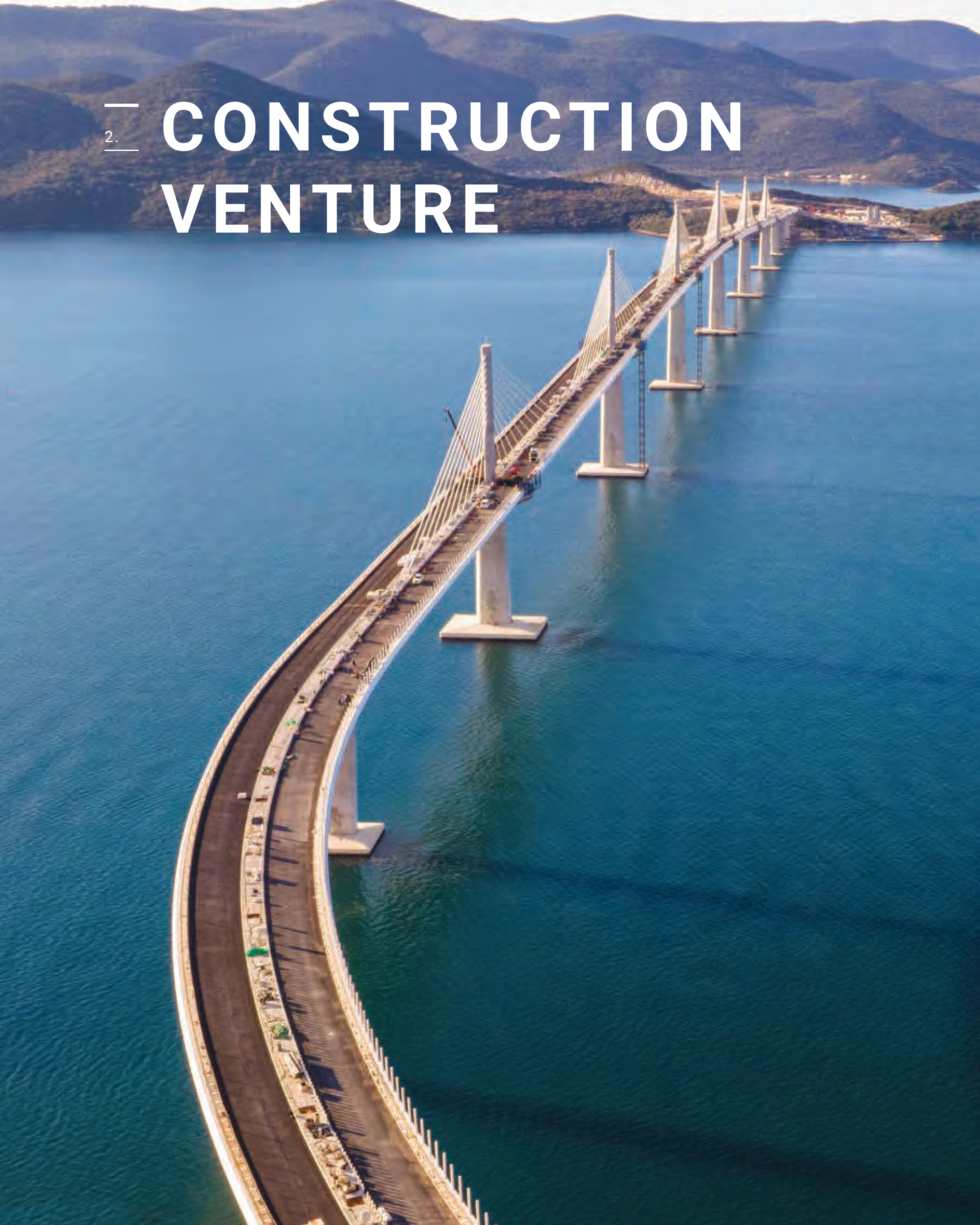
The Ministry I lead is the biggest driver of investments in Croatia, transport infrastructure investment amounting to HRK 25 billion at the moment. However, one can always do better and more. The construction of the Pelješac Bridge is only one step on the way, we continue fiercely with investments in all aspects of transport infrastructure.

I might say that the Croatian infrastructure is significantly different and more advanced than in 2016, when I was appointed Minister of the Sea, Transport and Infrastructure, and that is the greatest achievement of my ministerial mandate.

An important and, symbolically, the most prominent achievement on this path is the Pelješac Bridge and the road connection to south Dalmatia.

2.

CONSTRUCTION VENTURE



Josip Škorić, B.Sc. in Civil Engineering, President of the Management Board of Hrvatske ceste, at the construction site of the Pelješac Bridge in 2021

2.1.

BRIDGE IN THE CONTEXT OF TIME

J O S I P   Š K O R I Ć, B.Sc. in Civil Engineering

President of the
Management Board of Hrvatske ceste

Project Road Connection to South Dalmatia

The construction of the road that bypasses the Neum Corridor, and which includes the Pelješac Bridge, was an once-in-a-lifetime venture for a generation of engineers. The project called Road Connection to South Dalmatia entered the state strategies on time, extensive study and project documentation was prepared, public support and co-financing from EU funds were provided and with much effort of a wider team the entire project was successfully completed. The network of state roads now connects all the mainland parts of our beautiful country, stakeholders in preparation and construction can be proud. However, we will not forget the obstacles that had to be overcome on the way to realization, because they contain valuable experience for future projects.

Preparation and obstacles

As a great advocate of this important road and a participant in the preparation and construction of the bridge, I can say that some difficult and unpopular decisions sometimes had to be made on the way to realization. The most difficult period was when the first construction contract had to be terminated, at the moment when it became clear that the project was irrational and the consortium that contracted the works could not do the job. We realized that the only solution was to terminate the contract and streamline the project. I, as the leader of the company that led the investment, was given the ungrateful role to end the contract when it definitely became harmful to both the state and the society as a whole. However, we continued to plan the project even in the years when circumstances did not allow its implementation. With the entry of the Republic of Croatia into the European Union, we welcomed the opportunity for a new, this time successful, beginning.

About 20 years have passed from the first projects to the time the bridge was opened for traffic. This may seem like a very long period, but it is actually not longer than the time in which some major projects from the past were realized. The construction of the Eurotunnel between France and Great Britain began in 1974, only to be stopped in 1975. Excavation began again in 1987 and the tunnel was opened to traffic in 1994. The construction of our Zagreb – Split motorway officially began during the Croatian Spring of 1971, and it was finally completed in 2005. I would say that many projects were prepared at a time when the technical possibilities for their implementation were ripe, and they were carried out at a time when the political and economic circumstances made it possible.

Twenty years from the first idea to the realization of a capital road infrastructure project – I would not say that the preparation took too long.

The project Road Connection to South Dalmatia was conceived at a time when it became obvious that the passage through the Neum Corridor was a brake to the development of the Dubrovnik-Neretva County. The project was realized after Croatia's accession to the European Union, during the mandate of the Government of the Republic of Croatia that resolutely supported it.

Co-financing from the EU Regional Development Fund

The project has been awarded European grants worth about EUR 420 million, and the total project worth was more than EUR 520 million.

Such large sums are allocated to infrastructure projects that fit into common European priorities defined by official policies, and are also integrated into national strategies.

The project was highlighted as a priority through the Transport Development Strategy, which was harmonized with EU policies and then presented as a national document. Pertaining to the EU priorities is clear from the position of this route on the so-called TEN-t network. In particular, this 32.5 km stretch of road is one of the roads on the Adriatic-Ionian Corridor, connecting the centres of economic activity and the Mediterranean ports of seven countries: Italy, Slovenia, Croatia, Bosnia and Herzegovina, Montenegro, Albania and Greece, from Venice in Italy to Kalamata in Greece.

It should be emphasized that in the future, the Pelješac Bridge with access roads will not be the direction of international transport. In the future, when the coast of the eastern Mediterranean becomes more developed and traffic increases significantly, it is likely that road transport along the coastal belt between Italy and Greece will take the toll motorway, which will be located in the coastal hinterland.

Our highway on the stretch from Zadar to Ploče is actually a model of the road that – I am convinced –one day will connect 7 countries on the corridor, and that includes the construction of a motorway from Ploče to Dubrovnik. Once the international transport on this route increases seriously, the road on which the Pelješac Bridge is located should not be part of that project as it is located in a sensitive environment, the quality of which would be impaired by heavy transit traffic.

Developmental role of the new road across Pelješac

The CPJD project provides an incentive and opens new opportunities for the development of the transport network in the extreme south of Croatia. This can be read from the strategic documents of the Republic of Croatia, which emphasize the importance of connections from Ploče to the border with Montenegro. The spatial plans include the Ploče – Dubrovnik motorway, and two projects should be mentioned from the state road development plans.

The first is directly related to the Pelješac Bridge project. It is a new road that will connect Brijesta with Orebić, i.e. with the new ferry port to Korčula.

This project is of great importance for the economy of Pelješac and Korčula, even Lastovo. The modern road will bypass the settlements on the peninsula, instead of passing through their centre, as is the case at the moment.

The second project will connect Dubrovnik with the airport in Čilipi.

These roads, along with properly maintained and reconstructed coastal road form a system that plays a significant role in the development of modern tourism and related economic activities, while opening views of both the coast and hinterland, discovering the new beauty of Dalmatia.

Impact of the Road Connection to South Dalmatia Project on Bosnia and Herzegovina

The fact that the project was occasionally disputed in the neighbouring state results from daily politics. The construction of the road across Pelješac will bring benefit to the coastal area of Bosnia and Herzegovina as well as the hinterland. The new road will definitely not limit the development of these areas. Road traffic through Neum will be reduced, which certainly opens better tourist prospects for that town.

Together with the Ministry of the Sea, Transport and Infrastructure, we are continuing talks with colleagues from Bosnia and Herzegovina on new road links with the neighbouring country, in an effort to open new opportunities for the development of cross-border cooperation.

Part of the public in BiH, influenced by some political structures, thinks that the bridge will thwart plans related to the country's maritime orientation. It should be said that the navigable profile was agreed before the design of the bridge in a way that corresponds to the largest dimensions of ships that will be allowed to enter the protected natural area of the Mali Ston Canal.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PRIŠTINA
KOSOVO
BAR
SKOPJE
SJEVERNA
MAKEDONIJA
JADRANSKO MORE
ITALIJA
DRAČ
TIRANA
ALBANIJA
VLORE
GRČKA
IGOUMENITSA
JONSKO MORE
PATRA
ATHINAI
KALAMATA

New road and environment protection

Part of the public is concerned, which is expected and reasonable, given the indisputable fact that the new road opens Pelješac to mass tourism and facilitates the development of other economic activities. There will certainly be changes in the way of life, there is no doubt about that, and every progress brings certain risks to the environment. This has been taken into account from the very beginning of project development.

It should be noted that the care of environmental aspects, which includes the relationship between the road and wildlife, also includes the sociological aspect. The impact on the development of settlements, on the economy, on the quality of air and sea has never before been the subject of such a detailed study as today. The impact that the new road will have on the environment has been studied twice, before joining the European Union and once again after accession.

The risks to the environment arising from construction and traffic on the bridge have been minimised by the efforts of designers and contractors and by us as the investment managers as well. It should be emphasized that this is a two-lane road, a state road that is, due to its elements, less aggressive towards the landscape than a four-lane road considered in previous studies. With responsible maintenance, we will also control the future impact on the environment.

Josip Škorić, President of the Management Board of Hrvatske ceste, and Marjan Pipenbaher, main Designer of the Pelješac Bridge, during the bridge load testing – testing with trucks weighing 800 tons in total showed that the bridge operates in accordance with the project.

New accessibility of the areas that have lived in relative isolation for centuries brings significant changes to residents. The way of life is changing, and it mostly depends on the local community whether this will endanger some material or cultural values. Modern transport infrastructure encourages sustainable development if we have enough wisdom to limit the use of resources today for the benefit of future generations.

When discussing the impact of a new road on the community life, one should start by considering the other alternative – the no-build option. We are witnessing the stagnation of many areas that are not well connected, and on the other hand, we have areas that have been revitalized by a new motorway or expressway.

I am convinced that the areas with better roads have better prospects for development, as evidenced by decades of work on the road construction and maintenance. And once the new road comes, it is up to the local community to regulate the direction and dynamics of future development, and thus the attitude towards environmental protection. It is up to us to fulfil the measures prescribed by the location conditions for as long as the road is under our management.

After the construction of the bridge with access roads, maintenance begins

During a long period of my professional carrier, I was in charge of maintenance of infrastructure and I can say that the importance of that segment is mostly underestimated. Maintenance is not as attractive as opening new kilometres of roads, maintenance works are inconvenient for users because traffic is limited, when you are fixing something you often encounter unexpected problems.

Our position is that when planning the budget, road maintenance should be given priority over investments in new kilometres, that is, we should invest as much as is necessary to keep our existing roads safe and comfortable, and then use the remaining funds for new construction.

The organization and continuous supervision of the bridge and traffic, which will be performed from the Traffic Control and Management Centre in Zaradeže, is important for successful maintenance. Immediately after the opening, a permanent patrol of the bridge will be established, and in addition, a specially trained team of engineers will systematically inspect the bridge. The facts established by the inspection will be supplemented by the findings collected by processing data from sensors on the bridge, through a monitoring system. We plan to include experts from our scientific institutions, who have been involved since the design phase. In addition to the local centre in Zaradeže, we also have our Technical branch office in Dubrovnik, which will carry out small-scale works and which has experience with large span suspension bridges. Namely, our team leads the maintenance of the Franjo Tuđman Bridge, which is also a cable-stayed bridge and has a main span larger than the Pelješac Bridge. A well-equipped Regional unit in Split supervises the branch office and only if a problem cannot be solved at this level will the central office of Hrvatske ceste in Zagreb get involved. The system is decentralized so that operational decisions can be made very swiftly.

Mali Ston Bay and the Pelješac Bridge

We are still creating a team for bridge maintenance. The goal is to create a core of several experts of various professions who will dedicate full time to the bridge and other structures on the new road.

We are planning roads that are justified in terms of traffic, that are safe for both modern traffic and the environment, that open new prospects and views and boost the economy.

What will be the cost of bridge maintenance?

When estimating the maintenance price of such a structure, we start from its design life. The design working life of the bridge is 100 years, only after which major repairs of non-replaceable structural parts might be required. For us who maintain the bridge, this means that all parts that wear out will be replaced, maintained and repaired without interruption. With regular maintenance, a bridge can last more than a century.

Experience has shown that in case of complex structures the necessary investment accounts for around 3% of the investment value. This generally occurs after many years of use, so a new bridge does not require such investment. For the Pelješac Bridge, the mentioned 3% would mean that theoretically about HRK 60 million per year should be provided for maintenance, which is a significant amount.

In the first years after the opening, there will be no major interventions, but we are prepared for preventive maintenance interventions, which cost many times less than subsequent repairs.

Construction of the Traffic Control and Management Centre in Zaradeže – Pelješac Bridge is supervised from this building

Pier concrete work: concrete for the Pelješac Bridge has special features that have not been achieved before on a structure of this size in Croatia. The concrete was produced by a Croatian company according to their own recipe, and the installation was supervised by our engineers.

Competent teams for large projects

At Hrvatske ceste, we are extremely committed to the development of project management, through bringing together teams with significant experience both in our country and abroad as well as through informatization and education. We created a team that prepared, initiated and monitored the construction of a huge and unique building in quite complex international circumstances. Namely, the main designer is from Slovenia, the control of the project was done from Denmark, the contractor was a Chinese corporation, and the supervision is ours, Croatian. The products installed in the bridge come from around the world.

In order to bring people together on a project, you need to motivate them. As a state-owned company, the possibilities of material incentives are limited, so we are committed to creating a stimulating working environment where new technologies, lifelong learning and good interpersonal relationships are promoted. There is a lot of stress along the way, but satisfaction with the work done is stronger. What is most relevant is that each member is familiar with their task and that power is given to everyone within the scope of their activities. I would like to emphasize that engineers must have autonomy in the area for which they are competent. Nevertheless, within the project leading team there should be a clear hierarchy that enables quick decision making and effective implementation.

I dedicate a lot of time to building successful teams, because once everyone is in the right place, the realization of the project is no longer in question. In doing so, I am guided by the principle that you need to build such a strong team in which it is unclear who the leader is.

Project management system

During the construction of the bridge with access roads, some concrete steps have been taken in the field of project management. The basis for the introduction of new management techniques is digitalization, followed by the development of new treatment protocols that make maximum use of technology. We monitored the construction process practically in real time, which means that we had up-to-date information on the performed works, financial realization, deadlines and obstacles that need to be removed.

The adoption of new technologies is one of my priorities in running the company, which was given additional boost by the European Commission supervision, due to co-financing from the funds.

Obstacles and risk management

Each major project also carries special risks, which no previous analysis can predict. The implementation of the project within which the Pelješac Bridge was built was marked by the global pandemic of the COVID disease, which first endangered supply chains, and consequently increased the prices of construction materials and equipment.

It was necessary to react quickly and decisively, with a dose of improvisation and the support of the competent state bodies. In the end, it could be said that we have solved the difficulties arising from these global events more easily than we do some procedural delays in project preparation occurring for years in the construction of road and railway infrastructure.

The completion of such a grand project is an occasion to elaborate on the oft-repeated thesis that the preparation, design and construction of new roads have their own particularities to which building regulations, public procurement procedures and other regulated processes are not optimally adapted. Therefore, many projects are not implemented according to the desired or planned dynamics, and this has significant financial consequences.

These issues are being resolved through the work of professional bodies at the official level, but the whole process is too slow for us. In particular, the preparation and obtaining of all necessary decisions and permits for the needs of a single line project takes five to ten years, from the conceptual design through environmental impact study to the main project and building permit.

Some important projects of state roads that are gradually being developed and constructed

Croatian companies included in bridge construction

During the time preceding the construction of the Pelješac Bridge, the Croatian construction companies did not have the capacity to carry out works of such complexity. It is often mentioned that the public procurement system allows smaller companies to come together as a consortium and then do work that none of them could do alone. This is confirmed in practice in case of the construction of less complex roads, there are a number of contracts with a consortium working on them.

However, in case of unique construction and demanding technology, it is not reasonable to presume that gathering small companies into a consortium will guarantee the expected quality. For example, in Croatia there was simply no machine or team that could drive 100-meter-long and 200-ton steel piles, or a team that could coordinate the construction of a steel structure with 6 pylons at once. The Chinese contractors have already built several large bridges across kilometres of wide muddy Chinese rivers, so at the time of the tender for the Pelješac Bridge they had the necessary experience and technology. I'm not saying we couldn't learn and master all of this, but for the purpose of constructing a single bridge it is not worthwhile, and having someone learn and train on your project always turns out to be more expensive and time consuming than having someone do the work for whom this is almost a routine task.

Therefore, in my opinion choosing the Chinese contractor contributed to the success of the project, but that success would certainly not have been possible without our people and companies, who worked as designers, consultants, supervisors and subcontractors. You will get to know some of them on the pages of this monograph.

The future of European co-financing of road construction

The road network of the Republic of Croatia is solid, but not yet at a level that would provide sufficient incentives for economic development and demographic renewal in all parts of the country evenly. In contrast to our situation, the developed members of the European Union have a well-developed road network, so the focus of joint investments in the last decade has shifted from infrastructure to projects that make road transport sustainable: intelligent transport systems, environmental protection and digital transition.

To put it simply, in the years after the construction of the Pelješac Bridge, there will be less European money for road projects, which is another confirmation of the thesis that we managed to implement this project at the moment when a unique set of favourable circumstances came into place.

Other major projects on the state road network

Hrvatske ceste are continuously preparing several projects of new state roads in line with traffic needs and national strategic documents. The projects are implemented within the available financing limits.

We build new state roads on routes that carry the burden of economic development or in those areas where the habits of the population have changed, and the existing network cannot satisfy traffic needs. A common reason for new kilometres occurs when the existing road passes through settlements, so transit endangers the safety and quality of life of the local population. Intermodal transport also demands new connecting roads to ports and railway terminals, and the motorway network requires new connecting roads to settlements and industrial zones to become fully operational. Traffic safety is significantly improved by smaller localized interventions that regulate dangerous places, and there are a large number of smaller interventions (intersections, pedestrian and bicycle paths, etc.).

Among over 60 new construction projects, we can single out the largest ones, which were prepared or built at the same time as the Pelješac Bridge.

An important state road is being built in Rijeka, from Škurinje to the Zagrebačka obala, as a junction of the new terminal of our largest seaport with the motorway system. This road, known as D403, will in future be part of an important international transport corridor. It is one of the most expensive and complex roads per unit length that we have built, because it largely passes under the densely populated part of Rijeka. EU funds have also been provided for this project

The bypass of the wider area of the city of Split is being built under the name Multimodal Platform of the Split Agglomeration, in the direction Solin – Stobreč – Dugi Rat – Omiš. It is a priority for co-financing from EU funds under the new Operational Program for the period 2021 – 2027. The dynamics of this project depends on attracting funds, but it should be said that construction from both the Omiš and the Solin (i.e. Split) sides was financed from the funds of Hrvatske ceste. The traffic improvement of the Split agglomeration will be achieved through the realization of several projects, among which we should also mention the new entrance to the city through the Vučevica junction on the A1 motorway. The project envisages the construction of a new two-lane state connecting road, which will link the motorway with the Split Ferry Port.

The Podravina Y (''Podravski ipsilon'') is a system of two expressways that will connect Podravina to the Zagreb – Varaždin motorway on one side and provide better connections with the Republic of Hungary on the other side. In the first phase, only one carriageway is being built, which is the model we apply on those roads for which constructing both carriageways immediately is unjustifiable, but one remains in preparation. The remaining sections to Bjelovar are already under construction, and the continuation to Virovitica is being designed, with the construction starting on the section Virovitica – Špišić Bukovica, that is, on both sides at once. Podravski ipsilon is also high on the list of priorities in the competition for co-financing from EU funds in the new programming period. The Podravina expressway, which is being built gradually, with priority given to parts of the highest traffic load, from the border with Hungary to the border with Serbia, will complete the network of the northern regions.

The border bridge over the Sava near Stara Gradiška is part of the connecting expressway that connects Banja Luka to our Zagreb – Lipovac motorway. The bridge is practically completed, and will be open to traffic when the connecting road to the first junction on the existing road is built. It is a route of international importance that connects the region with Lake Balaton in Hungary and with Banja Luka, and that, according to some projections, ends in Split.

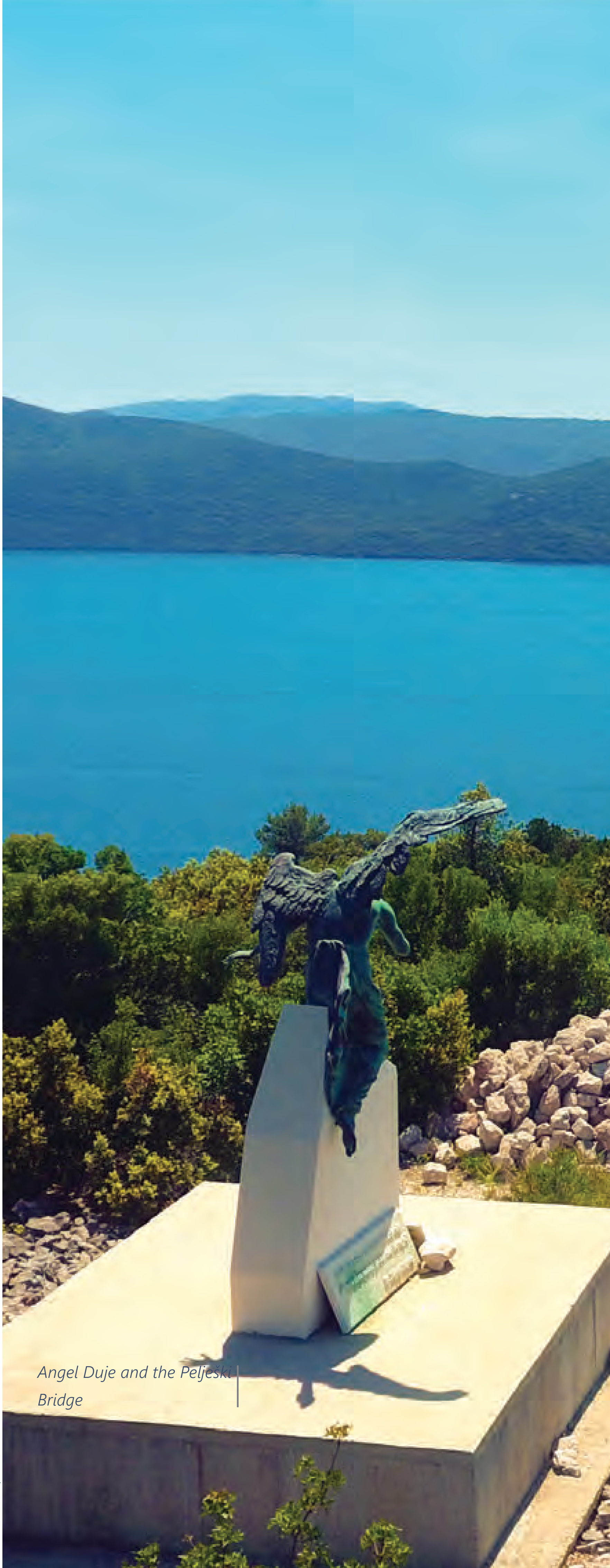
The transverse connection of the far east of Croatia with the motorway network is one of the projects of strategic importance. The road from Ilok to the Zagreb – Lipovac motorway, called the Srijem Transversal, stretches along the state border and gives a new perspective to an area that is scarcely populated but has significant potential. We have provided funds for the first, southernmost section of this road through European co-financing for dealing with dangerous spots, since it is a settlement bypass. The northern part of this road, when built, will be part of the previously mentioned Podravina route.

Simultaneously with the construction of the last section of the Zagreb – Sisak motorway, Lekenik – junction Sisak, a state connecting road is being built, which starts in the city of Sisak, and which will eventually connect it to the motorway system.

The Zagreb ring (''*Zagrebački prsten*'') consists of the expressway Popovec – Marija Bistrica – Zabok with a connection to Breznički Hum. Part of the expressway that will connect the far west with the far east of the capital's agglomeration has already been built. A road that will enable faster development of areas that are close to Zagreb, but are separated from it by the Medvednica mountain connects Zabok and Popovec, Zagorje and Prigorje.

The connecting road Zabok – Krapina runs parallel to the Zagreb – Macelj motorway. On the stretch from Gubaševo to Krapina, where the motorway route once passed along the state road route, we are building a new state road that will enable alternative traffic in the corridor of the motorway itself.

We will not list the bypasses separately, since the total number of projects we have recently implemented, or which are being implemented or prepared is around 30. Each bypass project starts when traffic through the settlement endangers the quality of life of the residents. By establishing priorities, we strive to find balance between financial possibilities and demands. As an example, I will mention two roads that were built around the same time as the Pelješac Bridge: the bypass of Turanj, a settlement near Karlovac, is officially the state road to Split, section Mostanje – Vukmanićki Cerovac, and the Novi Marof bypass is a classic example of a road that will change city life because it transits traffic from its centre.



Angel Duje and the Peljeski Bridge


HRVATSKE
CESTE

2.2.

BRIDGE DATA

Location of the 32.5 km long state road with the Pelješac Bridge: Road Connection to South Dalmatia Project

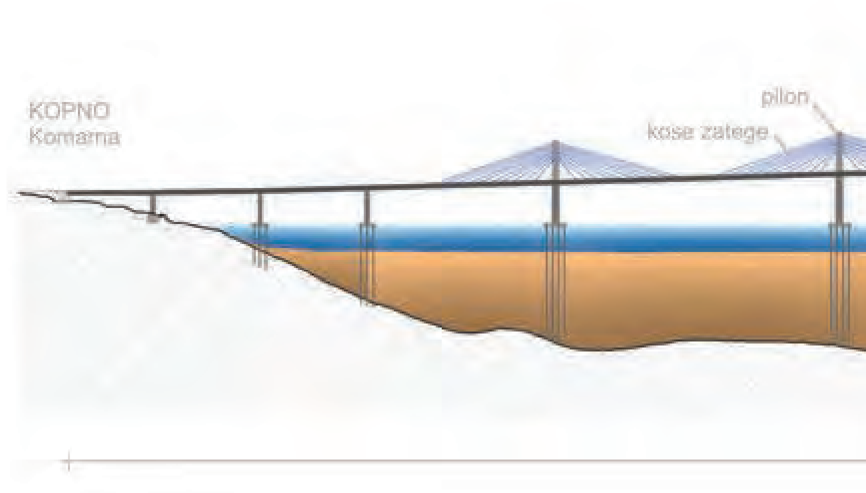
The Pelješac Bridge was built as part of the state road that bypasses the Neum Corridor, that is, as part of the ***Project Road Connection to South Dalmatia.***

The project includes the construction of the Pelješac Bridge, access roads to the bridge and the Ston bypass, thus establishing a strong road connection between the separated parts of the mainland territory of the Republic of

Croatia. The two-lane state road, 32.5 km long, connects the extreme south and creates an important precondition for the development of the mainland and the islands of the Dubrovnik region. The most demanding part of the project is the bridge over the sea strait – the Mali Ston Canal, 2.404 meters long. It is a technically innovative construction, since the central part of the structure is made without interruption – expansion joints and bearings.

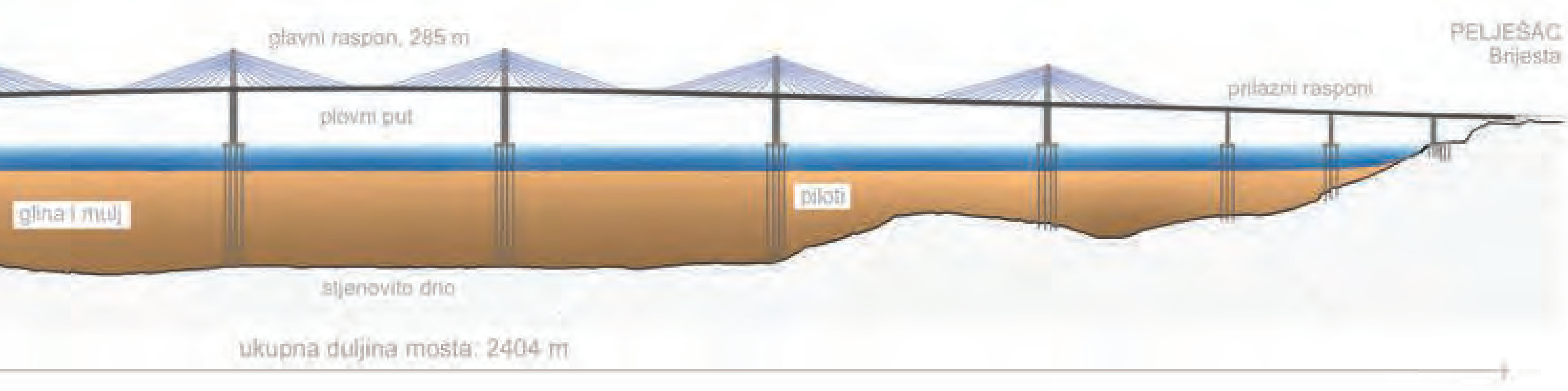
The construction solution of the bridge including a series of main spans of 285 meters each was adopted in 2013. In parallel with the design, efforts were made to ensure co-financing of the construction from the European Union funds. The main project was completed in 2016 and immediately applied for co-financing.

The grant agreement was signed in mid-2017, and the public procurement procedure for the bridge construction was completed on May 21, 2018, when a contract was signed with a Chinese consortium led by China Road and Bridge Corporation. The construction works began in July of that year. The originally contracted deadline for construction was 36 months, or 3 years, but it was extended due to extraordinary circumstances, and the bridge was opened to traffic along with part of the access roads in the summer of 2022.



The value of the contract for bridge construction was HRK 2.08 billion (about EUR 278 million), excluding value added tax. The largest part of this amount, 85 % of the total amount, has been financed from the European Regional Development Fund, while the remaining 15 % has been financed with national funds, that is, from the State Budget of the Republic of Croatia.

Pelješac Bridge in the Mali Ston Canal, cantilever construction with the installation of steel sections with the support of stay cables, May 2021

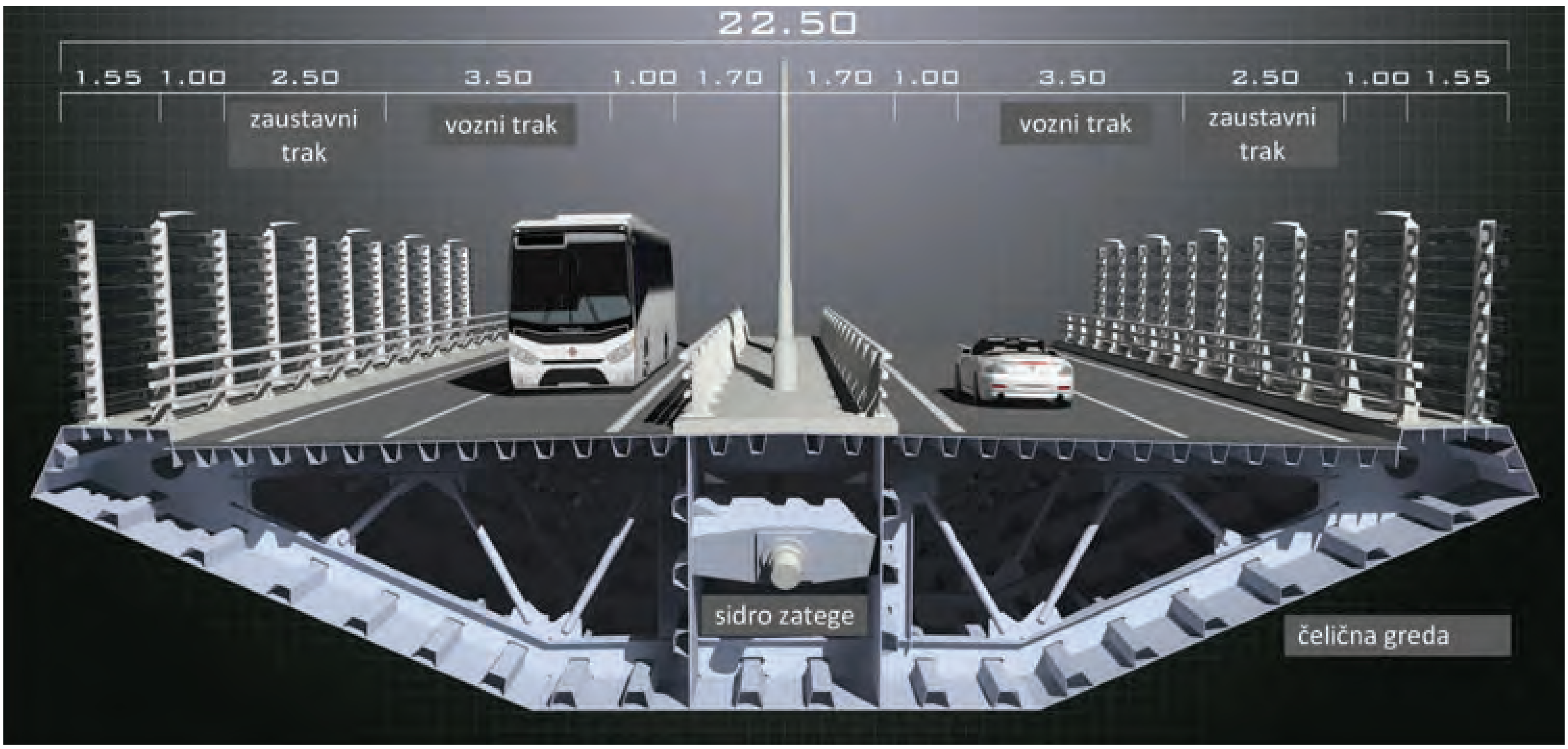


The load-bearing structure of the Pelješac Bridge consists of a span structure with 13 spans, which rests on 12 piers and two end supports – abutments. The central part of the structure is the suspension bridge, which consists of a beam girder, a pylon and a stay cable system. The edge parts of the structure are simpler girder bridges, in which the girder rests directly on the piers.

The central part of the load-bearing structure of the bridge consists of five main openings measuring 285 meters each and six pylons – main piers on deep foundations, 85 to 100 meters above sea level. The main load-bearing structure, a 22.5-meter-wide beam, is made of steel, with parts of the concrete structure above the pylons. The road on the bridge is a two-lane road, one for each direction, with stopping lanes and a central reservation between opposite directions.

According to the terms of reference, the navigation profile under the bridge is 200 meters wide and 55 meters high.

In terms of the foundation depth, the complexity of construction and consumption of materials, this is by far the largest bridge in Croatia, which, thanks to its original concept, will find a place among the most significant European architectural achievements of our time.



Pelješac Bridge – multi-span superstructure with traffic lanes

ACCESS ROADS AND THE STON BYPASS

Access roads and the Ston bypass together with the Pelješac Bridge form a project called *Road Connection to South Dalmatia* (CPJD), a road that bypasses the Neum Corridor. This is partly a new road, and partly the reconstruction of the existing D414 state road. This main road of the Pelješac peninsula separates from the main Adriatic coastal road – the D8 state road, the so-called Adriatic Highway, near Zaton Doli and leads to Orebić, where the ferry to the island of Korčula departs.

Prior to the initiation of the CPJD project, the network of Croatian motorways reached Ploče and all traffic to Dubrovnik went along the coastal road. The only possibility to visit the Neum Corridor was to take the Ploče – Trpanj ferry, and then take the roads across Pelješac to Zaton Doli.

The new road that includes the Pelješac Bridge was designed and built as a road reserved for motor vehicle traffic – the first category state road, in line with relevant legislation. The technical elements were selected for a design speed of 90 km/h. It is a single-carriageway road with two traffic lanes, one for each direction of travel, without an emergency stopping lane. Lay-bys are provided for emergency stops.

Cross-section elements of access roads are:

- two traffic lanes, 3.5 m wide
- two marginal strips, 0.5 m wide
- shoulders, 2 m wide, both sides
- embankment width 12 m, cut width 14 m

Road network of part of the Dubrovnik-Neretva County before the CPJD project. Ferry connections to the islands of Korčula and Mljet depart from Pelješac

The cross slope of the pavement is single-pitched, it is 2.5 % in the direction, and the maximum applied cross slope is 5.8 % in a bend with a radius of 450 m. The road clearance is 4.8 m from the highest pavement elevation.

Environmental protection requirements on the greater part of the route, as well as on the Pelješac Bridge, dictated a comprehensive solution to the road drainage in such a way that rainwater from the road is collected and purified before being released into the environment. The closed drainage system is impermeable and controlled. Rainwater from the road is treated in separators and facilities behind the separator, that is, lagoons and infiltration trenches. The drain pipe runs along the perimeter of the road.

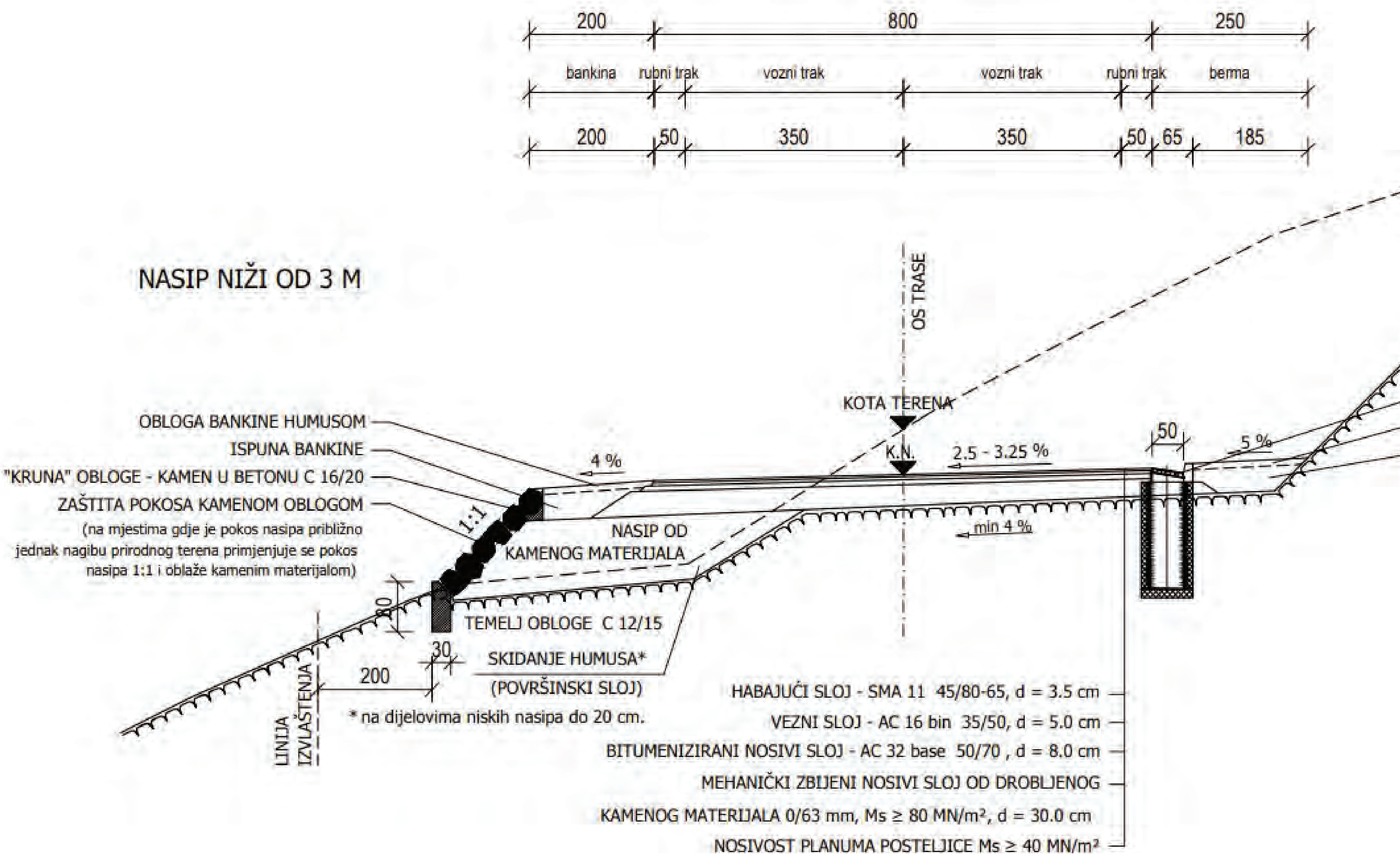
In parts where this is permissible, an open drainage system has been constructed, with gutters and channels along the roadside directly into the ground.

Environmental protection measures also include passages for small animals under the pavement, in the trunk of the road embankment. The backfilled areas along the road are arranged in such a way that the growth of native plants is possible on them, and the agricultural areas are connected to the settlements by passages through a new road, so that agricultural roads are preserved.

Furthermore, the protection measures apply to agricultural and built-up areas, which are bypassed by the route of connecting roads and the Ston bypass, as the route passes mostly through forest areas, areas of grasslands, shrubland and those of sparse vegetation as well. A large part of the route was difficult to pass through, and only a small part of the new road passes through agricultural land and built-up areas. At these locations, agricultural roads along the route have been relocated and arranged, and a larger number of passages have been made, in order to ensure access to all agricultural plots.

The beginning of the new state road in the west, on the side of the Neretva delta, is located between the settlements of Rab and Duboka. The access road to the Pelješac Bridge

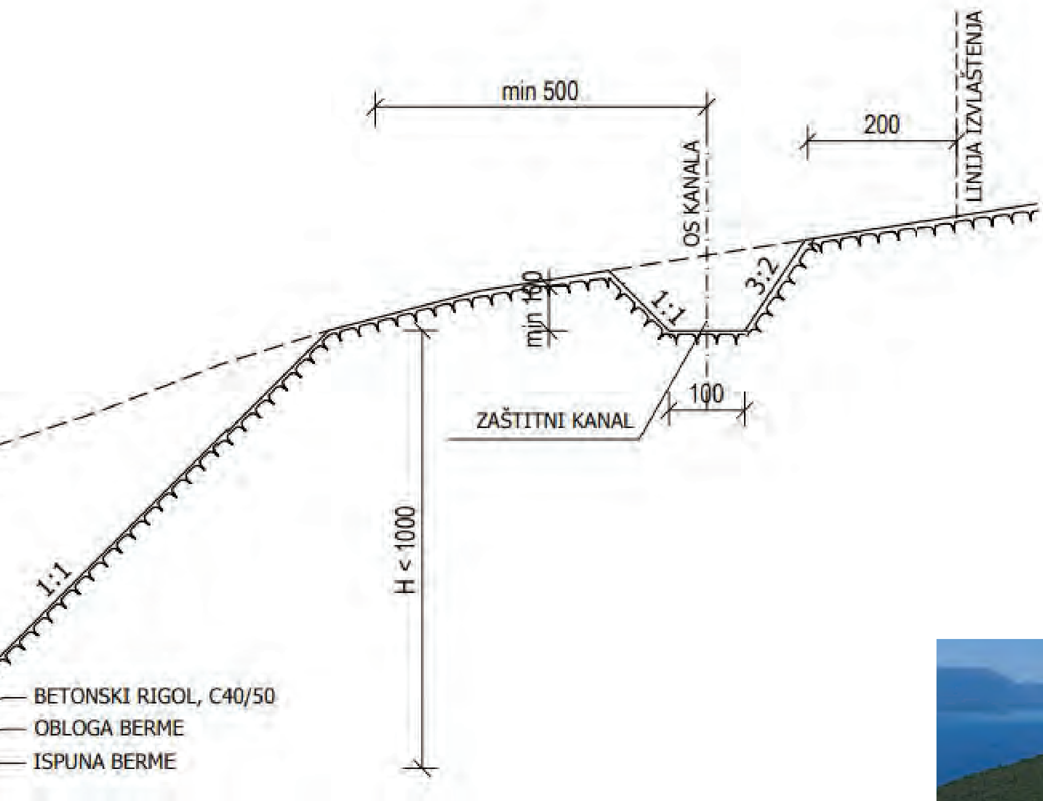
Normal cross-section in a side cut of the state road built as part of the CPJD project



branches off to the left of the D8 state road to become the main direction towards the peninsula. Duboka junction is located about 500 meters from the beginning of the route, thus enabling the connection of the existing D8 state road in the direction of Neum and BiH. The route further crosses the existing road towards Neum, then, above the settlement of Komarna, descends towards Cape Međed and takes a right turn to the Pelješac Bridge, which crosses the Mali Ston Channel to reach the Pelješac peninsula.

On both sides, before the beginning and at the end of the bridge, road service facilities are built, rest areas Komarna on the mainland and Blaca on the Pelješac side with parking lots, sanitary facilities and rest areas.

Getting to Pelješac, the route reaches the lowest elevation of 30.27 m above sea level, and then begins to go up, passing alternately through cuts and side cuts south of Oštri Vrh and then crossing steep slopes north of Brijesta. The Brijesta junction, located near the settlement of the same name, enables the connection of the settlement, but also the connection via the local road to the main state road towards the town of Janjina and further to Trpanj, Orebić and Korčula.



Through the Kamenica hill, the route passes through a 499-meter-long tunnel, and further ascends south of Kobinja Glava hill, to cross the canyon via bridges Dumanja Jaruga 1,488 m long, and Dumanja Jaruga 2, 80 m long. The next kilometre of the route is still uphill as it stretches in a south-easterly direction and then turns right in a south-westerly direction and passes the mountain massif through the Debeli Brijeg tunnel, 2,467 m long. The highest point of the road is in the tunnel at an altitude of 262.23 m above sea level, after which the route begins to descend towards the main state road on the peninsula, D414. The southern portal of the tunnel is located southwest of the village of Dančanje.

After exiting the Debeli Brijeg tunnel, the new road descends slightly and turns left into the state road at the Zaradeže junction. The Zaradeže Traffic Control Center (CKP) is also located there, from which conditions on the new road will be monitored and where the headquarters of the bridge maintenance team will be located. On the plateau behind the Zaradeže Center is the Exhibition Room for the Project Road Connection to South Dalmatia.

After passing the Zaradeže junction, the route passes through the saddle of the Planina and Crkvena Glava hills, avoiding settlements and agricultural areas. In the valley, there is a roadside service facility Sparagovići, north and south of the route.

As part of the works on the construction of the new road, parts of the state roads D414 (main Pelješac road) and D416 (ferry port junction) were relocated. In the zone of junctions and roads on this stretch, four new parallel roads have been constructed for providing access to cut-off areas and vineyards, and access to a telecommunication transmitter has also been provided.

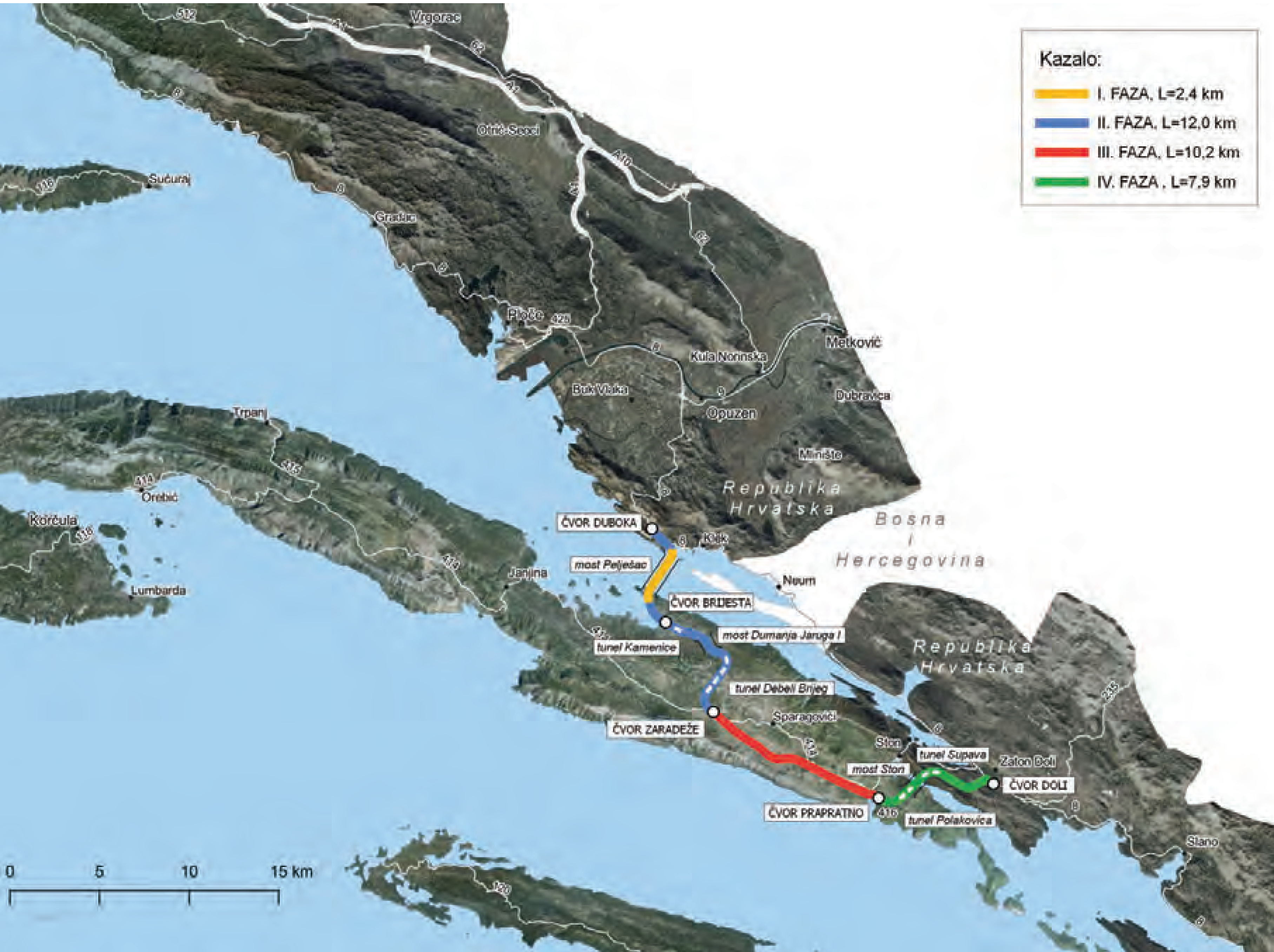
After the Prapratno junction, the route continues towards the Polakovica tunnel. So as to protect the valuable historical and natural environment, the road has been moved away from Ston and the saltworks by means of two tunnels, Polakovica and Supava, between which the Ston Bridge is located.

Access to the Pelješac Bridge from mainland – road service area Komarna under construction

The Polakovica tunnel is 1.242 m long, and exiting the tunnel the route reaches the Ston Bridge. Before entering the tunnel, a connection was made between the service road and the Polakovica service tunnel, which is north of the main tunnel tube. The service tunnel is connected to the main tube with three pedestrian and two emergency passages.

The Ston Bridge, across the Ston Canal, is 485 meters long. At the end of the bridge, the route enters the Supava tunnel, 1.290 m long. This tunnel, in addition to the main one, also has a service tube, which is located north of the main one.

The route continues south of the settlement of Zamaslina, to the intersection where it connects with the existing D8 state road. This intersection of the new road with the main coastal state road is a temporary solution, since the plan is to turn it into a grade-separated junction after the construction of the A1 motorway towards Dubrovnik is completed.



Pelješac Bridge – location in the Neum Corridor bypass project

Construction of the Debeli Brijeg tunnel

Contracted prices

Total amounts of contracted works and supervision for the Road Connection to South Dalmatia project are shown in the table. Values for the Brijesta junction are missing, since this was not co-financed from EU funds.

The second phase of the project (the first phase is the construction of the Pelješac Bridge) is officially called "Construction of access roads to the Pelješac Bridge, construction of the section: Duboka – Sparagovići / Zaradeže" and includes the construction of a new route, two tunnels, one viaduct and two bridges, total length of 12 km. The contract for the second phase was signed on October 9, 2019, and the works began on November 13 of the same year. The section was built by the group of economic operators, STRABAG AG (Zagreb Branch STRABAG d.d.), and STRABAG d.o.o. Zagreb.

The deadline for completion of works was 33 months.

The third and fourth phase of the project consist of the construction of the Ston bypass – a new route of the D414 state road with subsections Sparagovići / Zaradeže – Prapratno and Prapratno – Doli. The third and fourth phase of the project include the construction of a new road route, two tunnels, one viaduct and one bridge, with a total length of 18.1 km. The construction contract was signed on October 9, 2019, and the Contractor started work on December 5, 2019. The subsections were built by AVAX S.A. (Maroussi, Greece).

The contracts for the power supply and equipment of access roads to the Pelješac Bridge and the Ston bypass were concluded separately. Contract for power supply was concluded with the group of economic operators:

VALARD ZAGREB d.o.o., Zagreb, ELEKTROCENTAR PETEK d.o.o., Ivanić Grad, TEHNO-ELEKTRO d.o.o., Đakovo and DALEKOVOD d.d., Zagreb.

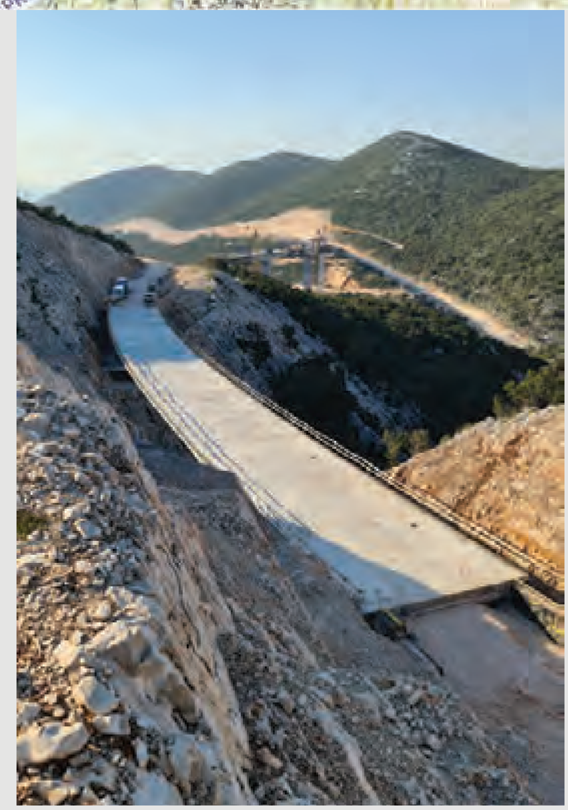
The contract was concluded on June 30, 2020, in the amount of HRK 69.487.734.65 (excluding VAT), with a deadline of 24 months, starting from the date of commencement of works, and the Contractor was introduced on July 7 2020.

The contract for equipment was concluded with TELUR d.o.o. Zagreb on July 6, 2021 in the amount of HRK 72.236.516.26 excluding VAT and with a completion deadline of 12 months.

Situational plan of access roads and the Pelješac Bridge, part of the CPJD project in the length of 14 km

Table 2.3.1Total contracted value of construction works and expert supervision for the project Road Connection to South Dalmatia (1 EUR 7.5 HRK)

CPJD: Road Connection to South Dalmatia: Contracts for construction, equipment and supervision		contracted (HRK, excluding VAT)
Phase 1: bridge	works	2.081.608.270,72
	supervision	49.379.561,00
Phase 2: access roads	works	478.398.402,80
	supervision	14.268.090,16
Phases 3 and 4: Ston bypass	works	511.569.355,91
	supervision	12.750.697,00
Power supply		69.487.734,65
Equipment		72.236.516,26
	Total	**3.289.698.628,50**



Roadside service facility during construction, May 2022, access to the bridge from the direction of Split

Construction site of the Brijesta junction on Pelješac, early 2022

Construction site of the Ston Bridge, March 2022: erection of the central part of the structure over the bay

2.4.

FEASIBILITY STUDY AND EU CO-FINANCING

Feasibility study

The feasibility study is a document containing an analysis and assessment of the potential of an investment project, and its main purpose is to enable decision making related to construction based on economic and social indicators. The justification of the Project Road Connection to South Dalmatia arises from the issue concerning the passage of the Neum Corridor, so the project was set as a strategic goal of the Government of the Republic of Croatia, with huge public support. Furthermore, the increased traffic volume in southern Dalmatia gave added impetus for the construction. Therefore, it is interesting to consider the central issue of the Feasibility Study, which is the analysis of technical variants that can be used to establish a connection around or through the Neum Corridor

The following connection alternatives have been analysed in detail, including certain sub-variants:

1. Bridge mainland – Pelješac peninsula with access roads
2. Immersed tunnel mainland – Pelješac peninsula with access roads
3. Motorway corridor through BIH
4. Corridor through BiH – tunnel
5. Corridor through BiH – Neum bypass with access roads
6. Ferry mainland – Pelješac: Ploče – Trpanj with road reconstruction on Pelješac
7. Ferry mainland – Pelješac close to bridge location (Komarna – Brijesta) with access roads.

The conducted Multi Criteria Analysis (MCA) indicated that the optimal variants are those bypassing the Neum Corridor by bridge or immersed tunnel with access roads. In addition, a cost and benefit analysis of those two variants was carried out and it indicated that it was more cost effective to build a bridge. The Study also included the evaluation of two bridge variants, which showed the advantages of the project that was eventually carried out.

The Study was conducted in line with the methodology harmonized with procedures required for EU co-financing and was positively assessed by JASPERS.

JASPERS (*Joint Assistance to Support Projects in European Regions*) is a European Commission body acting in cooperation with the major joint policy initiative of the European Investment Bank (EIB) and the European Bank for Reconstruction and Development (EBRD). JASPERS provides support to infrastructure projects, and its goal is to provide technical assistance to member states in preparation of major infrastructure projects, thus enhancing quality, quantity and implementation dynamics of projects applying for EU co-financing.

EU co-financing – chronology of application procedure

The activities on the preparation of the Project Road Connection to South Dalmatia for application to the European Commission began even before the Republic of Croatia joined the European Union, based on the Transport Development Strategy of the Republic of Croatia for the period 2014 to 2030, which was adopted in October 2014. The prerequisites for the project application matured with the adoption of the Operational Programme Competitiveness and Cohesion 2014 – 2020, the basic programming document which implemented the cohesion policy of the European Union.

Hrvatske ceste d.o.o. (Project Beneficiary) prepared and, on June 9 2016, submitted to the Ministry of the Sea, Transport and Infrastructure (MMPI) the Major Project Application. The application was prepared in cooperation with and with the help of MMPI and with the knowledge of the Ministry of Regional Development and EU Funds (MRRFEU), as the Managing Authority of the Operational Programme (managing authority is responsible for effective programme management and implementation).

The main goal of the project was to reduce the negative consequences of Croatia's entry into the Schengen area and to provide a permanent transport connection between the separated territories of the Republic of Croatia, in line with future transport demands. The operational goals of the project were to increase employment and economic activity in general, through supporting the mobility of labour and investments in the tourism sector, which is clearly the main flagship sector of the wider region.

On June 10, 2016, MMPI submitted the application to JASPERS experts for an opinion, so that they could evaluate the project and issue an Action Completion Note.

The Action Completion Note was submitted on December 22, 2016.

General layout of variant solutions for bypassing or passing through the Neum Corridor, from the Feasibility Study.

On February 7, 2017, the MRRFEU sent the final version of the Application for review and further action to the Independent Quality Review (IQR), which reviews the submitted applications for the needs of the European Commission. In parallel with this process, the MMPI conducted the decision-making procedure of the Government of the Republic of Croatia on project financing.

On February 16, 2017, the Government of the Republic of Croatia adopted the Decision on financing the Road Connection to South Dalmatia project. By adopting this Decision, the Government of the Republic of Croatia expressed its readiness and determination to construct the Pelješac Bridge, access roads and the Ston bypass, as the most important geostrategic project in the Republic of Croatia. This act opened the possibility for Hrvatske ceste to select the contractor and conclude the contracts after the completion of the public procurement procedures.

On March 20 of the same year, MRFEU and MMPI received a positive opinion for the project from the Independent Quality Assurance. The project was assessed as eligible for co-financing from EU funds in the maximum amount of 85%. After that, on March 28, 2017, MRRFEU sent to the European Commission an application for a major project called Road Connection to South Dalmatia.

On June 7, 2017, the European Commission adopted a Decision on project financing in the amount of EUR 357 million (85% from the European Regional Development Fund).

On June 13, 2017, the grant agreement for financing the Pelješac Bridge (in order for Hrvatske ceste to receive funds for the implementation of the project) was signed in Dubrovnik between MMPI, Hrvatske ceste and the Central Finance and Contracting Agency (SAFU).

Preservation of the protected Mali Ston Canal was one of the important preconditions for co-financing the Pelješac Bridge from the EU Regional Development Fund

Shellfish have been grown in the Mali Ston Canal since the time of Ancient Rome, and one of the important requirements for the design and construction of the bridge was that this sensitive ecosystem is not endangered

3. PREPARATION FOR CONSTRUCTION

3.1

VISIONS, STUDIES AND UNREALIZED PROJECTS

Connecting the north with the south of Croatia

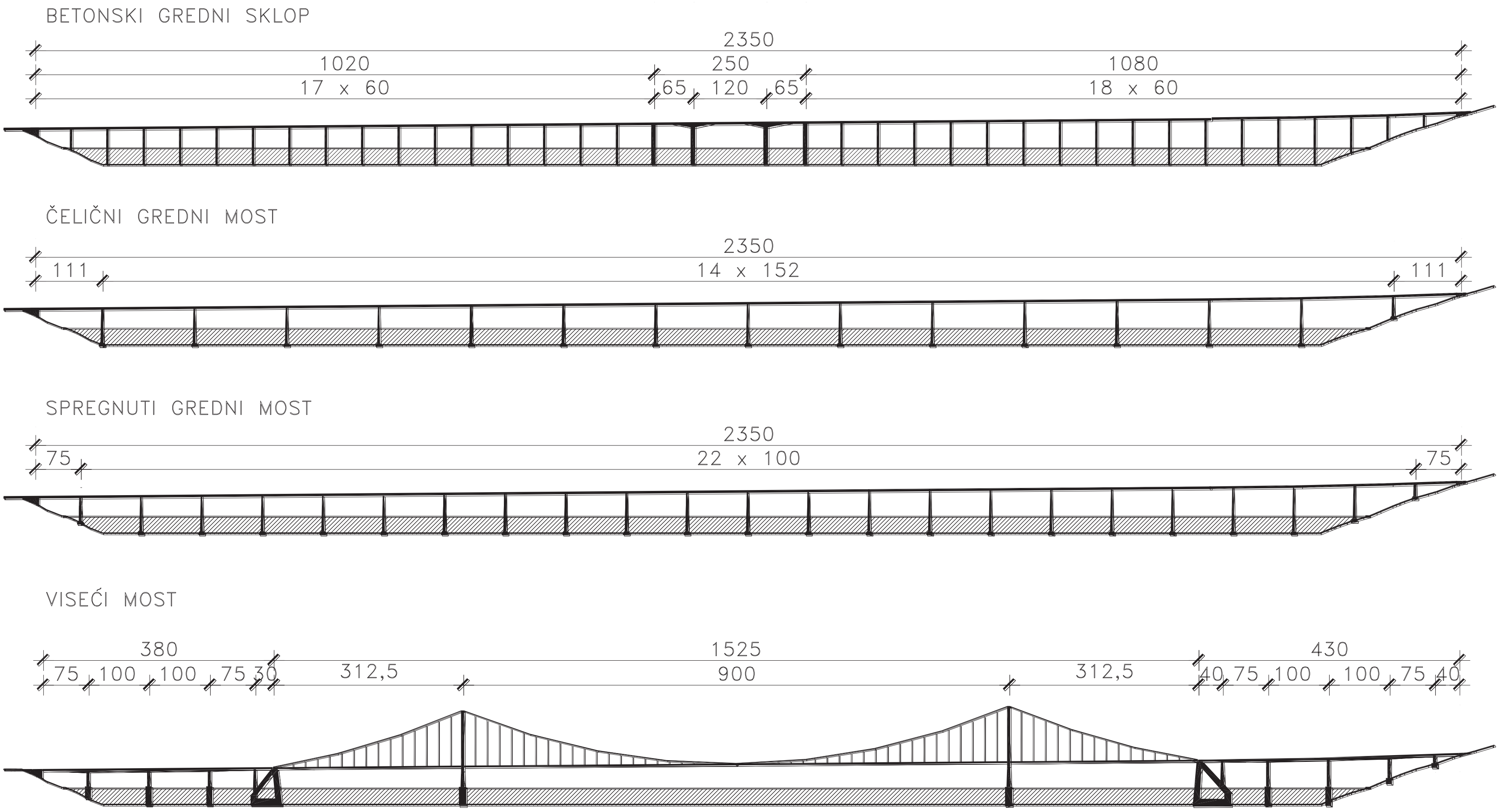
Every major construction venture begins with a bold vision that at the time of its creation seems frivolous or even unattainable to most. At the moment when the idea of a solid crossing to Pelješac appeared in public, there was no dilemma about the technical feasibility of its realization, since the crossings of similar sea straits or watercourse obstacles of other types had been built around the world. The justification of such an intervention for the Republic of Croatia was not in question, since the connection of the divided territories carries a dose of sincere and justified national pride. The elaboration of the solution followed by the discussion of the variants of the link took place at a time when it was objectively not possible to ensure sustainable financing of the project. Controversies and delays on the way to realization have ultimately led to a solution that is fascinating and technically optimal.

At the turn of the millennium, a motorway network is being intensively built in Croatia, with an emphasis on the direction from Zagreb to Split and further south. The Transport Development Strategy, adopted by the Parliament of the Republic of Croatia in 1999, envisages that the Zagreb – Split – Dubrovnik motorway crosses the territory of Bosnia and Herzegovina via the Neum Corridor. The population of the southern part of the Dubrovnik-Neretva County is looking for a connection with the rest of Croatia that will not require crossing the state border. Public opinion, with the support of politicians from the Dubrovnik region, is turning into an articulated idea of connecting the extreme south of Croatia with a strong connection – the mainland bridge – the Pelješac peninsula.

The road across Pelješac, which includes the bridge, enters the spatial plans at the turn of the millennium. It can be said that at that moment the circumstances were created for the beginning of the development of a project that will ensure a solid connection of the separated mainland parts of Croatia by crossing the Mali Ston Canal. Over time, this project of immense symbolic, economic and political significance has received strong support from the Croatian people, and has been recognized as a European priority. However, the road to its realization was long and full of challenges.

Prior to outlining the chronology of the Pelješac Bridge project, access roads and the Ston bypass, it should be emphasized that the plan to build a motorway that would continue from the Ploče junction on the A1 motorway to Osojnik and Dubrovnik, passing through the Neum corridor shall remain interesting even after the construction of the Pelješac Bridge as part of transport and spatial strategies, as well as spatial plans.

In 2018, the builders of the Pelješac Bridge found an abandoned bridge construction site from the time about ten years ago, when construction began unsuccessfully for the first time.

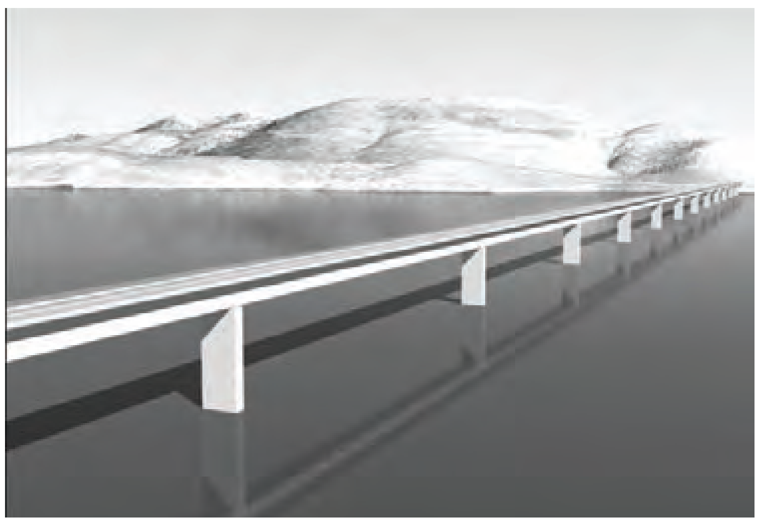


The first variant solutions of the Pelješac Bridge, authors Jure Radić and Zlatko Šavor with associates from the Department of Bridges, Faculty of Civil Engineering, University of Zagreb in 2004, were created before defining all the parameters of the terms of reference.

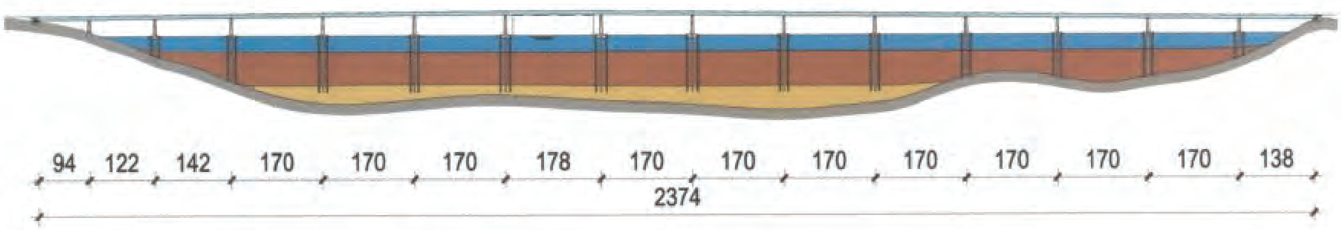
The variant solutions of the bridges proposed as a crossing to Pelješac are interesting as a presentation of various reflections, evaluations and discussions, which eventually led to a mature, optimized project. They should be viewed as part of an engineering study process during which radical variants of a solid crossing are also considered, in a process leading to a balanced and sustainable final solution.

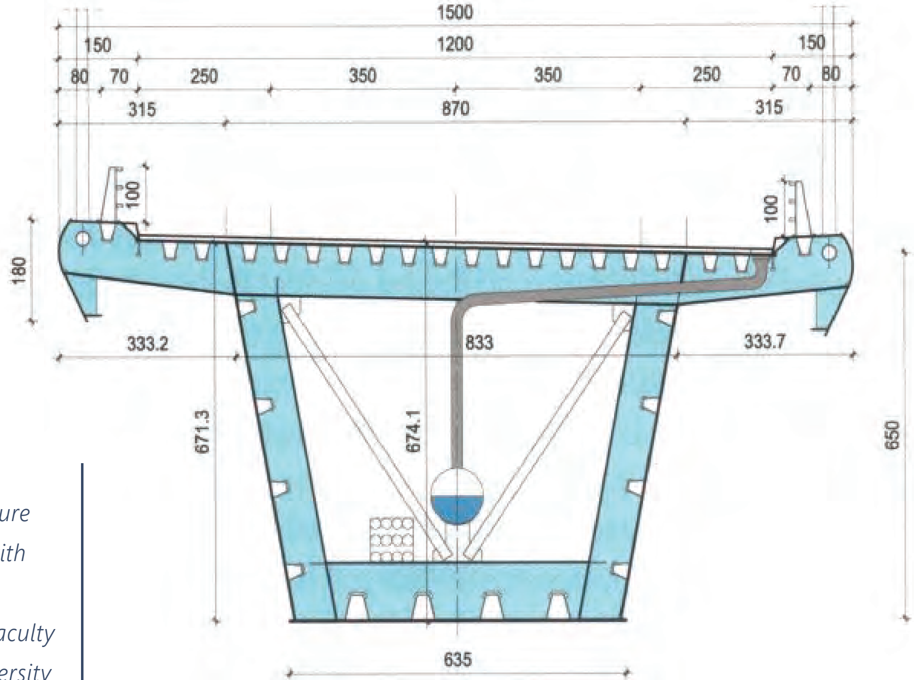
Some conceptual sketches of the crossing were made before the study of the Department of Bridges of the Zagreb Faculty of Civil Engineering, but we point out that particular study here since the first preliminary design of the Pelješac Bridge was made based on those considerations. The team under the mentorship of Professor Jure Radić, under the operational guidance of an experienced bridge designer, Professor Zlatko Šavor, developed several variants of the bridge. The effort to achieve an economical structure with standard elements, following the example of some modern sea strait crossings, is visible by lining up medium-sized spans.

The navigable profile under the bridge was determined by a width of 150 m and a height of 35 m. A girder bridge with box cross-section and constant height were selected for elaboration to the level of the preliminary design. The steel structure would bridge the central part of the strait with a series of 11 equal characteristic spans of 170 meters each, with slightly shorter edge spans, and the road on the bridge would be 12 meters wide in total.



Solution of the Pelješac Bridge from the first Environmental Impact Assessment Study of the new Pelješac road, from 2004.





Preliminary design of the Pelješac Bridge, authors Jure Radić and Zlatko Šavor with associates from the Department of Bridges, Faculty of Civil Engineering, University of Zagreb in 2005.

During the development of the preliminary design, the research of underwater geology at the crossing location was conducted, which showed that the load-bearing soil is far deeper under the deposits of silt and clay than could initially be assumed. The first serious geotechnical and geophysical investigation works were completed in March 2005 (conducted by CROSCO).

The publicly presented conceptual solutions of the future bridge provoked reactions from the neighbouring Bosnia and Herzegovina, caused by the thesis that the bridge will limit the future development of maritime traffic on that country's only access to the sea. It should be said that in the time preceding the construction as well as during the construction of the bridge, there was no significant maritime traffic towards Neum, and there were neither port facilities on the Bosnian-Herzegovinian part of the Adriatic coast.

Poor foundation conditions and an increase in the navigable profile under the bridge set a new starting point for designers, so versions of structures with smaller spans, relatively low above sea level, were abandoned in favour of a bridge with a prominent – large central span. For the new bridge variants, a free navigable profile 400 m wide and 55 m high was determined. Therefore, a suspension bridge with two pylons and a main span of 568 m, for the width of a single carriageway and two-lane state road, was chosen to be elaborated to the level of the main project.

The original location permit for the project Bridge mainland – Pelješac with access roads on D8 and D414 was issued on September 29, 2005.

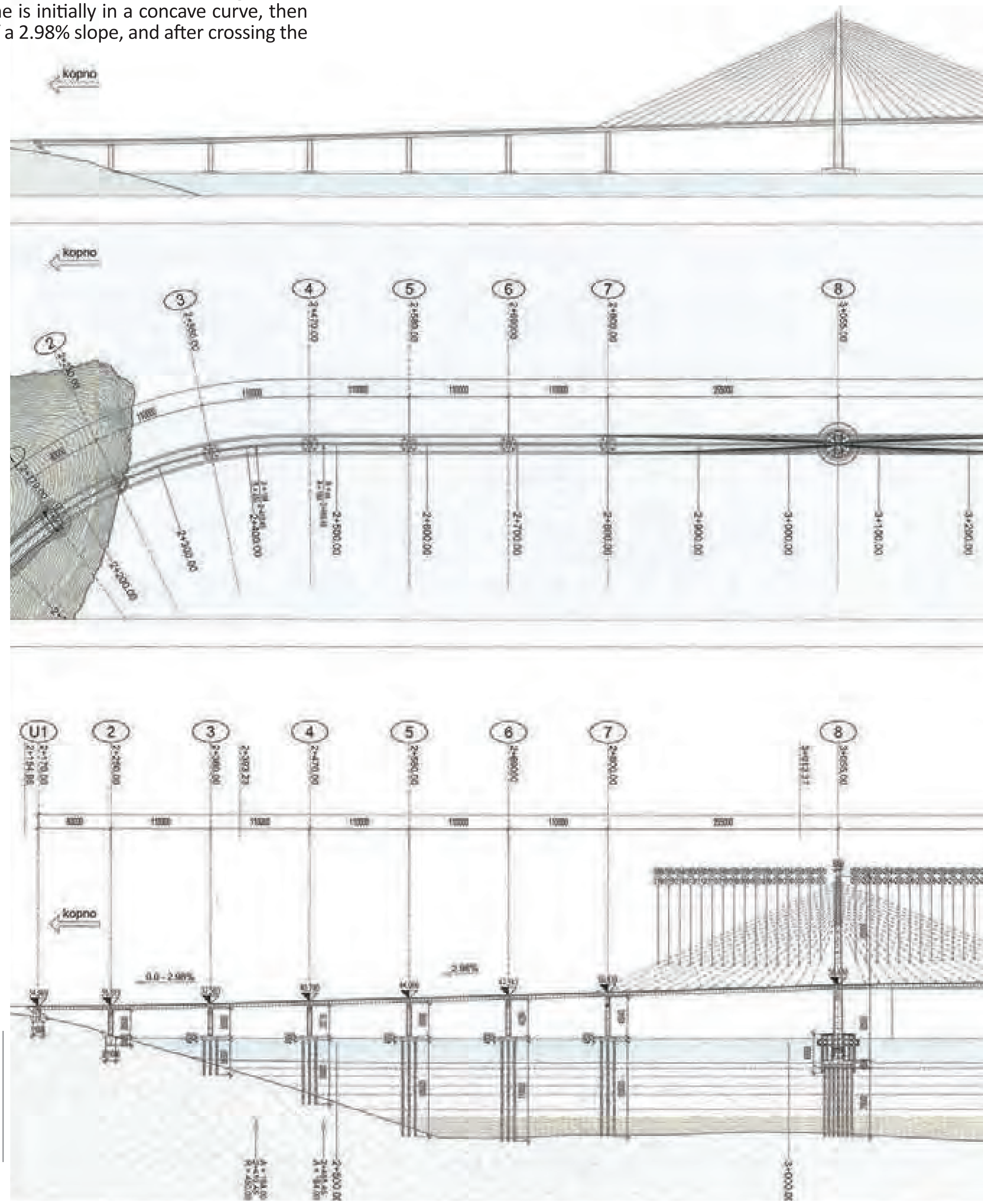
The main project of the bridge was carried out at the Faculty of Civil Engineering, University of Zagreb in 2007, and a building permit was obtained based on it. The designers of the main project were Zlatko Šavor and Jure Radić and their associates. In October of the same year, the construction works on the bridge were initiated, contracted between Hrvatske ceste as the investor and a consortium of the three largest Croatian construction companies of the time (Konstruktor from Split, and Viadukt and Hidroelektra from Zagreb).

The selected contractors made certain adjustments to the project in order to perform more economically. In the meantime, the elements of the route were changed: instead of a state road, the route across Pelješac became an expressway with four lanes and central reservation. The scope of the requested changes initiated the development of a design variant made by the same project team, with an effort to optimize the construction. It is interesting that one of the members of the consortium hired engineer Pipenbaher to modify and adapt the bridge, so in 2007 he became acquainted with the terms of reference of the bridge, the bridge which he will eventually sign as the main designer.

The optimized main design from 2009 was carried out for a carriageway 20 meters wide. The traffic area on the bridge consists of two pavements 8 meters wide and a central reservation 3 meters wide. Outside the traffic area, there is a space 2 m wide on both sides, in which there are barriers, service paths and anchorages for stay cables, so the total width of the upper surface of the bridge is 23 meters.

In plan, the beginning and end of the bridge are in a curve or transitional curve, while most of it is in a straight line. Vertically, the grade line is initially in a concave curve, then rises in the direction of a 2.98% slope, and after crossing the convex curve, the grade line descends in the direction of the same slope.

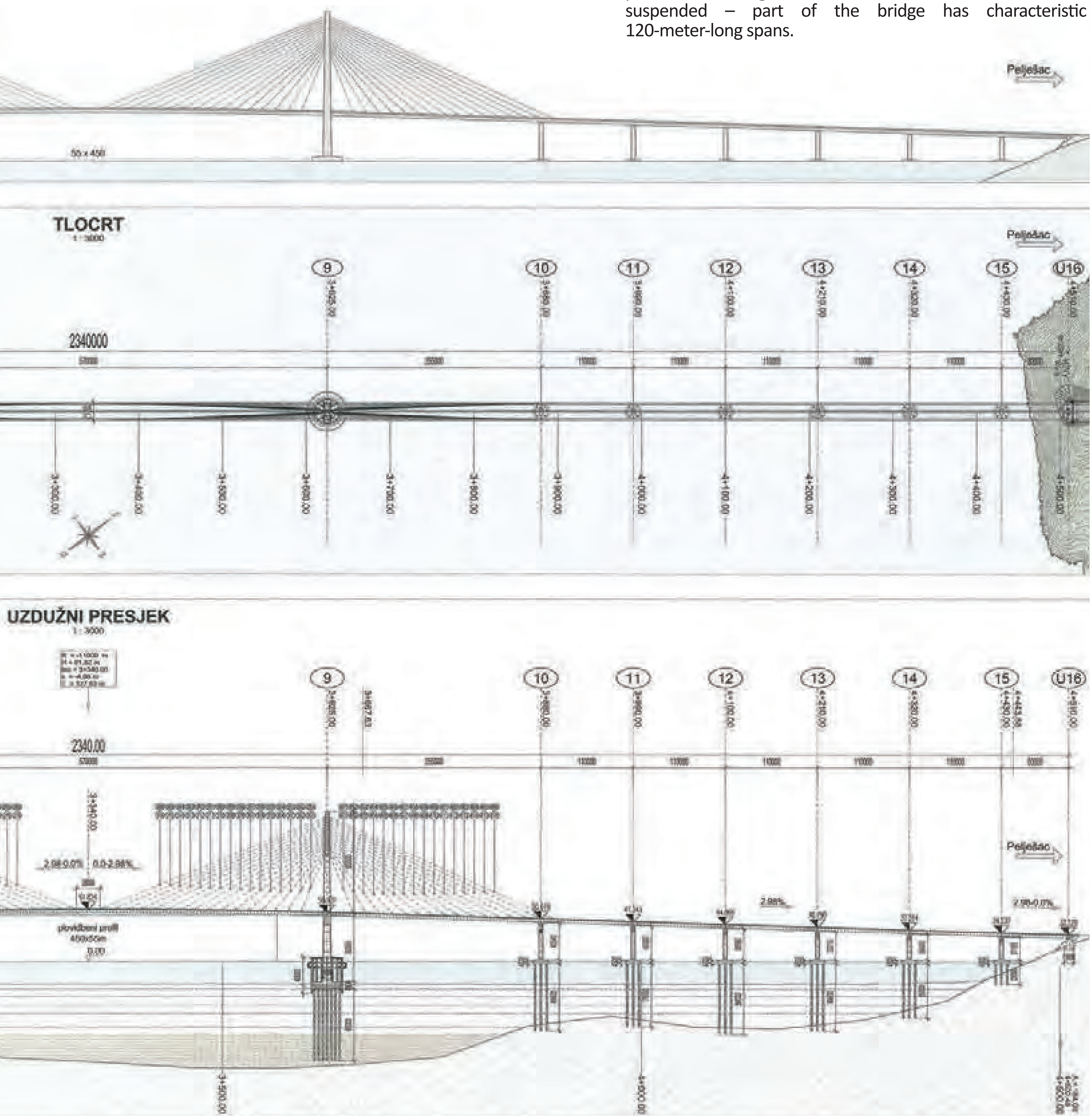
The span structure is continuous along its entire length, from one abutment to another. The length of the bridge over a total of 17 spans is 2,404 meters. The structural system of the central span structure is a suspension bridge with lateral suspension, and the access spans from both banks are bridged by a girder structural system.

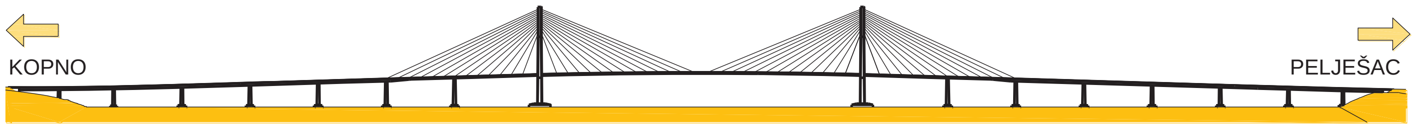


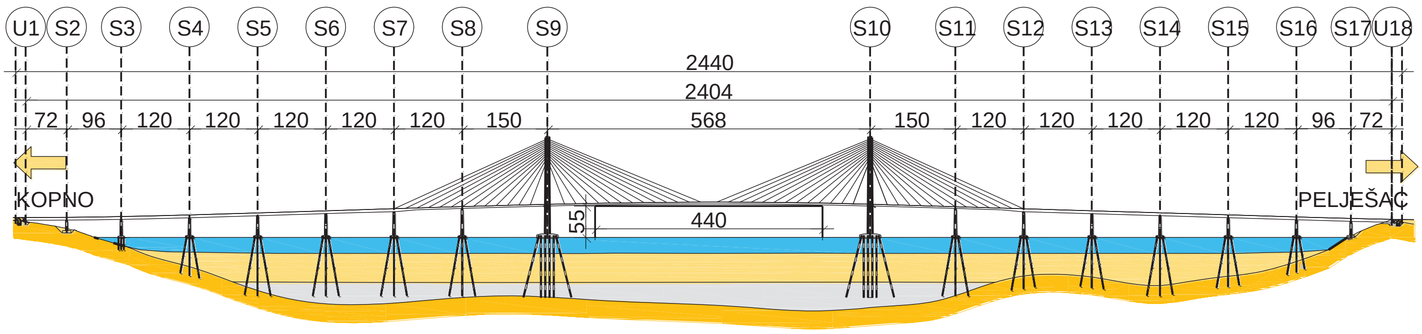
A variant of the Pelješac Bridge project, by Marjan Pipenbaher, made for the company Viadukt d.d. in 2007.

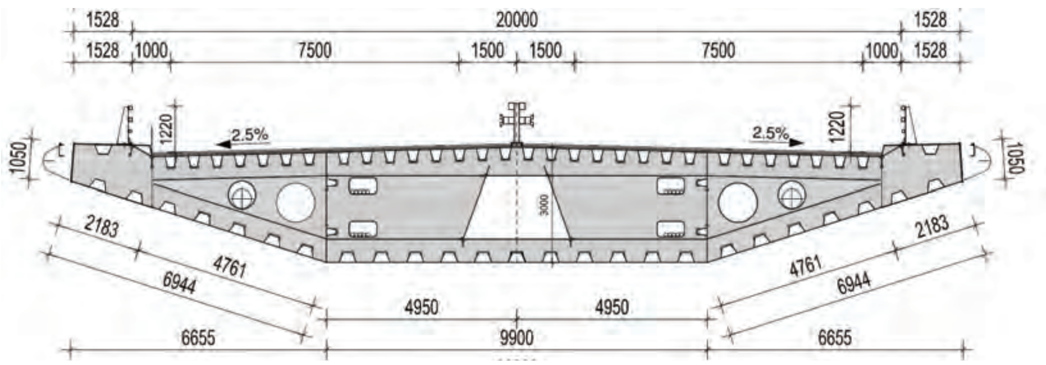
The central suspension bridge dominates the entire crossing. It extends over a navigable profile of 568 meters and above two adjacent openings, 150 and 120 meters wide, respectively. In plan, the bridge is a straight line, and the grade line is symmetrical. The span structure is supported by stay cables at 20 m intervals, with the exception of the first stay cable, which is at a distance of 30 m from the pylon. The steel span structure is a box cross-section, with constant height of 3 meters, with three chambers, aerodynamic in shape. The pylons are made of concrete, in the so-called diamond shape, with a box cross-section. Their total height above sea level was supposed to be 176 meters. On the upper parts of the pylon, stay cables are anchored in two planes (a pair of cables hold a steel box on both sides), with length from 86 to 297 meters.

At the ends of the central part of the bridge, the height of the span structure increases to 5 meters, in order to achieve continuity of the steel box with the construction of access parts. The access girder structure on both sides of the main – suspended – part of the bridge has characteristic 120-meter-long spans.









Main design of the Pelješac Bridge (authors Zlatko Šavor and Jure Radić with their associates from the Faculty of Civil Engineering, University of Zagreb, 2009)

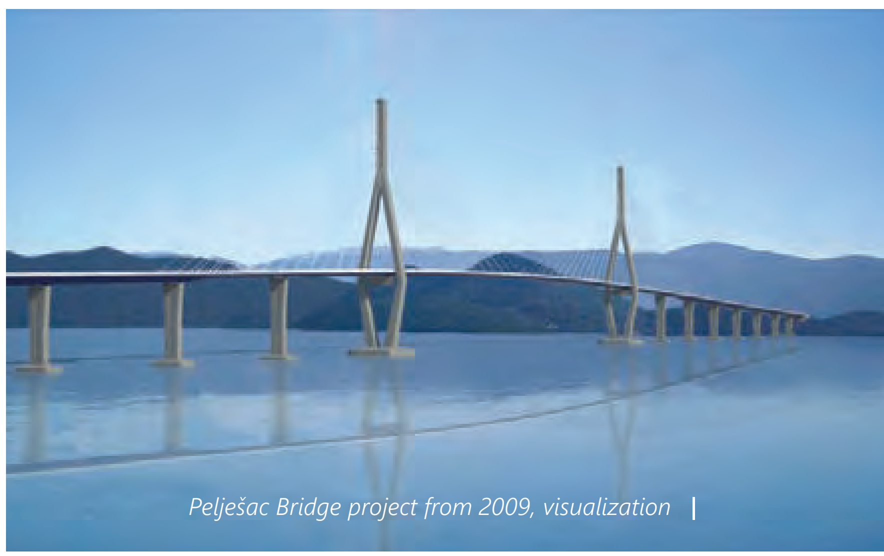
The vertical actions of the structure on the substructure would be taken over by bearings, and the horizontal actions would be received by a combination of viscous dampers, fixed bearings and spring dampers. This classical concept of transmission of horizontal forces from the upper to the lower structure differs significantly from the integral system applied on the constructed bridge.

The foundation of the bridge bearings in the sea was envisaged in a similar way as it was achieved on the constructed bridge – on groups of piles connected by a semi-submerged concrete cap. The only difference is that the edge piles of the pier seats of this version were supposed to be inclined. The piles were to be steel pipes 2 m in diameter, 40 mm thick, reinforced at the bottom.

The construction of the bridge did not go according to plan from the very beginning of works. There are several reasons for this and it is difficult to determine which of them prevailed so that the works never moved much further from preparations. As early as 2010, the works were stopped, after the operational shores and parts of the substructure on land were built and the pier piles closest to the shore were driven in.

Even in this situation, the preparation of the construction project continues, with the undivided support of the public, especially the citizens of the southernmost part of Croatia. In September 2012, they came to the abandoned construction site in their boats and connected them to a kind of pontoon bridge on the location of the future structure. About 500 boats were connected at a length of about 2,300 meters between Komarna and Brijesta.

New circumstances for this capital project occurred with the accession of the Republic of Croatia to the European Union in 2013, when the investor, the state-owned company Hrvatske ceste, restarted the design procedure. The new terms of reference required a solution for the bridge that would emphasize the rationality of its construction and maintenance, a solution that would be suitable for co-financing



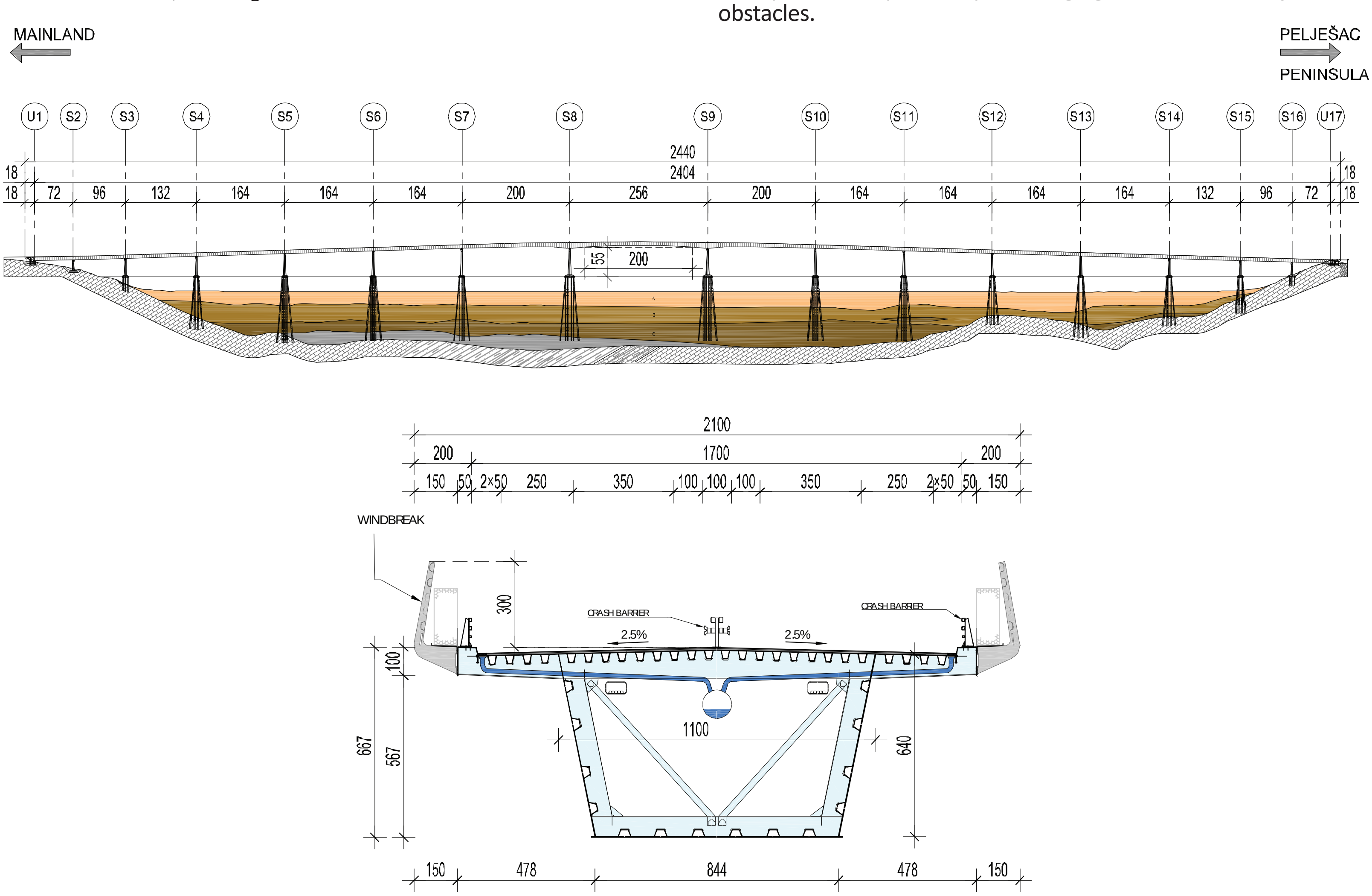
Pelješac Bridge project from 2009, visualization from EU funds. The required free navigable profile under the bridge, 200 meters wide and 55 meters high, was agreed, while the feasibility study determined that the road on the bridge should be a two-lane road (two traffic lanes, one for each direction). From 2004 to 2011, extensive geological and geotechnical surveys of the site were made, a total of 60 wells were made, the deepest of which went to a depth of 106 meters below the seabed, so the foundation project could be optimized.

The work was entrusted to a consortium consisting of a team of Professor Radić from the Faculty of Civil Engineering, University of Zagreb, in association with two companies led by the Slovenian bridge designer Marjan Pipenbaher: Ponting d.o.o. Maribor and Pipenbaher Engineers d.o.o. Projects of large bridges from Pipenbaher's offices have been realized in Slovenia, Turkey, Montenegro, Israel and Algeria, which give their author a worldwide reputation as a designer of economic viaducts, but also special bridges of significant spans, including some large suspension bridges.

The consortium of designers re-elaborated a dozen new solutions, among which the investor was offered two preliminary designs as optimal for final selection. Various structures and alternative solutions were developed, from those with the smallest reasonable spans (about 120 meters) to those with the largest span appropriate to the obstacle. In the final aesthetic judgment of the bridge, the rhythm of the supports, the proportions of the structural elements, the design harmony of all structural elements as well as the fit of the bridge equipment into the general image of the structure were evaluated.

The first of the two prominent projects envisaged the construction of a steel girder span structure, with box-shaped cross-section, with a maximum span size of 256 meters. The span structure would be continuous from the abutment on the mainland side to the abutment on Pelješac (Brijesta), and the total length would have been 2,404 meters. The author of the project is Professor Zlatko Šavor and his associates.

In the end, this project was not chosen, but it was decided that the bridge would be built according to the project of Professor Radić and engineer Pipenbaher. As with a number of achievements previously developed, it remains a valuable example of the possibility of bridging some future major obstacles.



Preliminary design of a steel girder bridge for the crossing to Pelješac from 2013, author Zlatko Šavor and associates from the Faculty of Civil Engineering, University of Zagreb.

Thus, after considering numerous variants of the structure, the concept of a bridge without a prominent central span and without extremely high pylon verticals was finally adopted, a concept emphasizing a series of equal spans over the central part of the channel with clearly defined, repeating elements of piers, girders and stay cables. The slender structure bridges the central part of the bay in five steps, with equal spans of 285 meters each. The symmetrical layout of the bridge with clear, architecturally clean horizontal and vertical lines in line with engineering practices aims to give the impression of a light and discrete structure.

On the shores along the future edges of the Pelješac Bridge, in July 2015, bronze statues of the guardian angels of the bridge were placed, in Komarna the angel Duje and in Brijesta the angel Vlaho. For three years, the angels pointed to the empty location of the future bridge, and then the works began, and they have been successfully completed. The statues are enlarged replicas of angels from the main altar of the church in Lepoglava. A photo from 2021 shows the angel Vlaho over the construction site of the bridge.

The symbolic initiative of connecting the shores with boats on the location of the future bridge took place in September 2012. (Photo source: Pixell)

Jure Radić

Professor Jure Radić was one of the authors of the Pelješac Bridge project, together with Marjan Pipenbaher. Unfortunately, his untimely death in 2016 prevented him from awaiting the realization of a project that, as an active politician, university professor and civil engineer, he had been promoting and elaborating for many years.

Throughout his entire active career, Professor Radić worked at the Faculty of Civil Engineering, University of Zagreb, and he went through all degrees, from assistant to full professor at the Department of Structural Engineering, mostly related to the Department of Bridges. Together with a group of collaborators, he designed several important Croatian bridges. He will also be remembered as a politician. He was, among other things, the Deputy Prime Minister of the Republic of Croatia and the Minister of Development and Reconstruction. Advocating for better transport connections in all parts of Croatia, he gave a great incentive and contribution to the adoption and implementation of the first Transport Development Strategy of the Republic of Croatia, which particularly emphasized the importance of connecting the north and the south. At the head of a private company, the IGH Institute, he contributed to the realization of some of the strategic ideas, conceived during the struggle for Croatia's independence.

Professor Jure Radić, B.Sc. in Civil Engineering, one of the authors of the Pelješac Bridge project

The combination of professional competence and talent for public action enabled Professor Radić to achieve a lot to create and implement key infrastructure projects, including a road connection of a high level of easement to the far south, to Dubrovnik and the Dubrovnik coast. In 2003, Professor Radić spoke directly and clearly about the bridge in an expert article entitled The Klek – Pelješac Bridge:

The bridge from the mainland to the Pelješac peninsula is primarily of strategic importance and represents a solid connection of the parts of Croatia within its borders.

The paper reviews the doubts concerning the route (through Bosnia and Herzegovina or across the peninsula, through Croatia), but also the challenge of the technical realization of a large solid crossing. The Pelješac Bridge is placed in the context of similar structures in the world, even through financial considerations, based on the realized unit prices. The conclusion is as follows:

The purpose of this paper is to stimulate discussion. Such large structures require comprehensive study and objective analysis so that the adopted approach to the construction is as thorough as possible. However, based on the above stated, it should be concluded that the Klek – Pelješac bridge is possible and realistic. The total gain of a solid and direct connection of Croatia into a single traffic unit is certainly so great that even the expected price of the bridge should not represent an obstacle to the realization of this connection.

The following year, realizing the need for a broader expert discussion on the plans for the development of the transport network of the far south, as the leader of the Croatian Engineering Association, Professor Radić organized an expert meeting in Dubrovnik called Transport Connection of the Dubrovnik-Neretva County. With eminent experts, he published an introductory program article on the management of the high-easement road to Dubrovnik and beyond. Analysing the current reflections on road management, in 2004 he wrote as follows:

From the Neretva valley to Dubrovnik and further to the Dubrovnik airport, a road of high-level easement should be built without passing through another country. ... By crossing Pelješac, it would bypass the territory of another state, ensure transport integrity of all parts of Croatia, and at the same time mark an important turning point for the development of Pelješac and the southernmost Croatian islands.

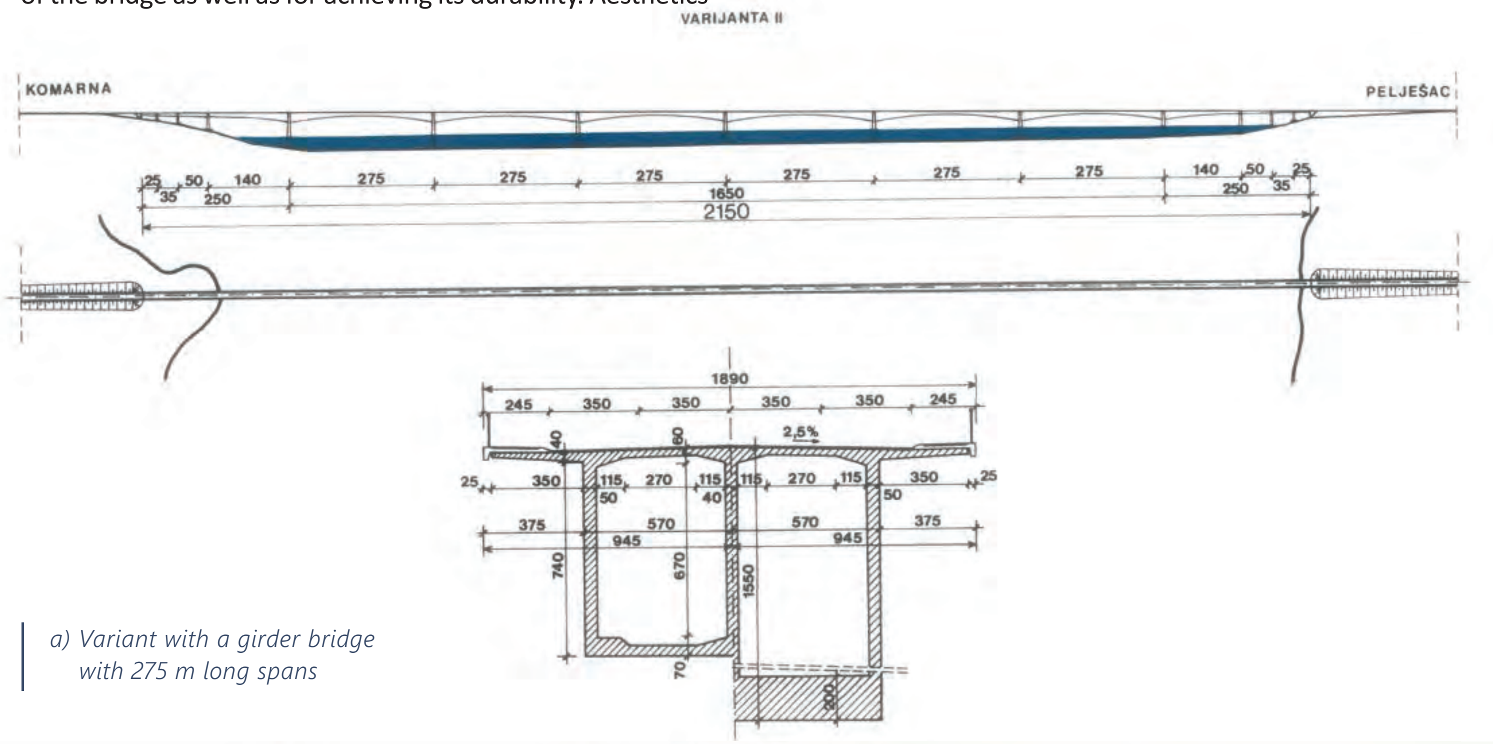
Cover of the publication of the expert meeting held in 2004 in Dubrovnik. By organizing expert discussions, Professor Radić encouraged a broad and comprehensive view of the issue of solid connection between the mainland and Pelješac

At that time, the team of the Department of Bridges was already developing versions of the mainland – Pelješac bridge. Professor Radić insisted on the analysis of even those solutions that were unlikely to be implemented from the beginning, all in order to achieve and maintain a discussion and positive atmosphere around the project. The conditions for the development of the main project of a large suspension bridge with a prominent central span, the size of which was close to the records of the time, matured gradually.

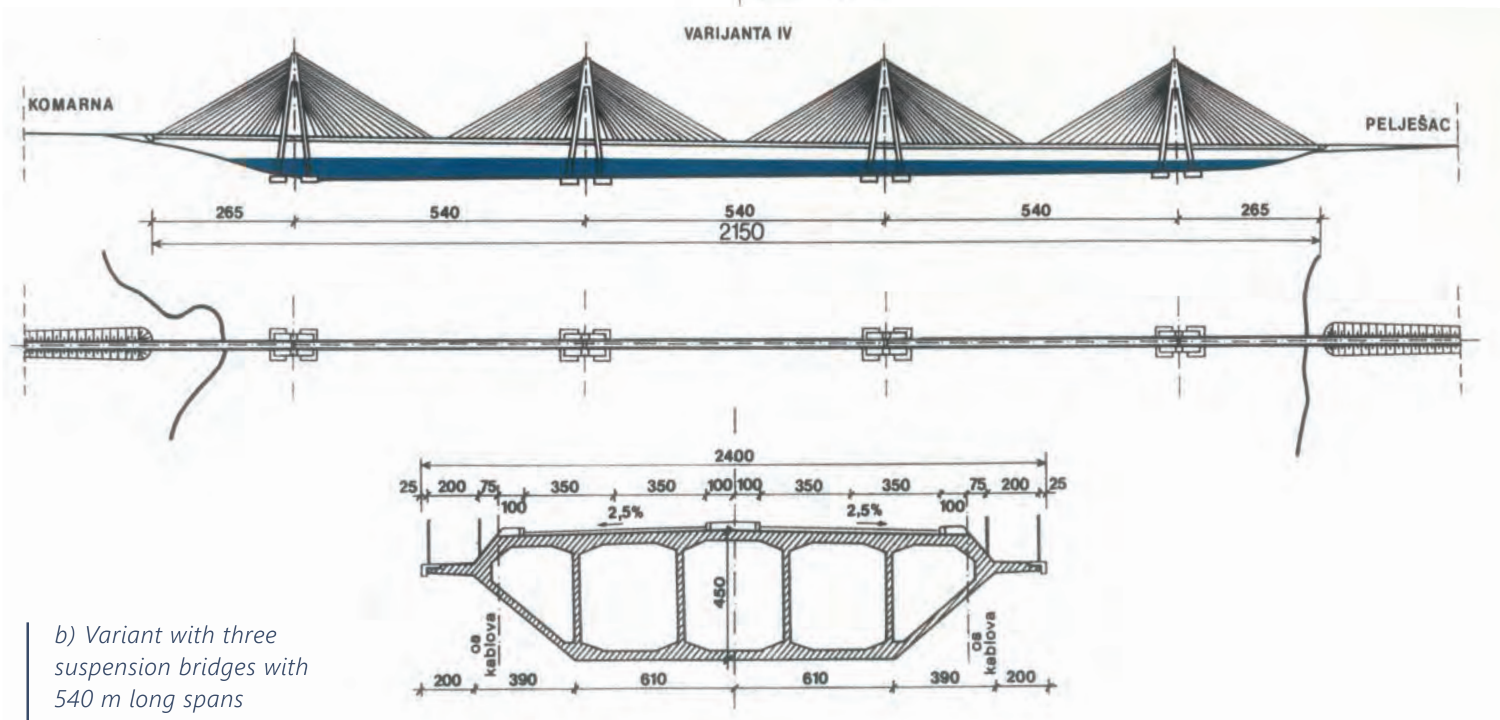
Due to a combination of circumstances, this structure was not completed, but Professor Radić still insisted on the preparation of the project, the justification of which he deeply believed. When the investor, after years of standstill, again asked for a new, more economical solution for the bridge, the professor grouped the team from the Faculty of Civil Engineering with the team of the famous Slovenian bridge designer Marjan Pipenbaher. This collaboration yielded a solution according to which the bridge was eventually built, with minor modifications during development.

In the structure that connects the mainland and Pelješac, we recognize the design contribution of Professor Jure Radić in the emphasized concern for shaping the visual perspective of the bridge as well as for achieving its durability. Aesthetics and durability are elements of bridge design that are often pushed into the background in favour of cost-effectiveness of the project. In his pedagogical, professional, but also public work, Professor Radić emphatically advocated for beautiful and durable structures.

By continuously advocating for the construction of a solid bridge crossing from the mainland to Pelješac, through public action and design, Professor Jure Radić made an immeasurable contribution to the achievement, which, unfortunately, he did not live to see.



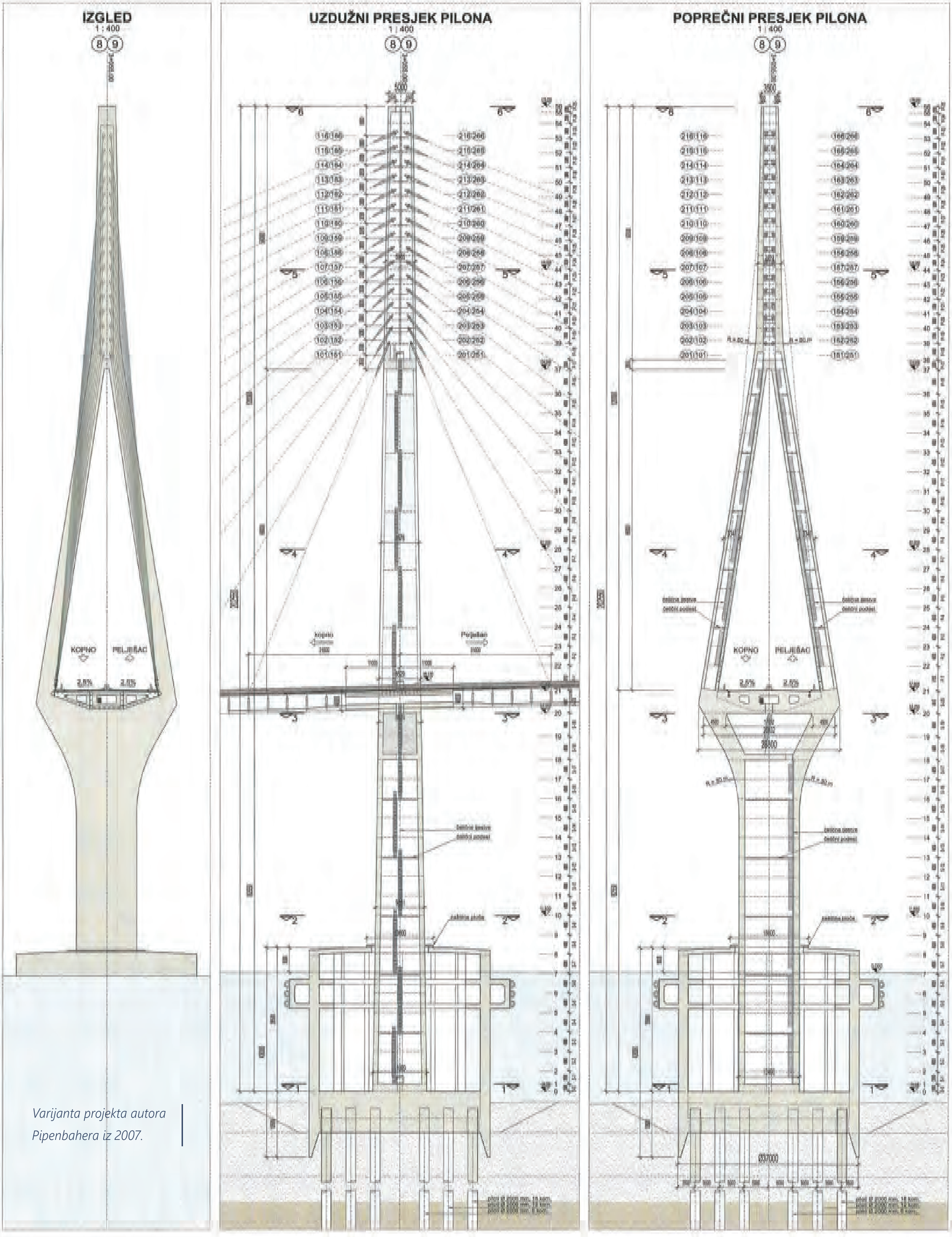
a) Variant with a girder bridge with 275 m long spans



b) Variant with three suspension bridges with 540 m long spans

The first study variants of the Pelješac Bridge project from 2003 reveal the line of thinking that ultimately led to the project according to which the bridge was built.

Computer simulation of the Pelješac Bridge based on the project from 2009, authors are Jure Radić and Zlatko Šavor with associates.



Varijanta projekta autora Pipenbahera iz 2007.

3.2

BRIDGE DESIGN

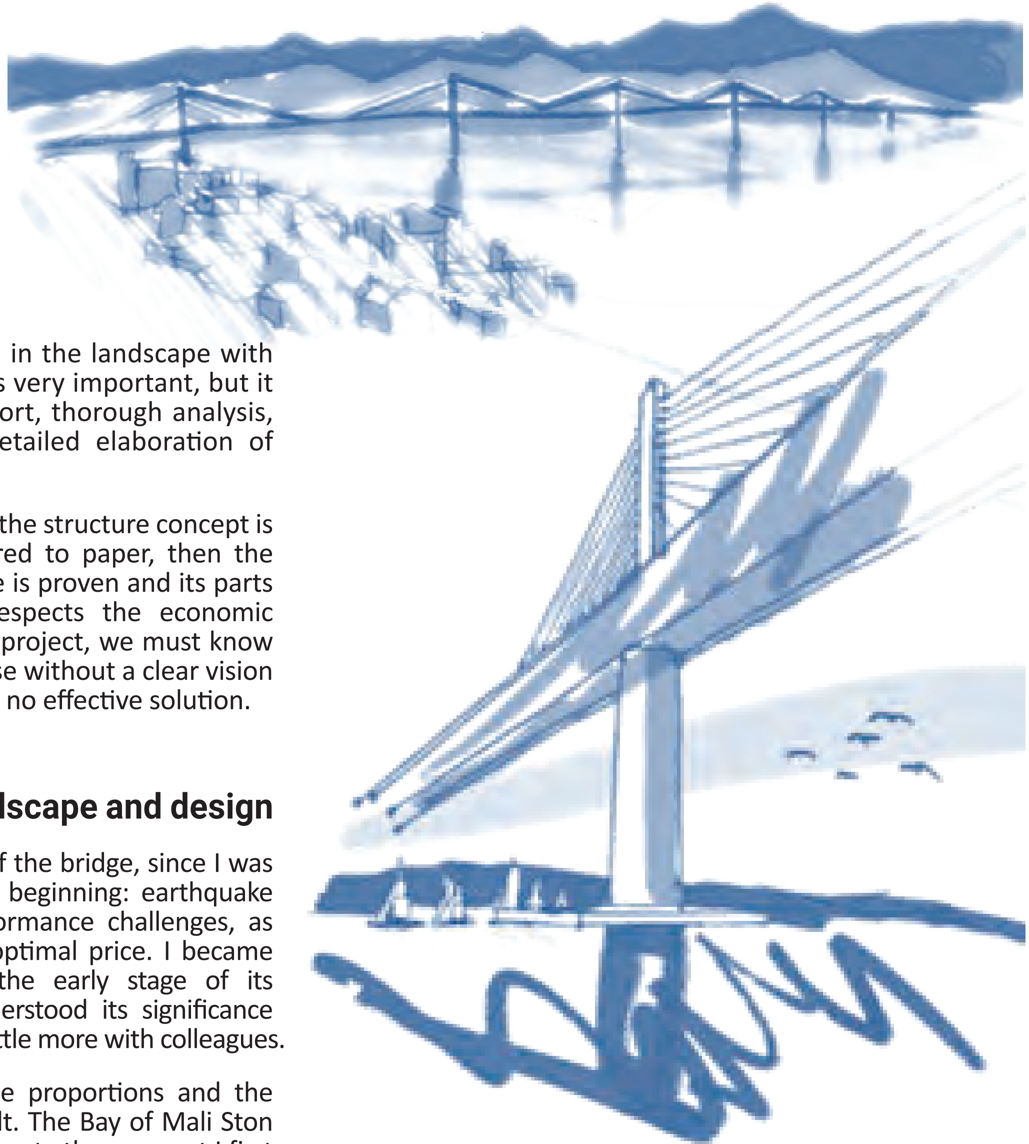
MARJAN PIPENBAHER

Marjan Pipenbaher B. Sc. in Civil Engineering, main designer of the Pelješac Bridge, Managing Director of Ponting and Pipenbaher Consulting Engineers, world-renowned Slovenian designer and author of large bridges in a dozen of countries.

Tell us about the process of creating a bridge project?

All modesty aside, designing large bridges requires top-notch engineering knowledge and experience. However, personally at the beginning of the process I always indulge in intuition and then an idea that is conveyed though hand and pen to paper comes to life and a concept slowly emerges. In doing so, it is crucial to visit and feel the location, as the bridge project needs to provide an answer to the challenges and constraints the location poses. The formation of the idea is imbued with a sense of structure, and with experience in designing similar buildings, but also with knowledge of modern transition solutions in somewhat similar locations. During my work, I have collected over 15,000 articles on bridges around the world. Extensive personal experience and good knowledge of practical examples is one of the reasons I can rely on intuition when developing a concept for a new location.

We came up with a lot of solutions and variants for the Pelješac Bridge, but the first variant somehow determined the direction of project development. It is always the first solution that comes about spontaneously, not yet burdened with big and limiting technological problems, that is fairly good. Such an idea is innocent and pure and carries within it that fundamental thought about the synthesis of architecture and structure. Such large bridges do not need any decoration. They become a recognized architecture in the landscape with their structure alone. Inspiration is very important, but it needs to be followed by great effort, thorough analysis, optimization and eventually a detailed elaboration of every single detail.



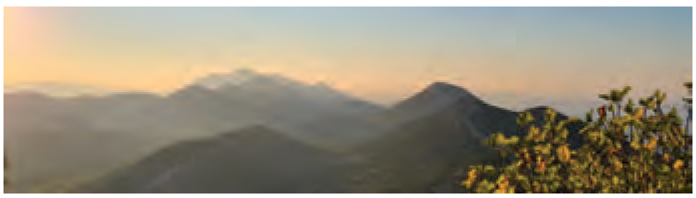
The first conceptual sketches of the architectural and structural solution of the bridge

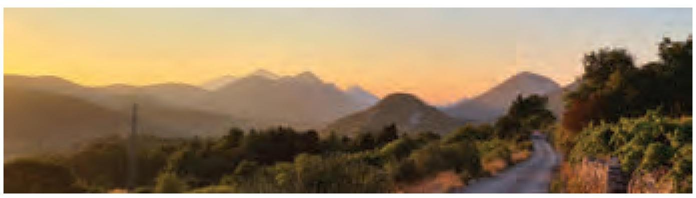
Based on experience and intuition, the structure concept is created. The idea is first transferred to paper, then the stability of the building needs to be is proven and its parts are developed in a way that respects the economic moment. At the early stage of the project, we must know how the bridge will be built, because without a clear vision of the construction process there is no effective solution.

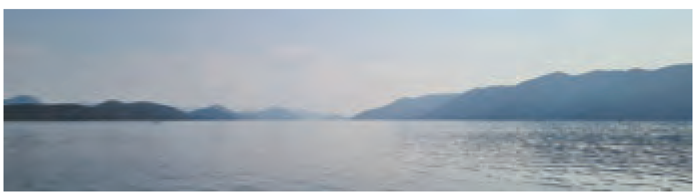
Location of the bridge, landscape and design

I thought a lot about the concept of the bridge, since I was aware of the limitations from the beginning: earthquake and wind, technological and performance challenges, as well as the effort to achieve the optimal price. I became acquainted with the project at the early stage of its development, but I only fully understood its significance when I visited the site and talked a little more with colleagues.

The location that defines both the proportions and the shape of the bridge needs to be felt. The Bay of Mali Ston inspired me with its breathtaking beauty the moment I first saw it. I immediately realized that this bridge had to be linear, like a road across the bay. Personally, I would also like it to be a bit lower. Still, it has a slope of just three percent so the climb is soft and the bridge elegantly crosses the bay.







Genius Loci – landscape of the Pelješac peninsula and bay with an infinite number of hills.

The bend on the land side and the vertical ascent and fall give a nice flow to the bridge.

On a clear day, in the Mediterranean sun, the bridge clearly shows its structure and function of individual elements, but for me the view is even more beautiful in haze, when shadows are soft, so the bridge seems even smoother in space. That was particularly important for me during the design process, since I wanted to make the structure interesting but not intrusive. During the last fifty years, many bridges of unusual construction systems have been built in the world, with architects having the main say in the design. Bridges, however, are engineering structures, so when architecture is the foundation of the design, if a new and unprecedented solution is sought at all costs, and if the feasibility of the building, its usability and maintenance are secondary, a good bridge, and mature and sustainable solutions will not be obtained.

Since there are belvederes on both shores alongside the bridge, I expect a lot of tourists, a lot of buses to stop and enjoy the breathtaking view. In addition, the area of Pelješac, Mljet and Korčula will surely gain a completely new value through greater access, and there are still many undiscovered potentials that will be activated by the construction of the bridge.

Two conceptual designs

The Pelješac Bridge is not the first bridge that I have designed in Croatia, together with my associates: we have previously designed the Baričević Viaduct on the A1 motorway near Sveti Rok and several viaducts on the Zagreb – Macelj motorway. That is actually how I met my Croatian colleagues. In 2007, when the construction of the Pelješac Bridge was being prepared according to the first project, the company Viadukt engaged us as consultants. During the process we had excellent cooperation with the Faculty of Civil Engineering in Zagreb. These circumstances coincided with the fact that the motorway program in Slovenia ended in 2005, so we decided to enter the foreign market.

In 2012, a tender was announced for the Pelješac Bridge. We intended to apply individually, but we realized that it was much better to combine knowledge and strength with the Faculty of Civil Engineering in Zagreb. When we got the contract, two variants of the bridge were elaborated and the investor was given the choice. One version was prepared by the Faculty of Civil Engineering, it was a girder bridge, and I developed the concept of a cable-stayed bridge.

We analysed the variants of the Pelješac Bridge with two, four and six pylons and eventually sent the six-pylon variant. In designing the bridge, we were guided by the principle that a simple solution is usually the best, so the designed structure has no bearings at more than 1800 meters, so it is the so-called integral construction. Such a large frame needs to be elastic to successfully compensate for changes in the length of the structure due to heating and cooling by internal displacements, and this is again a good feature when considering the resistance of the bridge to earthquakes.

Estimates showed that the construction prices of both variants are roughly equal. In the case of a cable-stayed bridge, the span superstructure is more expensive, because the girder bridge would have smaller spans. However, with the girder bridge, the cost of the foundation was higher, due to the larger number of piers.

In the end, it was decided to build a cable-stayed bridge with fewer pylons in the sea and five large, 285-meter openings.

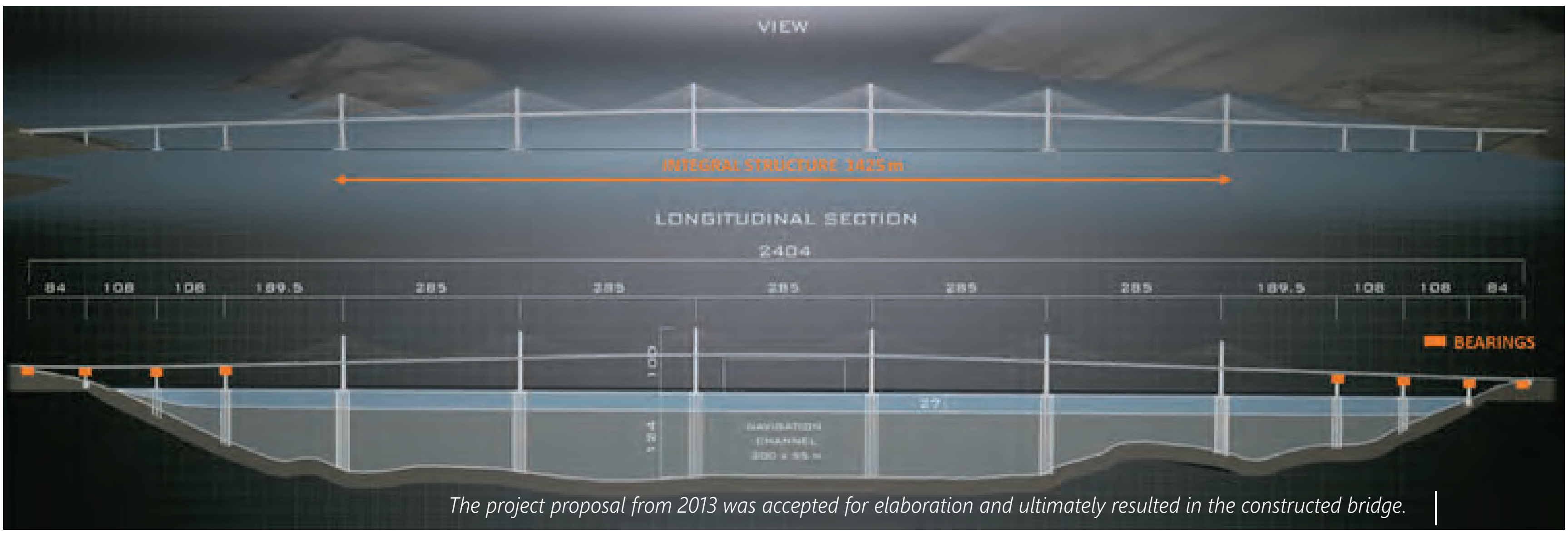
Navigable channel under the bridge

The navigable channel 200 meters wide and 55 meters high has been left for navigation from Bosnia and Herzegovina. Personally, I think that such a height is not really necessary because the beautiful bay should be preserved as a protected natural and historical entity, and it will be very challenging if large ships sail into it. A bay with small settlements and shellfish farms is a treasure, as it is a rarely preserved Mediterranean landscape that has been enriched by centuries of human effort.

Such navigable channel is similar to those in Hamburg, Singapore, the world's largest ports. Thank God, this beautiful bay is protected by Natura 2000, so in my opinion it is unlikely that a larger port will be built, in neither Croatia nor Bosnia and Herzegovina.

Large structure in a protected environment

The Bay of Mali Ston is so beautiful that it would be inappropriate to build a bridge that would dominate the landscape. That was my first guiding principle in designing, to find a structure that would gently blend in with the existing landscape. There are only few parts in the world



The project proposal from 2013 was accepted for elaboration and ultimately resulted in the constructed bridge.

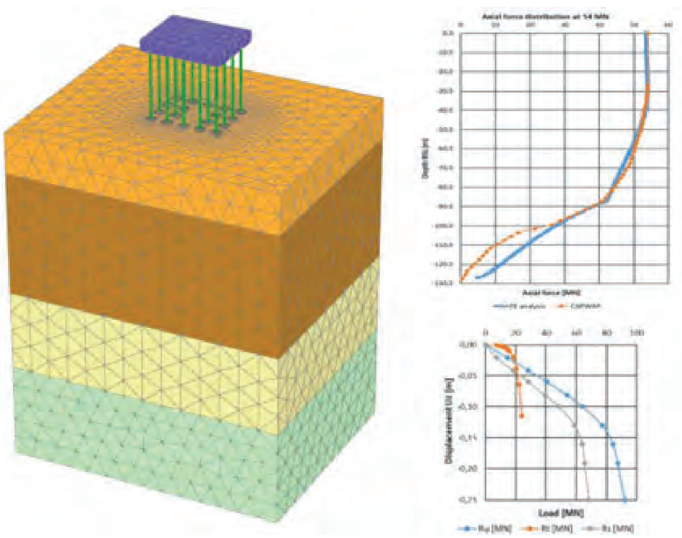
where we can find such a harmonized fusion of the sea, the Mediterranean coast with small towns, vineyards, gardens and olive groves, and I was thinking about it while designing the bridge. I believe that I responded to the challenge of the location in the most honest way in terms of engineering logic and sense of proportion and rhythm of the structure.

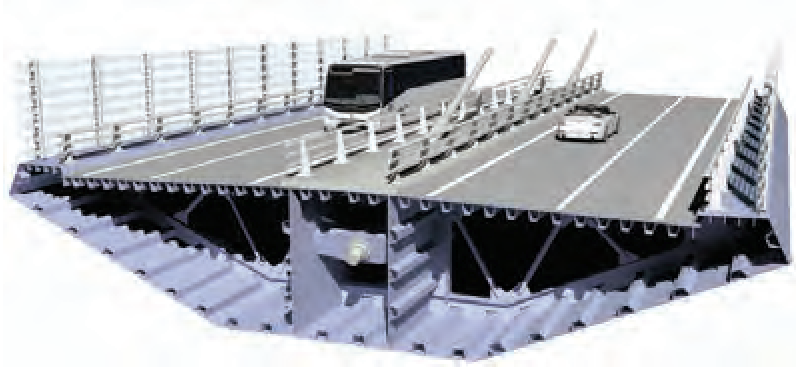
That idea was immediately supported by the late professor Jure Radić, as a co-author of the bridge.

It is a large bridge, but if you look at it from a distance, it seems calm, modest and structurally harmonious, that is the beauty of it. The intention was to design a composition of space and structure that fits into it evenly. However, the bridge remains subordinate to the space, and it was very important for me to create such an impression and I think I have succeeded.

The task of the designer when designing a large bridge is to design a structure that will enhance the landscape without imposing upon it.

Once the concept is established, numerical tests of the entire structure are performed on several independent models, using different computer programs for static and dynamic analysis of structures.





Steel span structure with three chambers and wind barriers.

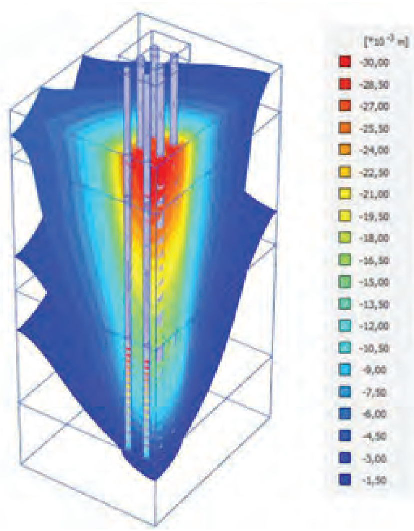
Obstacles in the implementation of bridge construction

During the construction of the Pelješac Bridge, I completed 40 years of work experience, and during those years I designed many large bridges. According to my professional experience, all large bridges go through a lengthy process from initial ideas to concept, followed by design and then construction, which takes a minimum of 10 to 15 years.

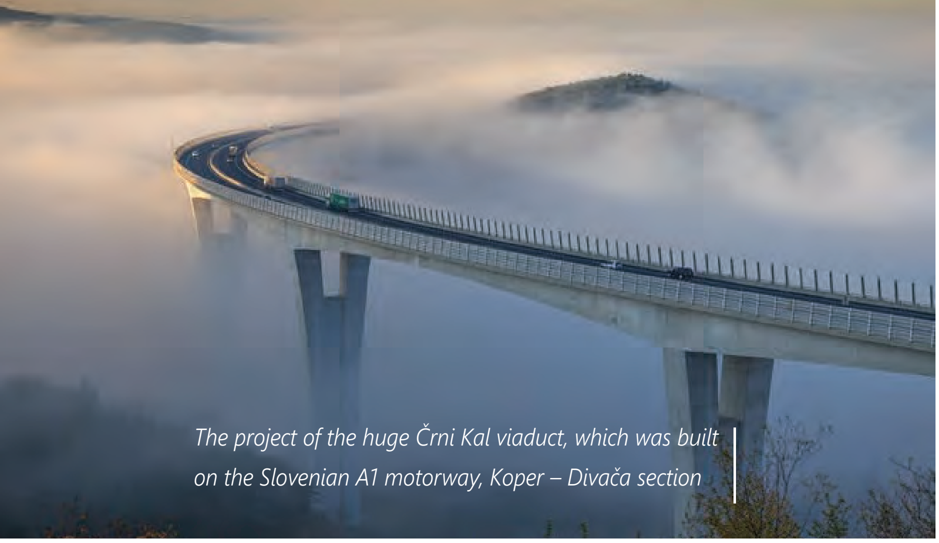
Once an acceptable conceptual solution is found, it is necessary to coordinate the project with the local community. Moreover, we should not forget about administrative processes, design, audits, field research, public procurement procedures, etc. A lot of time is lost on complaints and delays in procurement procedures.

The big problem of bureaucratized Europe is that at the level of legislation everything seems clear and easy to implement, but in practice there are many obstacles and ambiguities that slow down the project. Colleagues from Germany, Austria and France deal with the same issue. A lot of money is lost in a lengthy and complicated procedure.

However, the duration of the construction of the Pelješac Bridge is a very good result, especially in the conditions of unforeseen problems related to the pandemic. The engagement and dedication of Chinese contractors was particularly evident.



After the global models, detailed numerical models are made. In the design of the Pelješac Bridge, particularly complex modelling included the foundation structure and the soil, since the interaction of the structure with the soil significantly affects the required resistance of load-bearing elements.



The project of the huge Črni Kal viaduct, which was built on the Slovenian A1 motorway, Koper – Divača section

Pelješac Bridge in the context of other projects

When I design bridges, my criterion is never the structure itself, but always the synthesis of landscape, architecture and structure. Among others, I built two beautiful cable stayed bridges over the Euphrates in Turkey, with even greater spans than the Pelješac Bridge. I also designed a large railway bridge in Israel, more than a thousand meters long, across a beautiful valley near Jerusalem. I look with joy at all the bridges I have designed, including the largest Slovenian viaduct, Črni Kal.

However, these are bridges that on a global scale will not have the echo that was destined for the Pelješac Bridge, because it is really a global bridge, a bridge that belongs to the achievements of great importance. It will be a topic of discussions in expert circles for a long time to come, because it is the project that aimed to solve three major problems at the same time: deep foundations on driven steel piles, high seismicity of the location and the impact of strong winds.

The Pelješac Bridge is one of the five largest European bridges built at the beginning of the 21st century. Also, bearing in mind the complexity of the project and execution of works, it is one of the most demanding bridges in the world. It is interesting that during the elaboration of the implementation design and during the construction there were no significant changes in the main design, which testifies to its quality. The pilot lengths were changed by less than two percent, which is very good for such a demanding foundation, and in terms of construction and architecture, nothing has been changed.

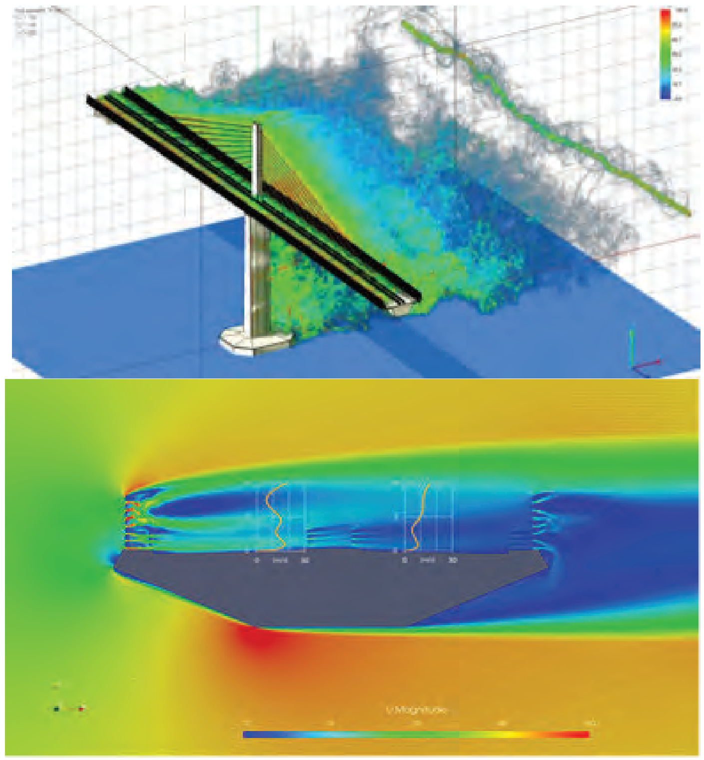
Wind and earthquake impact

Earthquake and wind are the main loads that affect the shape and dimensions of the bridge. We tested the model of the Pelješac Bridge in a wind tunnel and adjusted its shape so that it can withstand wind gusts of up to 250 kilometres per hour. According to all statistics and hydro meteorological analyses, it was concluded that winds in this area reach maximum speeds of up to 180 kilometres per hour.

However, the problem with bridges is the construction phase: large bridges are far more stable when they are built than during the construction. Since the risk of wind and earthquakes is greatest during the construction phase, we made detailed calculations of all construction phases and adjusted the elements of the bridge accordingly.

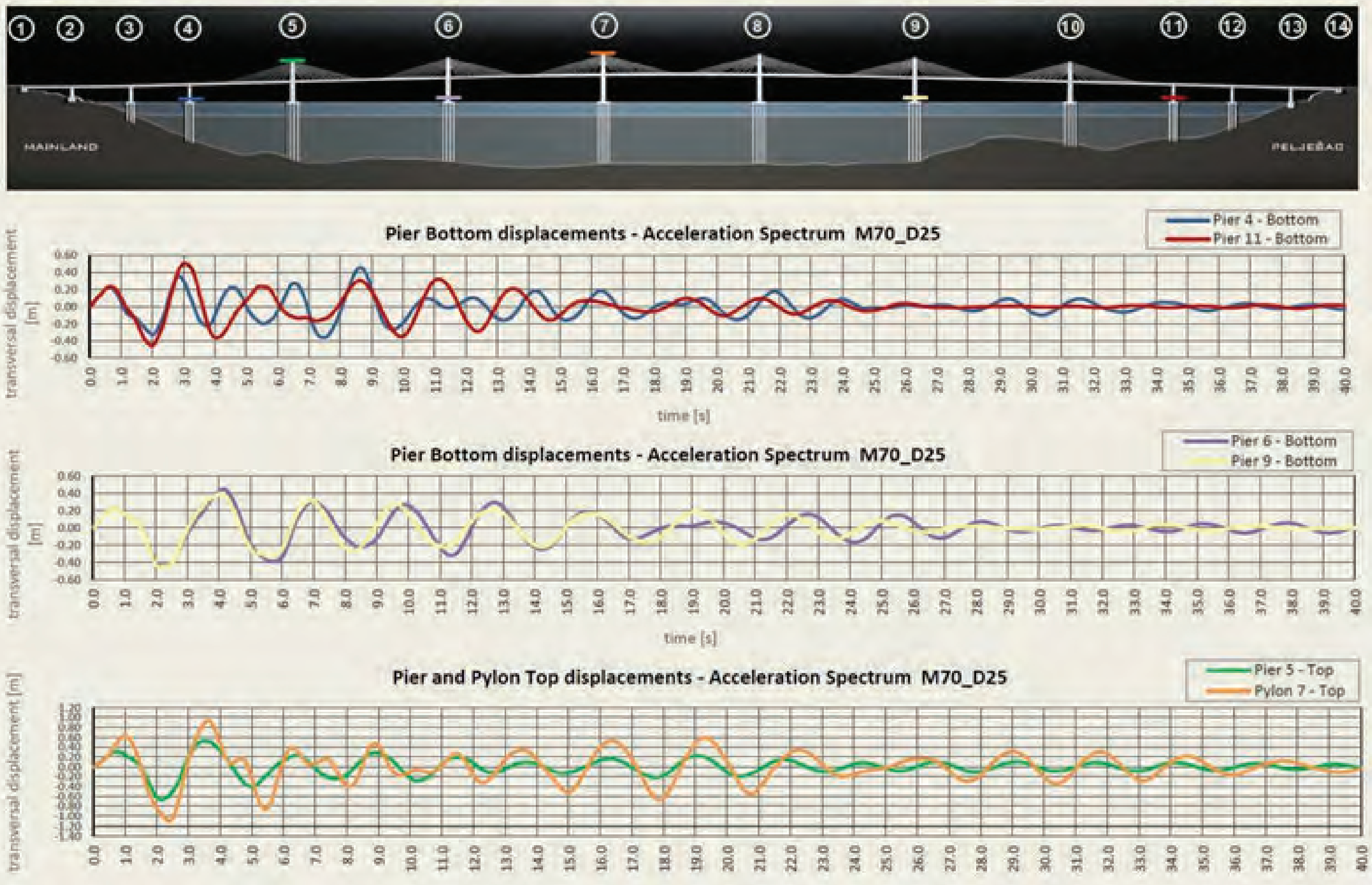
The validity of such an approach was confirmed by the events on the construction site: during the construction, we experienced the jugo and the bora speed of over 150 kilometres per hour. Within a radius of 100 kilometres from the location of the bridge, more than 40 earthquakes of magnitude up to M4.2 occurred during the construction, that is, during the period of 3 and a half years. On April 22, 2022, there was an earthquake in Stolac (BiH) of magnitude M6.1. Due to the small distance from the epicentre (54 km), the earthquake was strongly felt at the location of the bridge. With GPS devices installed on top of up to 100 m high pylons, displacements of up to 16 cm were measured. This is far less than the displacement in the case of a strong earthquake of magnitude M7.5 when the displacements can be over 80 cm.

Cable-stayed bridge Nissibi across the Euphrates River in Turkey with a 400 m wide main span – this bridge and Črni Kal viaduct introduced Marjan Pipenbaher among the leading bridge designers in the world .



Results of CFD analysis of the impact of wind currents on the bridge structure and analysis of the protection efficiency of the wind barrier.

Testing the bridge model in the windy tunnel .



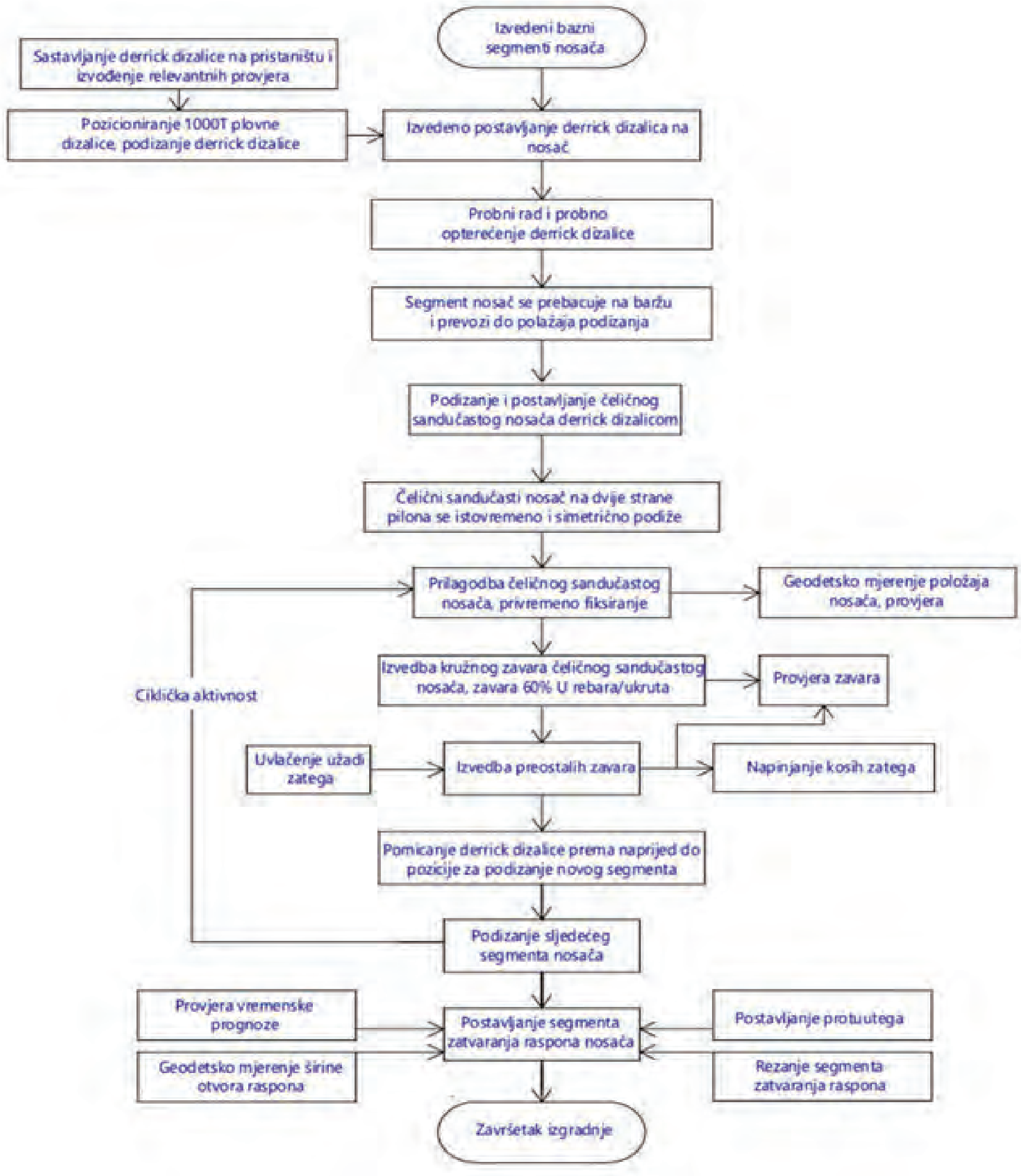
Numerical simulations of the impact of strong earthquakes on the bridge showed that the displacements in such events will reach over half a meter at the bottom of the pier, the top of which will move by more than 80 cm, so the bridge is designed to withstand such events without significant damage.

Designer's supervision of construction

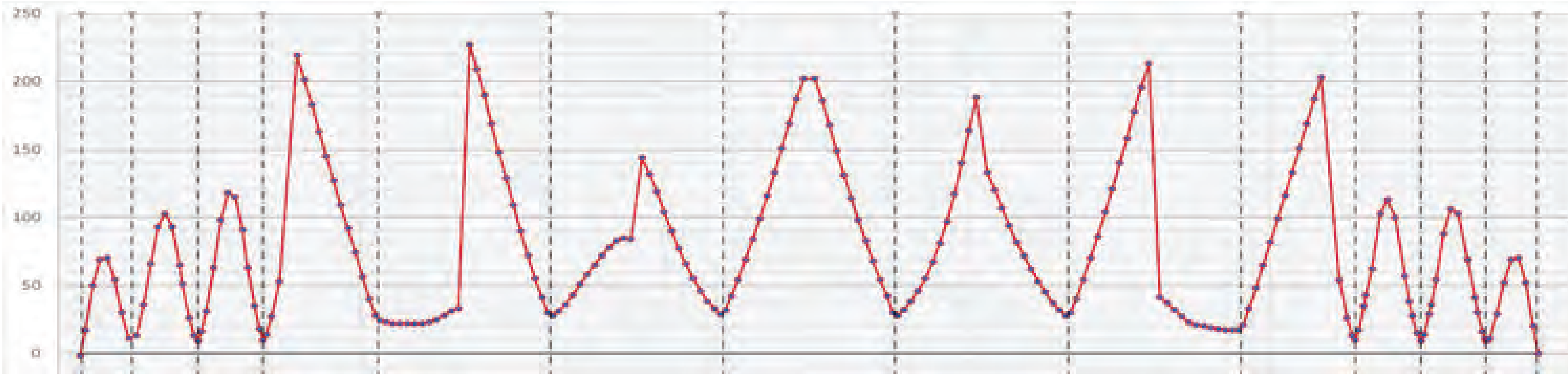
I overlooked the construction of the Pelješac Bridge every day. We have all observed the bridge progress rapidly, but great care and effort stands behind. This implies daily recalculation and implementation of minimal corrections in order to achieve the most ideal lines of the span structure, that stay cables are strained properly. A designer does not finish his job when design is completed. His real work at a bridge like this starts only when its construction starts. Every step should be followed and daily activity is required.

I spent a few days at the construction site twice a month, and I am in contact with the CRBC every day. We had a good and decent cooperation. The Chinese contractors of CRBC have shown great will and have worked hard to achieve quality in accordance with strict European standards. They engaged massive technological mechanization. It was never difficult for them to finish something, to fix something, they always did it without much complaint. Their goal is for this bridge to be built on time and at the highest possible level of quality. I insisted that for each stage of construction a detailed description of the performance (Method statement) is made before the work begins - the contractor needs to cooperate with the designer to develop a detailed construction technology and only then can the construction begin.

There were also some objective difficulties in the construction phase: let's just mention that the steel structure segments were made in China at a temperature of about 15 ° C and then installed on the construction site at some 35 ° C, which means that their dimensions were somewhat different due to thermal stretching. All this should have been taken into account when assembling the segments and during tensioning of stay cables, but we solved that as well.



The flow diagram describes the methodology of implementing the span structure - in the implementation phase the designer corrects and approves a detailed description of work operations



The final curve of the bridge camber shows that some parts had to be made so that they were over twenty centimetres higher than the projected position, which they come to after the assembly of all elements is completed.

Another lifetime achievement

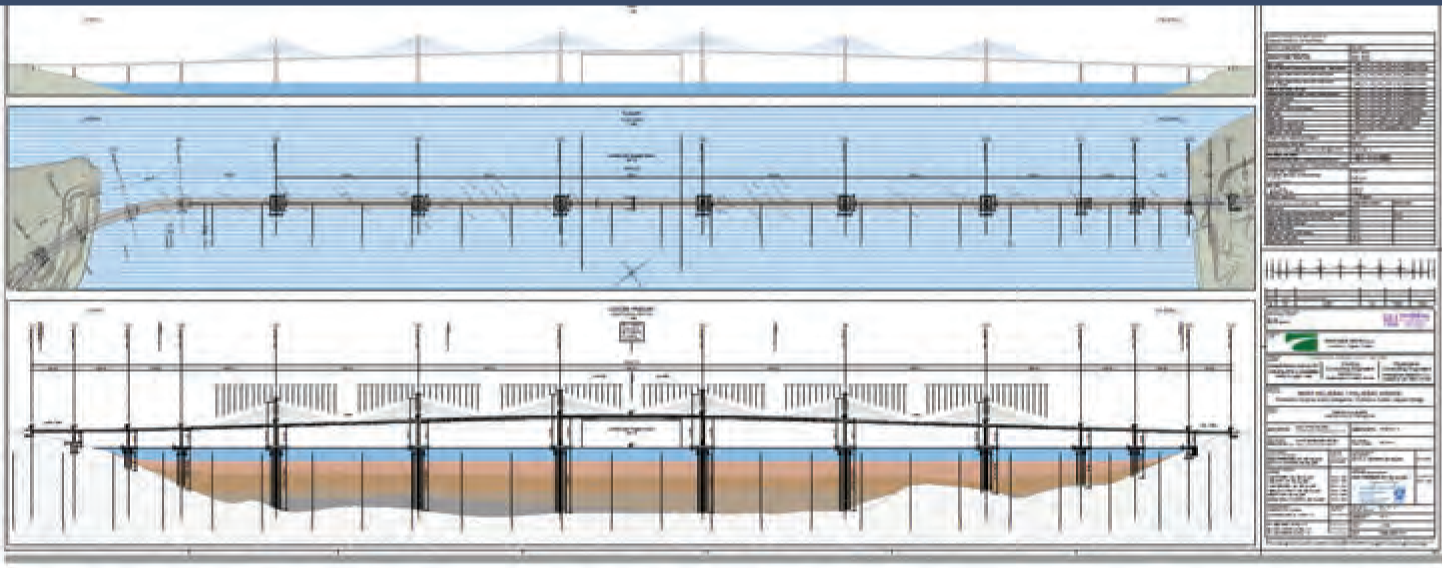
The Pelješac Bridge is my lifetime achievement, fourth or fifth in a row to be exact. Apart from it, there is the Črni Kal viaduct, the largest Slovenian viaduct, and the large bridges we have built in Israel and Turkey.

The Pelješac Bridge is a massive structure, a pure structure that has become an architectural achievement. Additionally, since the bridge connected the territory, it has become one of the symbols of modern Croatia, a country so dear to me. At the local level, it has a special importance: you need to go to Pelješac and talk to the residents to understand how much the bridge means to them.

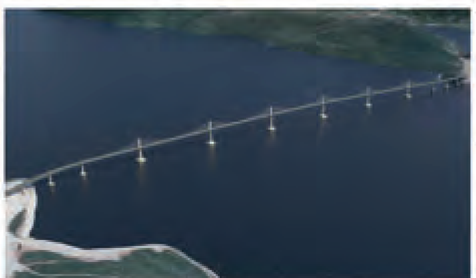
However, I should also mention the associates from our companies, Ponting and Pipenbaher Consulting Engineers, as the bridge is designed by one man, author, main and responsible designer, but a team of very professional people participates in the preparation of the drawings and budget. It is a team that specializes in design of long-span bridges, wind analysis, as well as geotechnical and seismic analysis.

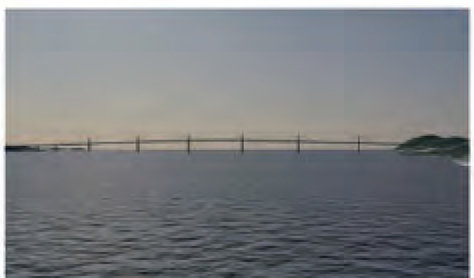
View of the Pelješac Bridge from the mainland

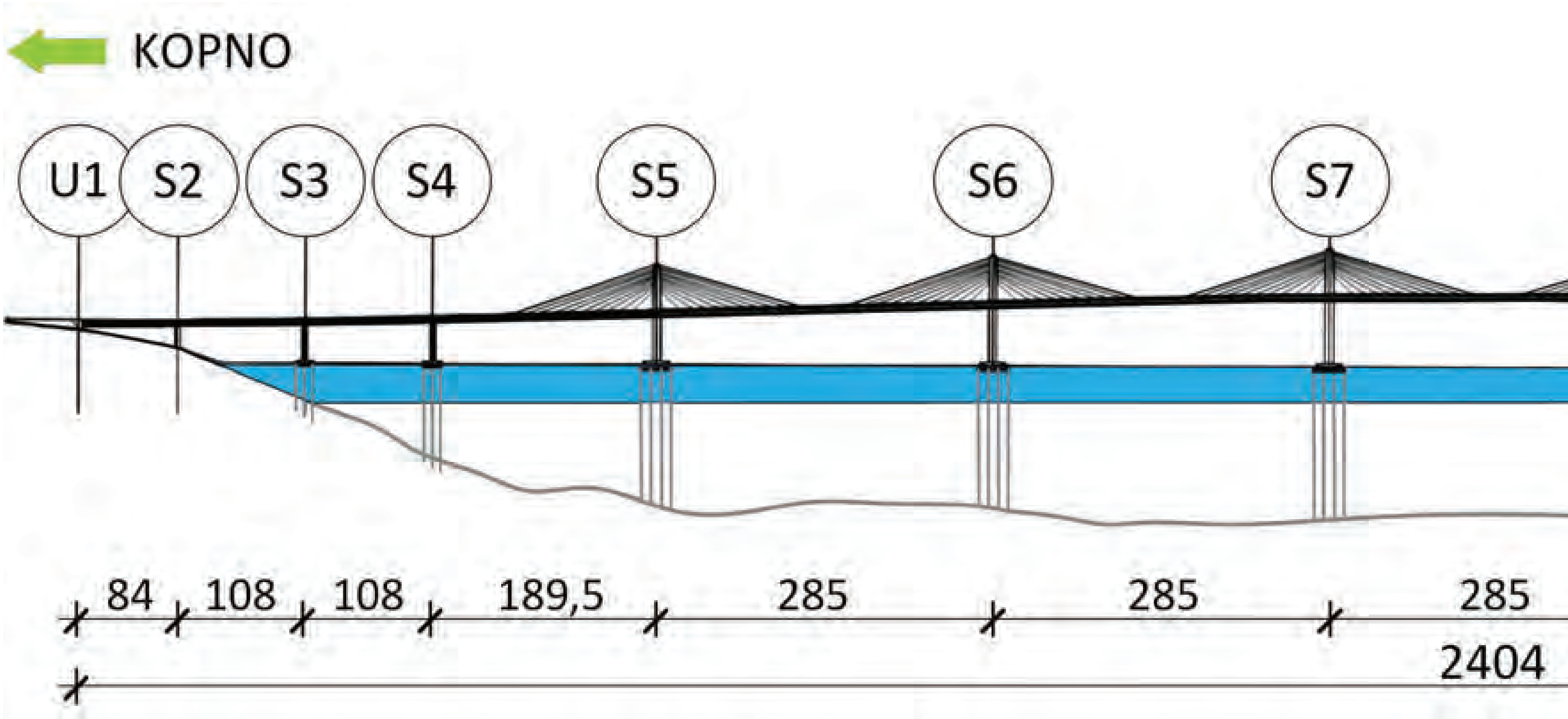
PELJEŠAC BRIDGE
DISPOSITION OF THE BRIDGE



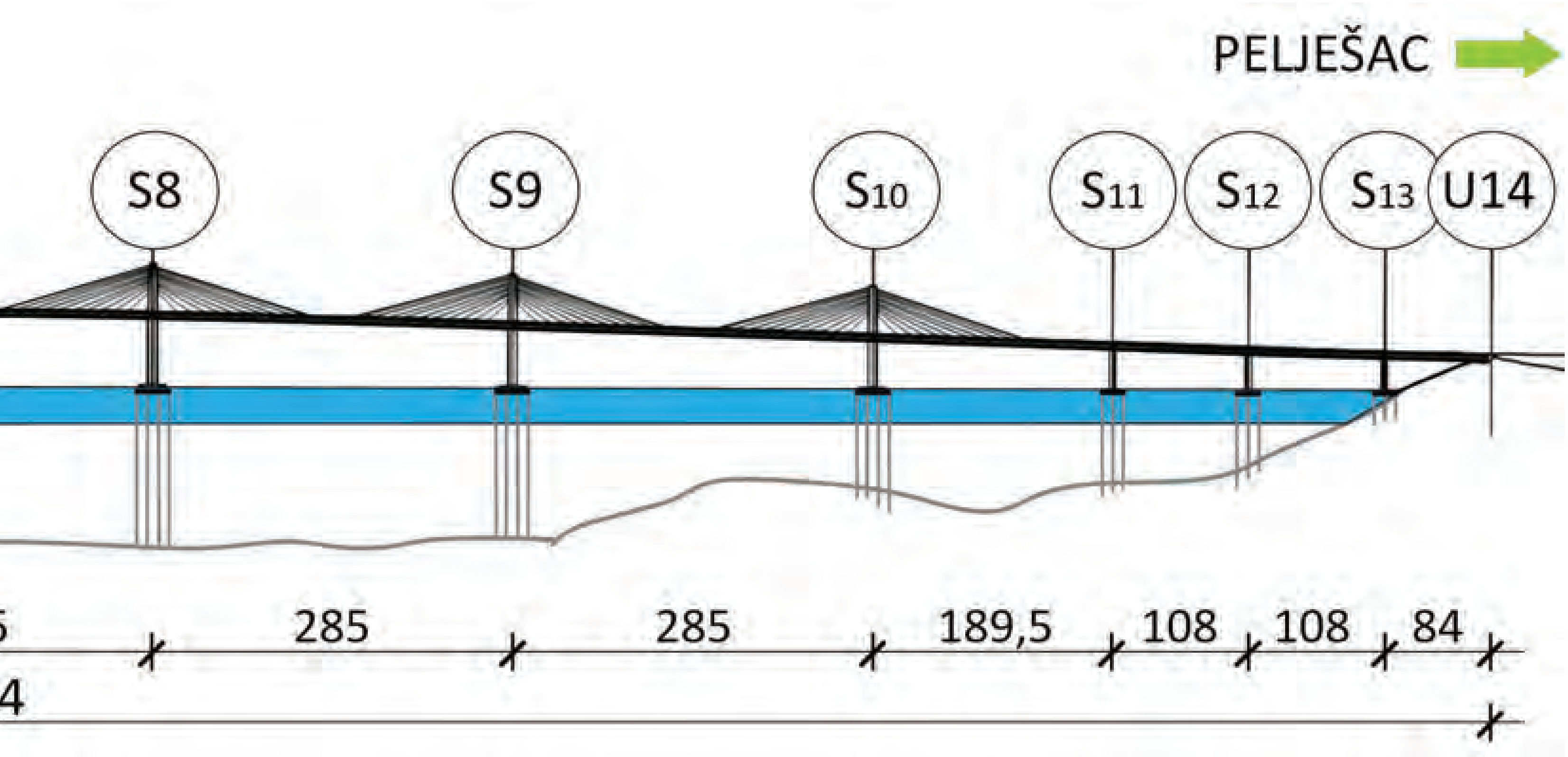
PELJEŠAC BRIDGE
BRIDGE PRESENTATION







The load-bearing structure of the Pelješac Bridge can be easily recognized from a distance: the girders of end fields rise towards the central structure of the suspension bridge (computer simulation of the future appearance of the bridge from the project).



3.3

MAIN PROJECT

Obstacle and limitations

During the elaboration of the Pelješac Bridge project, very different construction solutions were evaluated because the terms of reference did not indicate a conventional solution, but it was necessary to take into account many requirements, some of which were mutually opposed. The position of the road above the sea, the width of the obstacle, the navigable channel, the depth of the sea and the foundation soil, earthquake and wind, visual perspective and environmental protection are all factors evaluated in the process of optimizing the bridge.

The beginning of the bridge on the mainland is on the cape between the settlements of Komarna and Duboka, and the end on the Pelješac peninsula, on the cape Blace, about 3 kilometres from the settlement of Brijesta. The road at the location of the narrowest part of the crossing over the Mali Ston Canal is almost vertical to the shores, in order to reduce the length of the bridge as much as possible.

Traffic analyses showed that a two-lane road with one carriageway and elements of an expressway (grade-separated junctions) should be designed. The design speed – according to which the road elements are determined – is 90 kilometres per hour.

The width of the sea bay at the bridge location is 2,140 m, and the average depth of the sea is 27 m. The navigable channel through the bay: the width of the given navigation profile is 200 m, and the height is 55 m. In addition to the main opening of the bridge, the navigable channel also affects the structure, which is reinforced due to the possibility of vessels hitting the base of the piers.

The foundation soil at the bridge location consists of thick deposits of powder and clay of small bearing capacity, under which there is limestone. The thickness of mud deposits varies in the range of 30 to 100 meters, which influenced the choice of the underlying structure that descends through to the rocks.

The bridge is located in the area of very high seismic activity. To illustrate, the 1996 Ston earthquake reached magnitude 6 on the Richter scale and 8 on the intensity scale describing the effects of an earthquake. Almost half of old Ston was destroyed, the damage was great, but fortunately, without human casualties.

In addition to earthquakes, the location is characterized by a strong wind from the northwest, bora, as well as jugo from the south. At the height of the road, 50 meters above sea level, the wind is much stronger than at sea level.

The canal, that is, the bay, is ecologically very sensitive and specially protected zone, a special nature reserve, protected by the Natura 2000 ecological network. Natura 2000 is a complete ecological network of areas designated by EU member states, with the main goal of protecting valuable biodiversity for future generations.

One of the aspects of the environment, which influenced the project, also refers to the visual perspective of the bridge – fitting into the landscape of a huge building that stands out greatly in space. Another important aspect relates to the protection of life in the sea, which depends on a delicate balance in the closed bay exposed to the influence of fresh water from the Neretva River. The symbol and main product of mariculture in this area are shellfish: according to historical data, oysters have been continuously cultivated in the Mali Ston Bay since the Roman times, and today oysters (*Ostrea edulis*) and mussels (*Mytilus galloprovincialis*) are grown on a total area of 842.683 m².

Bridge structure

The structure consists of a suspended bridge with six pylons and five main openings measuring 285 meters each, on deep foundations made on driven piles. Thus, we see a total of 13 openings, with initial and final supports on bridge abutments and a total of 12 piers. The total length of the bridge between the mainland abutment and the one on Pelješac is 2.404 meters. The concept of a bridge without a prominent central span, symmetrical in view and without extremely high pylon verticals, with a series of equal spans over the central part of the channel and with clearly defined, repeating elements of piers, girders and stay cables was adopted.

Six central piers, that is, pylons, rise 40 meters above the road and they delimit 5 main openings of 285 m each. The stay cables stretch from there – beams of steel wires that support the span structure in large openings, at intervals of 12 meters. From each pylon on both sides, 10 stay cables extend to both sides.

The road on the bridge is two-lane: it contains one lane for each direction, but the lanes are supplemented by stopping lanes, and the directions are separated by a central belt, in which there are pylons and anchorages. Therefore, it can be said that the traffic surface on the bridge consists of two carriageways, each of which is 7 meters wide in total: each carriageway includes a 3.5 m wide lane and a 2.5 m wide stopping lane, with two marginal strips 0.5 m wide. Between the carriageways there is a central reservation with a safety barrier, and at the edges of the bridge there is a traffic barrier and a wind protection barrier. Between the two barriers there is an inspection path that allows the passage of officials (pedestrian traffic on the bridge is not foreseen).

Shellfish farming in the Mali Ston Canal is one of the factors of strict protection measures both during the construction and use of the bridge.

The piers that are extended upwards, above the carriageway, are called pylons and there are 6 of them. The span structure, that is, the structure between the bearings, above the openings, is made as a steel beam with parts of concrete cross-section above the piers. Between the pylons, the beam is held in place by stay cables. We say that the bridge has one row of stay cables, since they are all located in the central longitudinal axis of the structure. The pylons and the main girder are firmly connected, so that they form a so-called integral structure, which is why the number of expansion joints is minimal (they are only at the beginning and at the end of the bridge). The number of bearings – devices through which the load of the beam is transferred to the piers – has also been reduced. The bearings are on abutments and piers of smaller spans, at the beginning and end of the bridge. These access sections to the main suspension part of the bridge consist of a steel girder, smaller openings, ranging in size from 84 to 189.5 meters.

The access fields of the bridge, above the non-pylon piers, are bridged by a steel girder structure, of the conventional system, with the external shape of the box completely following the shape of the central structure.

The height of the piers, between the pier cap in the sea and the pylon is 37 to 53 meters, while the span structure (main span girder of the bridge) is 4.5 m high, which means that the highest piers, pylons S7 and S8 rise about 100 m above sea level. The height of the gradeline (central line of the road) above the sea, in the middle of the structure, is 62 meters, while towards the ends it descends to 31 and 35 meters, respectively.

The steel main girder has a box-shaped, that is, hollow cross-section, the interior of which is longitudinally divided by vertical ridges into three separate chambers. The height of the girder in the central chamber is 4.5 m, while the edge chambers become thinner towards the ends. Inside the closed steel box of the main girder, there are transverse girders and longitudinal trapezoidal stiffeners that guarantee the stability of the structure. The carriageway structure is an orthotropic deck: a steel deck reinforced with longitudinal stiffeners.

Design features that make the Pelješac Bridge original

1

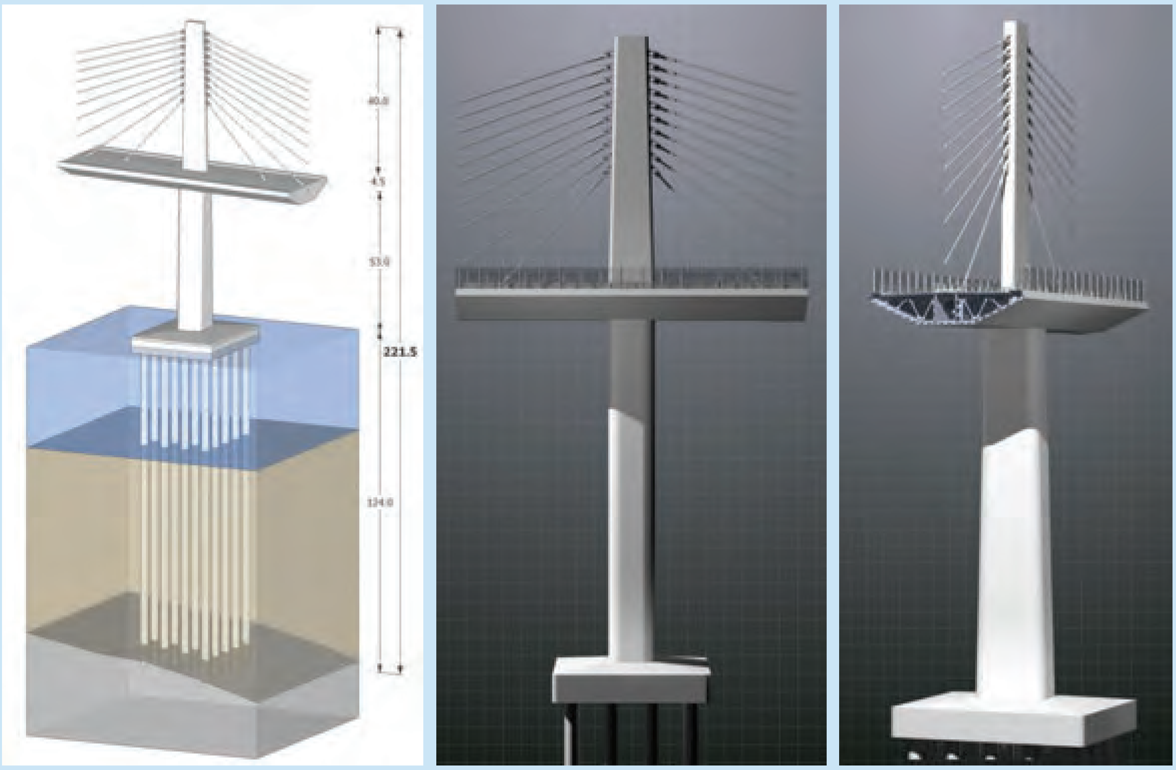
We say that the pylons of the Pelješac Bridge are low because the ratio of height above the carriageway and span is smaller than is usual with conventional suspension bridges. The ratio of the height of the pylon to the spans is 0.14 which is less than the ratio of 0.2 to 0.22 that is otherwise recommended. Low pylons were chosen because of the designer's belief that the suspension effect can be achieved with a lower pylon height. This is one of the design features of the bridge that make it unique.

2

Another important feature of this building is the semi-integral concept, that is, the rigid connection of the central piers, pylons, with the steel structure of the beam. The conventional suspension bridge solutions leave the possibility of longitudinal displacement of the beam relative to the pylon. When connecting a long structure with piers, a frame is formed in which large forces are created from prevented displacements, for example, in the case of temperature oscillations causing the bridge to stretch. An integral structure of such great length is unique, and the designer has adjusted the features of the structure to be rigid enough for live loads and elastic enough to absorb the earthquake forces.

3

The third special feature is the combination of steel and concrete in the design of the beam girder. Between the upper and lower part, the pylons contain a part of the span structure of the same shape as the steel beam, but made of prestressed concrete. Thus, steel beams of five middle spans extend from pylon to pylon, where they are interrupted by concrete parts of the structure that has the same external shape. The ends of the steel beams next to the pylons are firmly fixed into the concrete elements by prestressing in order to further guarantee the transverse stability and ensure the continuity of the structure. In other words, the steel structure above the sea continues with a prestressed structure above the piers so that they are firmly connected. The designer chose this concept in the belief that it contributes to a better distribution of forces between the piers in the event of an earthquake or strong wind.

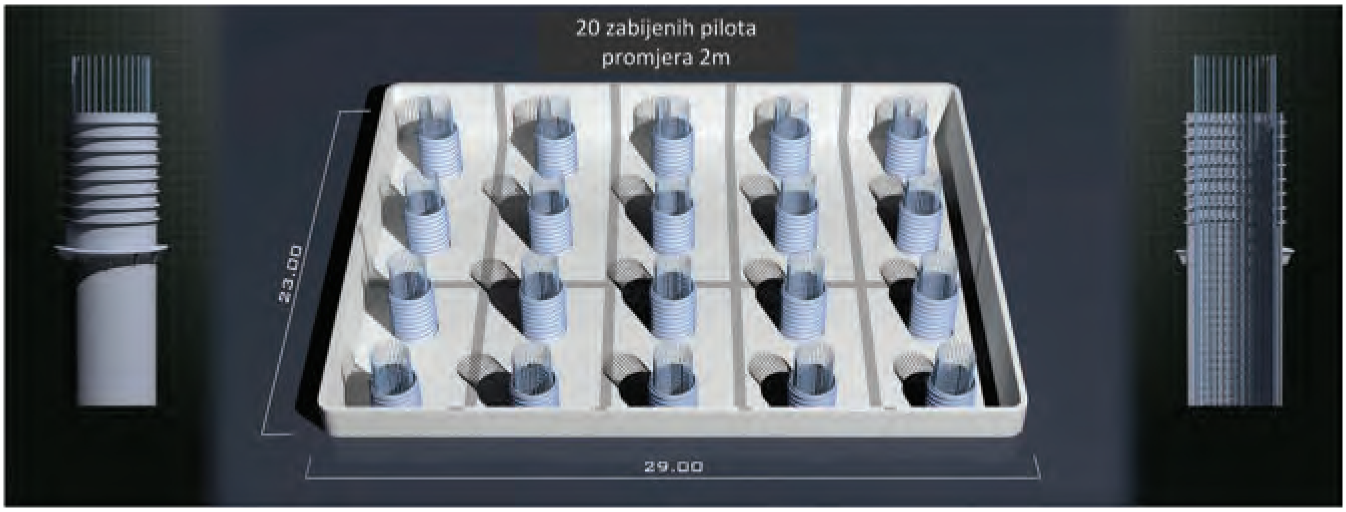


Pylon, inclined stay cables, suspended span superstructure and foundations of the Pelješac Bridge on driven piles.

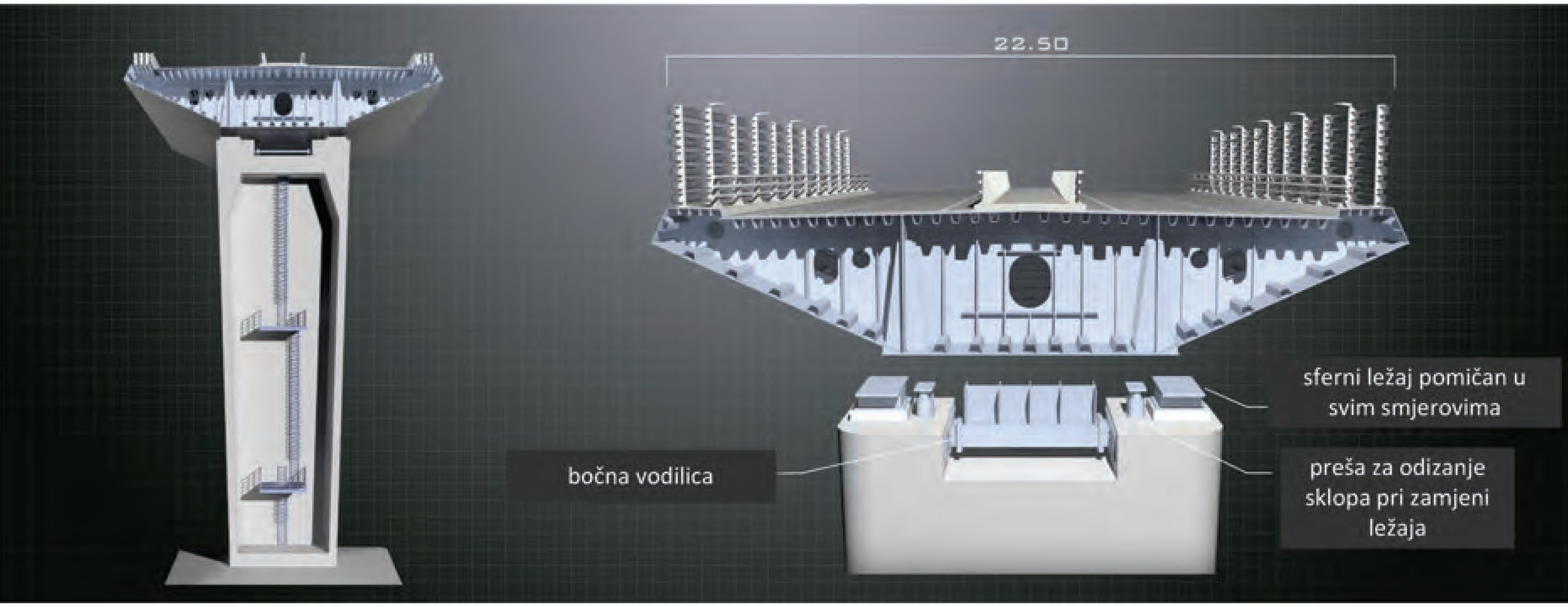
The lower parts of the pylon are 7 meters wide in side view, and in the transverse sense, they narrow from the bottom, where they are 11 m wide, to the top, where they are 8.1 m wide. Above the lower part of the pier is a concrete segment of the span steel structure, and above it is a pylon part, 40 meters high. The pylon elements above the span structure are a full concrete cross-section, located in the axis of the bridge, 40 meters high. In the longitudinal sense, they are 2.2 meters wide, and in the transverse sense, they vary in width from 7 meters at the level of the span structure to 5 meters at the top. The inclined stay cables are anchored in the pylons by means of special steel elements, so-called saddles, which pass through the concrete, one above the other. Each pylon has 10 saddles, in which 10 inclined stay cables are anchored on each side, symmetrically.

The piers of the part of the bridge that approaches the main suspension structure are narrower than the pylon piers, 4.25 meters wide along the bridge and 10 to 8 meters across the bridge. At the top they end with bearing blocks supporting the span structure. Between the beam and the concrete pier are steel bearings that allow the bridge structure to move relative to the pier. Along with the bearings, longitudinal rails are also installed, thus preventing the bridge structure from falling off the piers in the event of a catastrophic earthquake. On both abutments, as well as on piers S4 and S11, built-in bearings can take over tensile and lifting forces.

All piers in the sea end at the bottom with a concrete pile cap. They are founded on nailed piles, and the pile caps got their



Pile caps S7 and S8



Cross-section through the pier and details of the top of the pier with support of the span structure.

name from the fact that - from the bottom - the tops of the piles enter into them.

At the bridge edges, the span structure rests on massive abutments - end piers that accept the load from the bridge on one side and the embankment of the access road on the other.

The principle consistently applied to the bridge has been derived from experience in building maintenance, according to which all hollow spaces within the bridge structure must be accessible for inspection. All piers have openings for entry and a steel ladder, so the entire inner space is accessible for inspection. Through the piers, you can also get inside the box, so the accesses are also used for repairs and maintenance of bridge equipment.

Foundation works

Most of the supports of the Pelješac Bridge are located in places where the soil has good bearing capacity at greater depths, so it was necessary to design deep foundations, which transferred the load through clay deposits to the rock. The deep foundation of the Pelješac Bridge was built on piles. It was a significant engineering challenge, as the load-bearing ground, a solid rock that can take loads from the structure over the sea, is located at great depth: the longest piles are 130.6 meters long.

All pylons lean on 20 nailed steel piles, which are connected at the top by a pile cap. The piles are partially or completely filled with reinforced concrete. On the piers, at a shallower depth, foundations are on 18 piles, and under the piers along the shore the foundations are on 9 piles each. Shorter piles have a diameter of 1.8 meters and longer ones 2 meters.

The foundation works project is based on soil investigations at the bridge location. Numerous results of previously made borehole testing, geophysical and other tests were collected.

Geotechnical works at the bridge location: drilling of samples from the seabed is performed by pipes in which soil samples from a certain depth remain. Analysis of these samples determines the extent to which the soil is suitable for foundation.

Samples from the seabed at the location of the future bridge foundation are placed in a box in order, that is, according to the depth from which they were taken. The boundary between the poorly bearing clay and the rock is visible at a depth of 127 m, or about 100 m below the seabed.

It is interesting that during the test drilling at the location of the foundation, the special features of the karst area were taken into account – possible caverns, so at least 12 meters were drilled into solid rock, in order to find possible cavities under the foundation.

For the final variant of the bridge, additional boreholes were drilled at the locations of each foundation, and two test piles, 2 meters in diameter, were driven, which are not part of the load-bearing structure. The development of test piles confirmed previous knowledge of the soil, and in addition they were used to test equipment and work technology before they were applied to load-bearing piles.

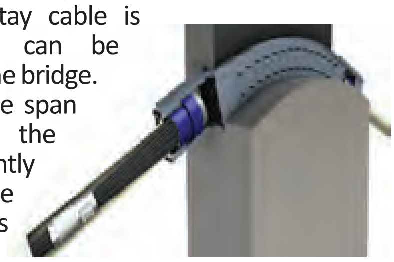
While being driven, the piles pass through layers of clay to lean on solid rock. They are arranged in a rectangular order, and there are a total of 148 in the load-bearing structure, not counting the 22 smaller drilled piles at the base of the pier S13. The groups of piles under each pier or pylon are connected at sea level by a thick reinforced concrete pile cap so that they jointly transfer load from the piers. The lower half of the pile cap is below sea level and the upper half above.

The steel pipes of the piles are 40 mm thick, and at the bottom – at the most loaded part – they thicken to 60 mm. Piles longer than 100 meters were filled with reinforced concrete to a depth of 40 meters, measured from the sea surface, while the others were filled along the entire length. The piles closer to the shore were made using a special technology, in such a way that the rock under the driven pile was drilled and filled with concrete, that is, a concrete foot 6 m deep was made under the pile.

Inclined stay cables

Inclined stay cables are the basic structural and load-bearing element of the bridge. The cable consists of a bundle of parallel steel strands, and each strand consists of 7 steel wires with a total area of 1.5 cm². The wires have G.U.T.S. of 1860 MPa. The tensile strength of steel stay cables can be assessed by the following comparison: a wire with a diameter of 1 mm² made of stay cable material could withstand a weight of 186 kilograms. However, only 45% of the strength is used in the operation of the bridge, which means that the maximum stress in normal use can reach 84 kilograms per square millimetre.

The length of the stay cables varies from 33 m to 137 m, and each consists of a minimum of 55 and a maximum of 109 strands. Two opposite stay cables on the pylon are connected by curved saddles. The cables end with anchors, one of which is attached to the pylon and the other is inside the steel structure of the bridge. Each strand of wires of each stay cable is anchored separately and can be tightened during the use of the bridge. Active anchors are inside the span structure, those on which the strands can be subsequently tightened, while there are fixed anchors on the saddles on the pylon.



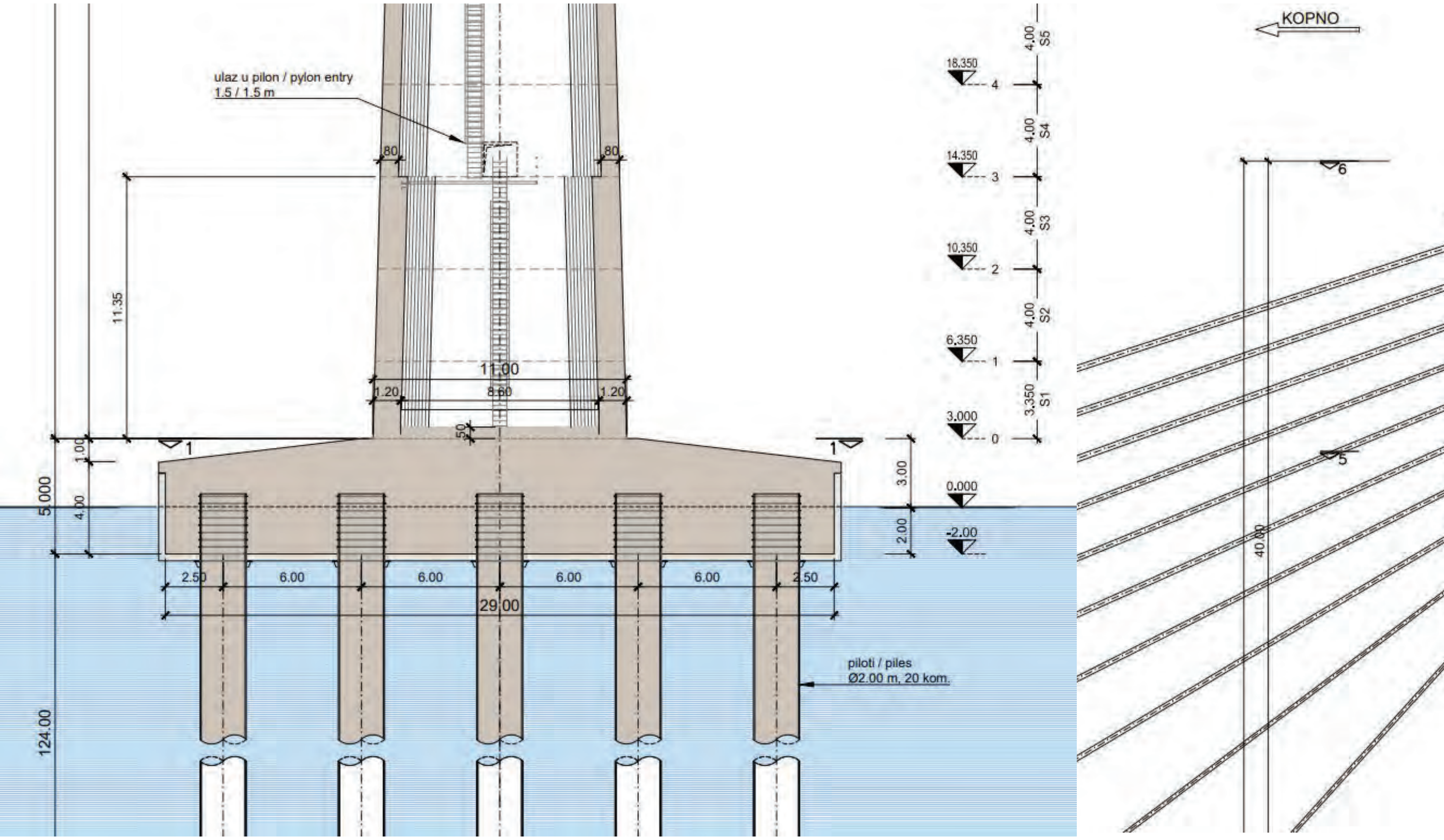
Pylon saddle

The stays cables are protected from corrosion, which poses the greatest risk to these bridge elements, and the final outer shell consists of high-density polyethylene pipes (abbreviation for this material is HDPE).

Special attention was paid to the prevention of stay cable vibrations that occur on windy days, since such phenomena have been recorded on the Dubrovnik bridge. Protective polyethylene pipes of inclined cables are profiled on the outer surface with special ribs that serve to reduce vibrations due to the combined activity of wind and rain. In addition, hydraulic vibration dampers are installed on the 5 longest stays cables. On the bridge over the Dubrovnik River (suspended Franjo Tuđman Bridge, at the entrance to Dubrovnik from the west), there were vibrations with moderate wind and rain to such an extent that the barrier and light poles of the bridge were damaged, so the protective elements were installed later.

If necessary, individual strands of steel wires or even entire stay cables can be replaced without interrupting the traffic on the bridge during the replacement, but by transferring it to stopping lanes. Thus, a part of the suspended structure without stay cables can withstand full traffic load on the bridge.

The inclined stay cables of the Pelješac Bridge consist of parallel strands, each strand holding 7 steel wires. The strands are pulled into the protective pipe on the construction site, then one by one the strands are tightened to a certain force. The stay cable consists of 55 to 109 strands tensioned with the same force.



The cross-section of the lower part of the pylon along the navigation profile reveals a special reinforcement – thickening of the concrete walls to 1.2 m due to the possible impact of the ship into the pier.

Bridge equipment

The bridge is not only a load-bearing structure, but also all those elements that enable safe and comfortable traffic on the bridge.

The span structure of the bridge stretches and shrinks under the influence of temperature changes, so transition devices are installed at the ends of the bridge, which compensate for these shifts, ensuring the continuity of the carriageway between the bridge and the shore. The transition devices of the Pelješac Bridge are the largest ever built into one of our bridges because they enable displacements of 70 centimetres in each direction (+/- 700 mm). This means that the difference between the lengths of the bridge structure between the end states can be 1.4 meters on each side.

Waterproofing is installed on the carriageway slab and two layers of asphalt are placed on it, first a protective layer, and then a wearing layer. Both asphalt layers are 4 centimetres thick.

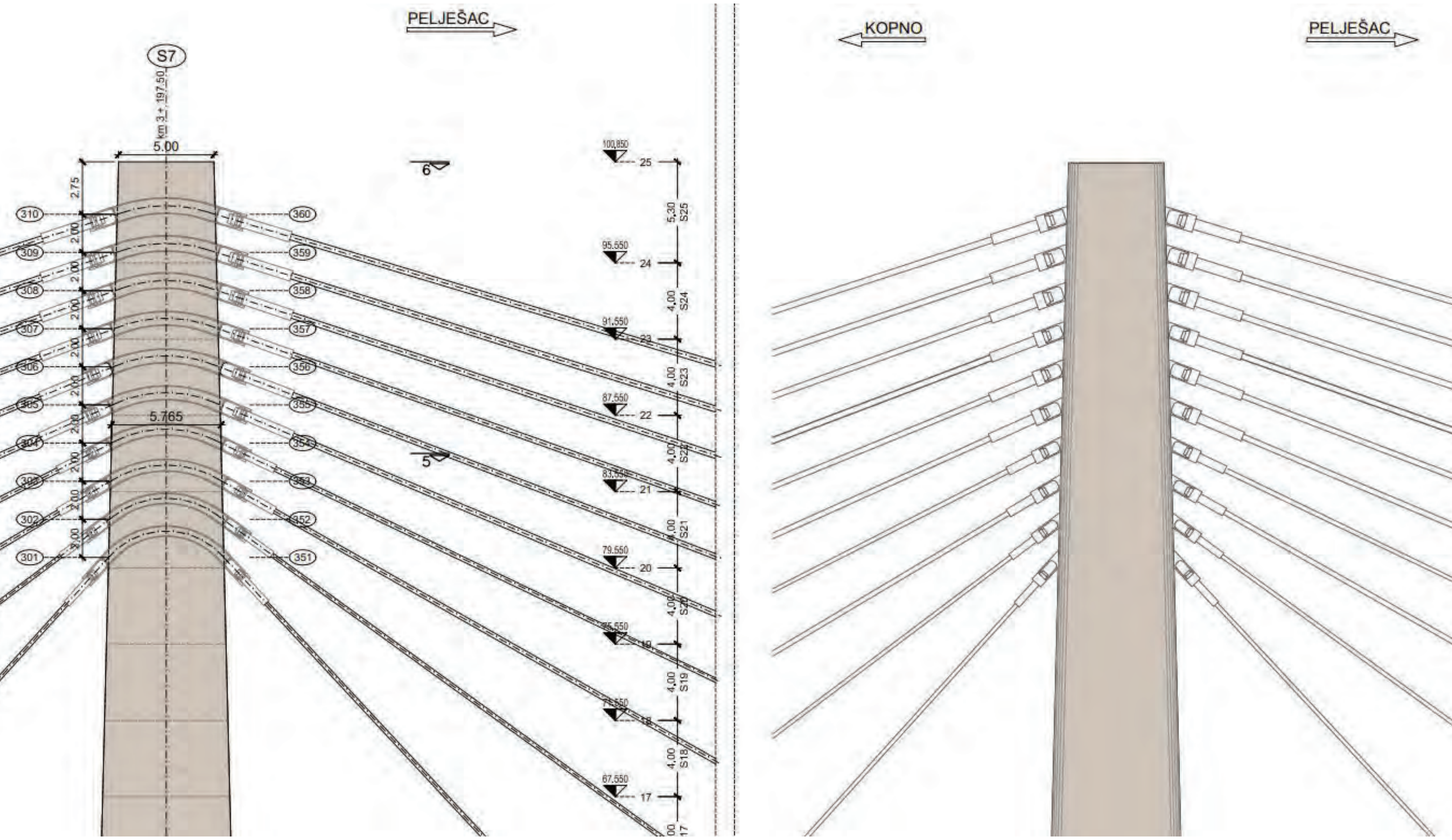
Traffic barriers on the bridge prevent the vehicle from falling off the bridge, that is, crossing into the opposite lane.

A wind protection barrier is placed at the edges of the span structure to protect the vehicles from the effects of the wind. The wind barrier height of 3.2 meters was determined by calculations and wind tunnel testing. The barrier consists of 7 cone-shaped strips, made of reinforced acrylic glass. The strips are 30 cm wide, and there is a distance of about 15 centimetres between them. This type of barrier has previously proved effective on some Croatian bridges in the area of strong bora.

The wind protection barrier is also a protective barrier for pedestrians on the service lane.

The bridge has a so-called closed drainage system: all the water from the carriageway is collected and drained away from the bridge by pipes passing through the box, towards the treatment devices. The system consists of drains, transverse and longitudinal pipes, and manholes. Interestingly, given the length and width of the structure, the drainage pipe at the end of the bridge is 50 centimetres in diameter.

Traffic signalling installations, road, decorative and service lighting, waterway lighting, telecommunication lines, and



Detail of the top of the pylon in cross section and front view: steel saddles are visible, which connect two opposite stay cables, anchored to the ends of the saddles.

high and low voltage electrical cables cross the bridge. All installations are located on shelves inside the box.

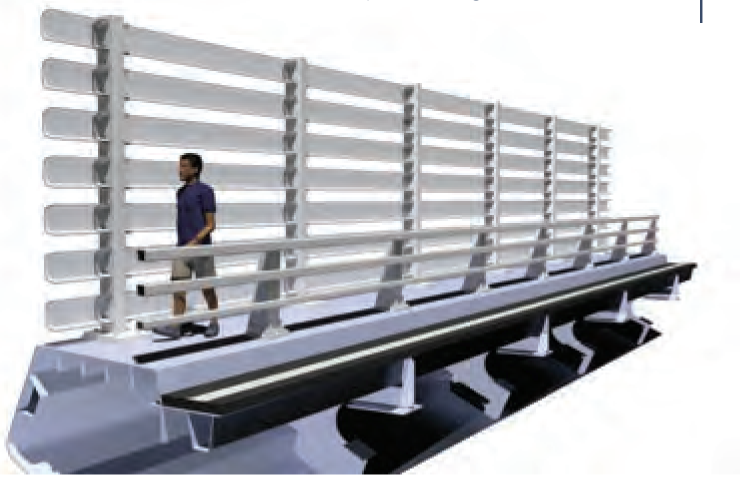
Several lighting systems are installed on the bridge:

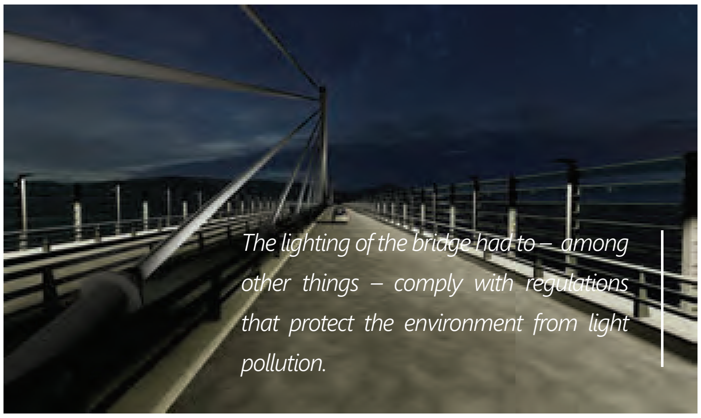
- road lighting is in the function of traffic safety
- decorative lighting was installed to emphasize the uniqueness of the bridge at night
- service lighting is placed inside all piers and boxes
- navigable channel markings are on the lower edge of the bridge in the fairway, and all piers and pylons are visibly illuminated to avoid vessel collisions
- signal lighting at the top of the pylon serves the safety of air traffic.

A special system of equipment – sensors – will be installed in the bridge, which are intended for monitoring the parameters of the bridge that are important for durability. Significant attention was paid to the issue of durability and future maintenance costs in the project, so a monitoring system was developed.

In particular, the occurrences indicating future damage to the concrete are measured, as well as the state of steel corrosion, that is, the state of protective coatings. The sensors at the measurement locations will be connected to the central computer for registration at the maintenance centre. In addition to regular inspections of the bridge, this system is expected to contribute to the prevention of major works. Nevertheless, the maintenance of the bridge is planned as a significant item of work that will take place continuously.

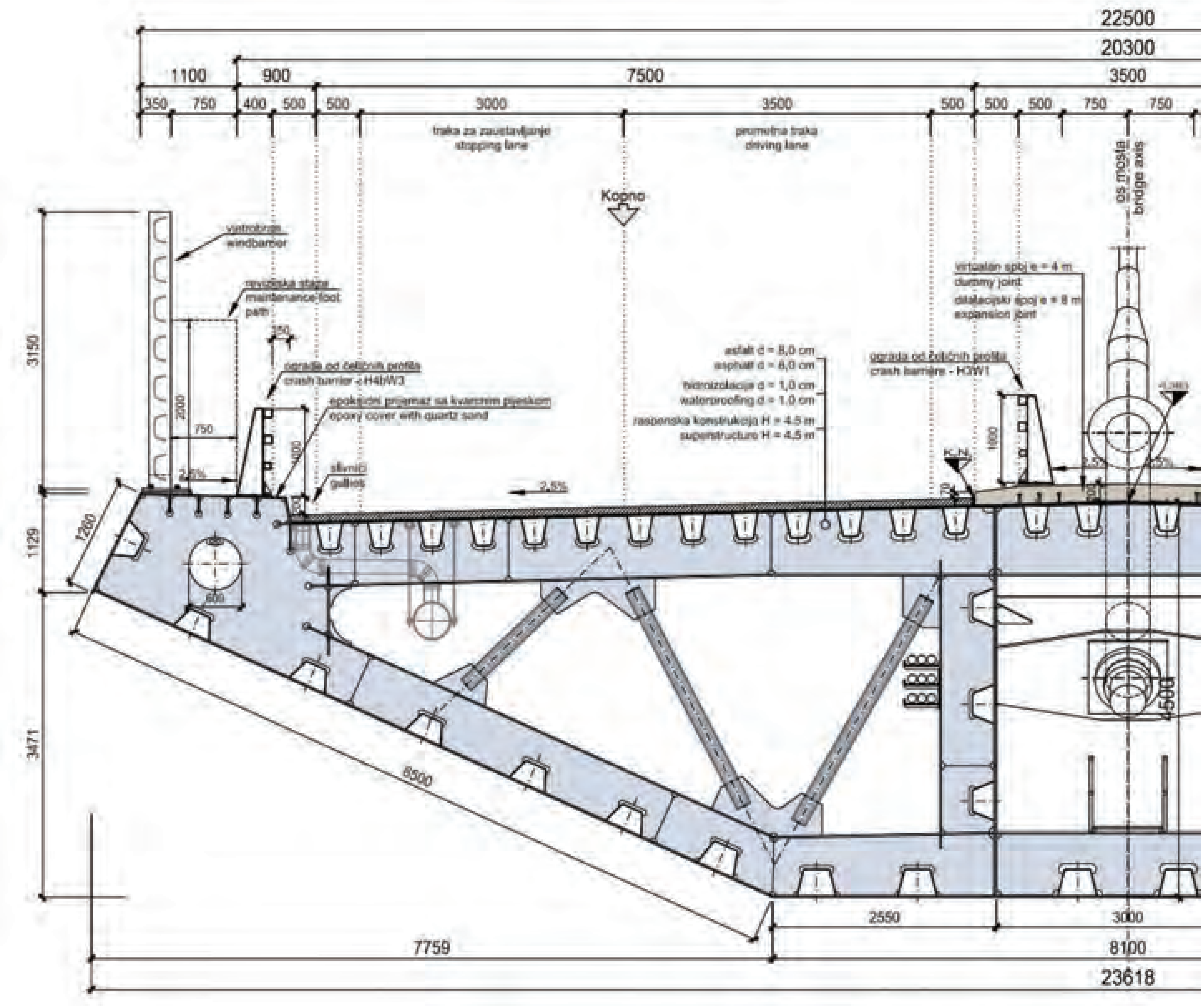
Detail of the edge part of the box span of the Pelješac Bridge with a wind protection barrier and railings – a simulation from the project. The drawing of the pedestrian is symbolic, only the official staff will be allowed to pass through the service lane.





The lighting of the bridge had to – among other things – comply with regulations that protect the environment from light pollution.

From the bridge decorative lighting project



Cross section of the suspended structure of the Pelješac Bridge with elements of equipment: wind protection barrier, safety barrier, carriageway, drainage and installation supports.

Bridge budget and model testing

As mentioned, the Pelješac Bridge contains some unusual design features, so the computational checks on the numerical models were quite particular and complex, and one test of the bridge model was conducted, in a wind tunnel.

Computer models of the bridge differ in complexity in relation to the purpose: some simulate the behaviour of the entire bridge, and some only a part of it. Thus, complete models were made for the Pelješac Bridge, then particular, precise models for some details, and simulations of the structure in the construction phases were made. Part of the computational checks was performed on two models, on different software, in order to minimize the possibility of error. Some of the models made include the soil as an element of the bridge, i.e. take into account the interaction of soil and structure, since soil deformations due to load significantly affect the distribution of internal strains in the building.

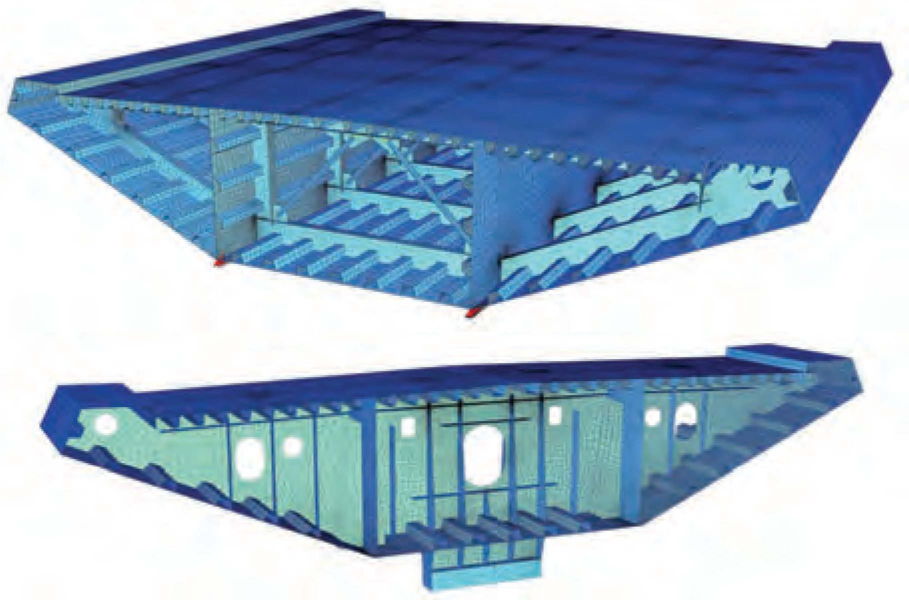
The design regulations require the designer to pre-determine the life of the structure, so the bridge is designed to last a hundred years. The estimated service life refers to non-replaceable parts of the structure, while replaceable pieces of equipment, such as fencing, lighting, carriageway structure and drainage parts, have less durability and are intended to be replaced if necessary.

Each structure budget begins with an analysis of the various actions we expect to occur over a lifetime. The actions are combined into budget situations, which simulate combinations of events that could cause the greatest forces on the bridge. For each part of the bridge, the most significant actions are determined, and then resistance is adjusted, for example, by adjusting the thickness of the steel or the amount of reinforcement in the concrete.

The visible elements of the load-bearing structure of the bridge clearly show the way vertical loads are transferred from carriageways traffic to the foundations under the sea: a strong beam is additionally supported by inclined stay cables, and the beam and cables are firmly connected by strong piers. However, in addition to vertical actions, the bridge is occasionally affected by very strong horizontal forces, predominantly earthquakes and wind, so the design includes a large number of load combinations (budget situations). The analysis of the effects on the Pelješac Bridge includes the effects of:

- own weight of the load-bearing structure
- additional permanent load (e.g. from bridge equipment)
- traffic load: the prescribed models of road vehicles were used, and it is interesting that one of the tests refers to the passage of a special vehicle weighing 300 tons
- fatigue: parts are checked for a large number of repeated loads
- braking force: an event in which a large number of vehicles cause a longitudinal force in the structure by braking
- differential displacements of the foundation: one of the calculation situations envisages the possibility of some of the pylon piers moving by 5 centimetres in relation to the others
- creeping and shrinking: the characteristic of concrete to change volume during time spent in a loaded state
- temperature changes: the structure stretches and shrinks due to temperature change, so for example, for steel, the calculation includes the situation when the bridge is cooled to -14 °C as well as when the structure is heated to +55 °C
- earthquake
- wind: for the calculation, the effect of wind that blows continuously for at least 10 minutes and occurs on average once in 50 years is observed – the maximum speed of such wind at the location of the bridge is 33.7 m/s, or about 120 km / h. However, due to the complexity of possible wind effects of different strength and direction, tests were performed in the wind tunnel.
- ship impact: the piers along the navigable profile are specially reinforced for the possibility of impact of a medium-sized ship, weighing 10.000 tons, sailing at a speed of 2.5 m/s. Larger ships will be towed through the bridge area. Other piers in the sea are resistant to the impacts of smaller vessels
- replacement of inclined cables: budget request which says that one stay cable or a pair of stay cables (symmetrical cables on both sides of the pylon) can be replaced without interrupting the traffic on the bridge
- inclined cable fracture: the possibility of abrupt fracture of one stay cable was taken into account.

Earthquake hazard is one of the circumstances that significantly affect the structural design of the bridge. In the past, the Dubrovnik coast was destroyed by strong earthquakes, the most famous of which is the one from 1667,



A fragment of a numerical model of the span structure of the Pelješac Bridge, the network represents the division into finite elements – virtual parts of the structure that serve to describe the imagined structure by equations.

which devastated the old city of Dubrovnik. Basically, in the area surrounding the bridge, within a radius of 100 km, 7 significant earthquakes of magnitude greater than 6 on the Richter scale occurred in the last century.

The main parameters that describe seismic actions at a location are two values of acceleration at ground level. The expected earthquake is described by acceleration because it causes inertial forces, which are the product of the mass of the structure and acceleration. These forces, for better understanding, are sometimes expressed as part of the structure's own weight, since the inertial forces created by the gravitational load are felt at all times and are therefore self-explanatory.

The bridge was calculated and built in such a way as to withstand the effects of a low-intensity earthquake without significant damage, that is, not to collapse in the event of a strong earthquake, but to be damaged to such an extent that repair is possible. The expected period in which a weaker earthquake is likely to occur is about 100 years, while a catastrophic earthquake is statistically expected once every 500 years. This concept is in line with European anti-seismic regulations, which also provide for a further increase in the budget in the case of buildings of special importance.

The peak load at ground level for an earthquake expected once in 500 years, expressed as part of the acceleration of gravity (g), is 0.34 g. This value, determined by a seismological study, is further multiplied by the importance factor of buildings so it is calculated at ground level in the amount of 0.54 g. It should be noted that, due to the elasticity of the structure, the earthquake forces above the ground increase significantly, so we can say that, in an extreme situation, the bridge must withstand a horizontal force greater than its own weight – the force stronger than normal vertical action.

The bridge is designed to withstand the action of high-speed wind, which can come from various directions (reference wind speed reaches 40 m/s). The wind creates pressure on the exposed surfaces of the bridge, which is taken into account in the calculation as one of the forces according to which the elements of the load-bearing structure are dimensioned. In addition to the effects that can be considered in the calculation as an additional force on the structure, the designer must take into account the dynamic effects of wind – vibrations and oscillations that can also compromise the load-bearing structure. In cases of extremely strong wind, traffic on the bridge is suspended, and in order to make such cases as rare as possible, the project envisages the protection of the road with special wind protection barriers.

The wind load on the bridge was tested using numerical models. However, due to the complexity of the phenomena that accompany the airflow (fluid mechanics), tests were made on the bridge model, in a wind tunnel. Tests in the wind tunnel also cover the stages of construction, as well as the action of wind from different directions.

These tests influenced the design of the cross-section (which resembles an airplane wing more than a classic box section) and the design of the wind protection barrier.

Basic bridge data:

Length 2,440 m
Width 23.6 m
Height 55 m
Largest height from seabed to pile top 220 m; 120 m in sea, 100 m above sea
Largest span 285 m
Sea depth under the bridge 27 m
Number of driven piles: 148
Number of piers: 12

Main material quantities:

Concrete:	68.000 m³ (C35/45, C40/50, C50/60 and C60/75 for pylons)
Steel reinforcement:	18.000 ton
Inclined stay cables:	1.100 ton
Prestressed steel:	300 ton
Construction steel:	33.600 ton (S355 / S460 – superstructure)
Construction steel:	31.200 ton (S355 – piles)

Participants in the construction of the Pelješac Bridge:

Client:	HRVATSKE CESTE d.o.o.
Designer – joint venture:	FACULTY OF CIVIL ENGINEERING – Zagreb, Croatia
	PONTING Inženirski biro d.o.o., Maribor
	PIPENBAHER INŽENIRJI d.o.o., Slovenska Bistrica
Authors of project:	Marjan PIPENBAHER, MSc. Civil Eng.
	Prof. dr. sc. Jure RADIĆ, MSc. Civil Eng
Main designer:	Marjan PIPENBAHER, MSc. Civil Eng.
Main design control:	Geodata Tunnel Ltd. and COWI A/S
Implementation design control:	RAMBOLL Denmark A/S
Contractor – consortium:	China Road and Bridge Corporation,
	CCCC Highway Consultants Co. Ltd.,
	CCCC Second Highway Engineering Co. Ltd.
	CCCC Second Harbour Engineering Co. Ltd.
Supervision:	Institut IGH d.d.
	Centar za organizaciju građenja d.o.o.
	Investinženjering d.o.o.
Client representatives:	Goran Legac, MSc. Civil Eng. Project Manager for CPJD
	Jeroslav Šegedin, MSc. Civil Eng. Client representative for Bridge Construction Contract

Administrative procedure

Location permit for bridge mainland – Pelješac with access roads	29 September 2005
I amendment	27 January 2016
II amendment	31 December 2019
III amendment	11 May 2021
IV amendment	20 May 2002

Construction permit:

Most Pelješac (part 1)

The Pelješac Bridge from km 2+120 to 4+560 – construction part	24 October 2007
I amendment the Pelješac Bridge from km 2+120 to 4+560 – construction part	21 October 2009
II amendment the Pelješac Bridge from km 2+120 to 4+560 – construction part	20 September 2017
''Bridge mainland – Pelješac with access roads on D8 and D414'', Phase 1 – the Pelješac Bridge from km 2+120 to km 4+560 – construction part Decision on error correction	12 March 2022

DESIGN AND DESIGN SUPERVISION

GORDANA HRELJA KOVAČEVIĆ, B.Sc. in Civil Engineering
NIJAZ MUJKANOVIĆ, M.Sc. in Civil Engineering

Gordana Hrelja Kovačević and Nijaz Mujkanović have been employed at the Faculty of Civil Engineering, University of Zagreb, at the Department of Bridges since the development of the first solutions of the Pelješac Bridge, on which they worked as associates, under the leadership of prof. Jure Radić and prof. Zlatko Šavor. The same team worked on the project for which permits were obtained and the construction of which began in 2007, as well as on later projects, from which the final one was selected, according to which the bridge was built. The main designer of the Pelješac Bridge, and later the Chinese contractor, recognized the qualities of a small Croatian team from the Faculty of Civil Engineering and engaged them in various roles during preparation of project documentation. Ms. Hrelja Kovačević was a design associate in the development of the main design, among other things in charge of achieving continuity of legal design procedures and obtaining the necessary approvals and permits. Together, they were engaged as consultants for the development of the implementation design and were in charge of reviewing the implementation design, as well as design supervision.

Gordana Hrelja Kovačević, B.Sc. in Civil Engineering and Nijaz Mujkanović, M.Sc. in Civil Engineering, faculty of Civil Engineering of the University in Zagreb; designers and associates in the Pelješac Bridge project .

Main design of the bridge and implementation design

The main design has its legally defined purpose in obtaining a building permit. It outlines the technical solution and provides evidence of mechanical resistance and stability. For such a complex structure, this means that it contains master plans and a large amount of very complex static and dynamic calculations. In addition to the main project, the detailed design contains a very large amount of drawings that elaborate every detail of the bridge, and the accompanying calculations serve the designers to confirm the final solutions and details of the structure. After all the interactions, we may say that the work of the Chinese colleagues is very professional and they made a very good implementation design. Parts related to steel structures were inspected in detail, and after minor additions, they were adopted for execution.

Comparison of two projects competing for the final solution

The joint performance of PCI, Ponting and the Faculty of Civil Engineering in Zagreb began with the optimization of the earlier project solution of the cable-stayed bridge with a central opening of 568.0 m. At the Faculty of Civil Engineering we developed, within the project team led by prof. Šavor, a project solution that meets the requirement of minimum construction costs. A project of a girder bridge with a central span of 256.0 meters was made, which summarized all the acquired knowledge about the location.

Under the leadership of engineer Pipenbaher, a comparative design solution was made – continuous extradosed bridge with six pylons with five central spans, each 285 m. This solution contains more freedom in terms of optimization settings (construction cost), and the applied solutions boldly balanced on the upper limit of engineering acceptability (extradosed frame span structure in the seismic area, high-strength concrete and large-diameter reinforcement).

Comparison of the realized solutions shows that the girder bridge was made according to the principles of strict engineering conditionality of the location (the girder relies on the lower structure over bearings and seismic dampers), which contains local construction tradition and construction potentials. This can be attributed primarily to the project team leader, dr. Šavor.

The project made in the project team of engineer Pipenbaher contains a greater emphasis on modern design solutions, which in terms of the definition of load-bearing structures and performance procedures reaches beyond the limit of engineering and performance optimum. This approach has achieved a superior design and functional solution of the bridge, and each new view of the built bridge provides additional evidence of compliance with the area of the indented coastline and the karst hilly surrounding mainland.

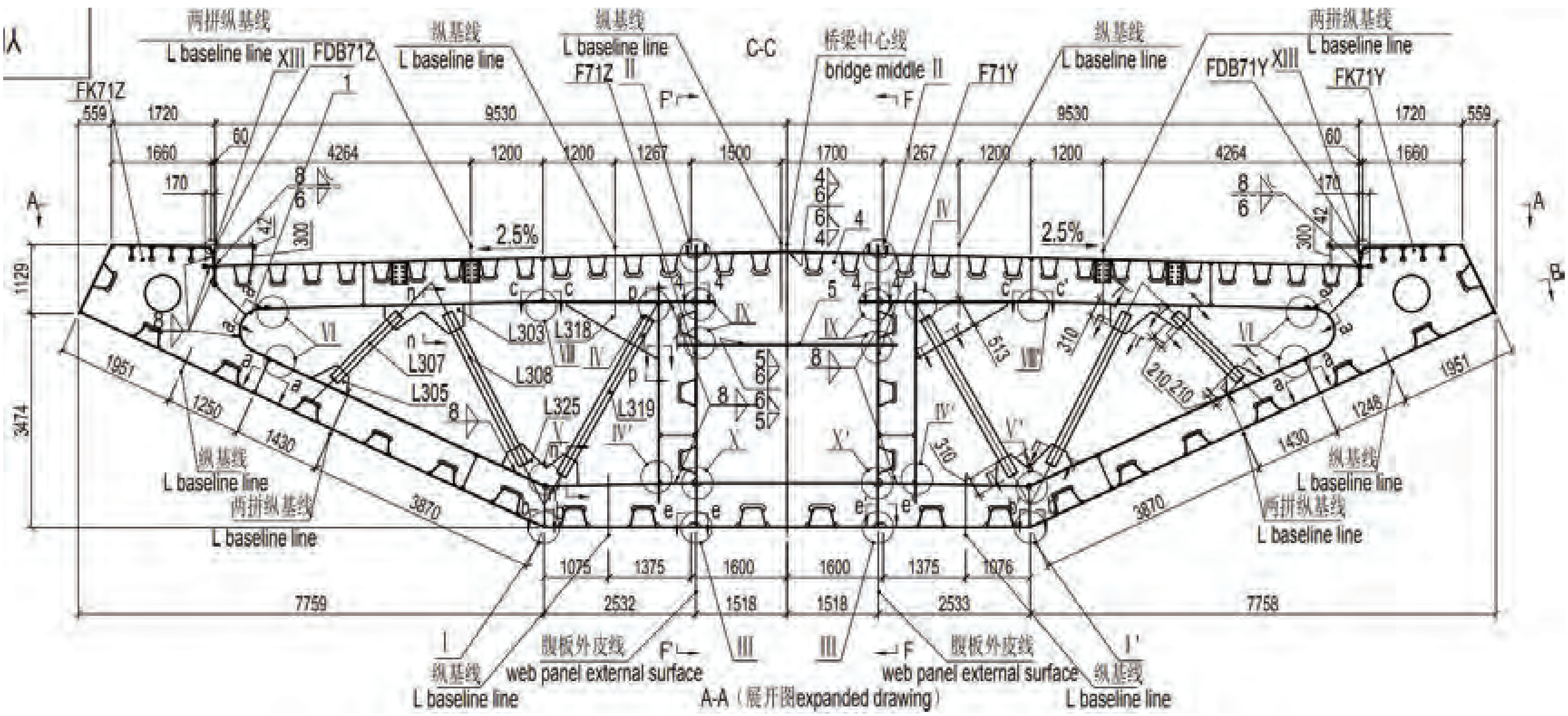
The investor adopted the solution of the Pipenbaher project team for the construction.

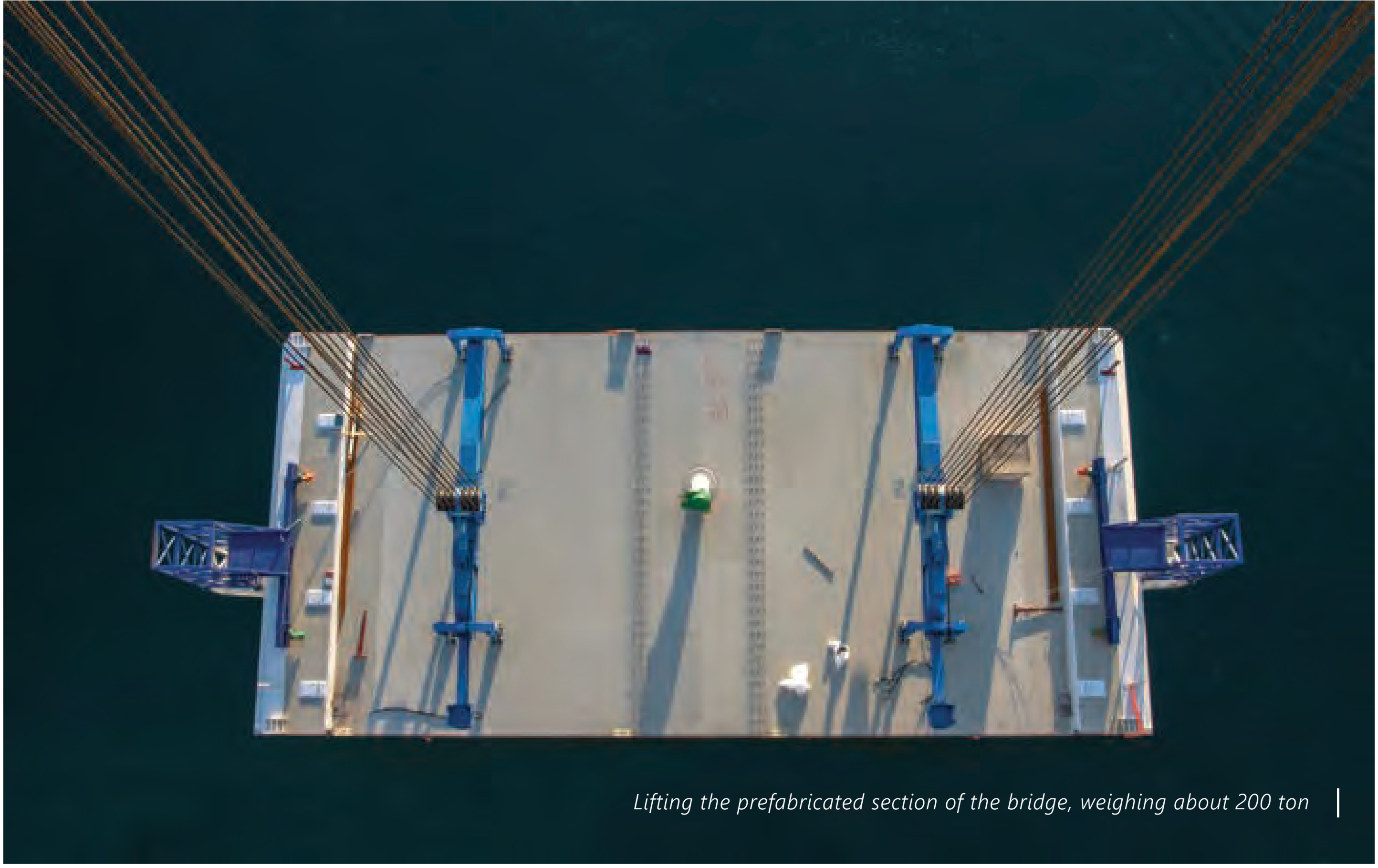
Elaboration of the steel structure draft in the implementation design

The steel structure contractor is usually in charge of making construction or workshop drawings. The development of the Pelješac Bridge steel structure began with the development of a detailed model of the bridge in the system we commonly call BIM, and in this case it means that detailed and precise three-dimensional drawings of the bridge were made. The spatial model of a steel superstructure is the basis from which segment drawings are gradually generated or extracted, then sections are taken out of them, so that the process ends in drawing individual positions. The positions are in fact pieces of sheet metal that the robot in the factory needs to cut from a steel plate of a given thickness to a certain extent, in order to be further bent and assembled by welding. Therefore, there are at least 4 levels of making draft drawings from a three-dimensional model to cutting sheets and we can say that the Chinese colleagues are very advanced in this, especially in making spatial models. The blueprints they make at first glance resemble video games graphics, but behind them lies the exact measurement and position of each point of the bridge in space. The BIM model is a completely faithful digital representation of the bridge that was materialized according to it.

However, there were difficulties that we – as can be seen in the final realization – successfully overcame. Communication between the Chinese offices of the same company was not on a high level, so we had difficulties in completing some phases of the implementation project, harmonizing the details. In particular, our requests for corrections were implemented quite slowly. Perhaps we can also attribute this to cultural differences, that is, difficulties in communication. The Chinese colleagues were very pleasant in communicating the doubts related to the project, there were no problems in

A fragment of one of the hundreds of drawings developed in the detailed design of the Pelješac Bridge.





Lifting the prefabricated section of the bridge, weighing about 200 ton

reaching an agreement, but a problem would arise when some agreement or even our order should be implemented: colleagues would simply continue to work on their own. Some things had to be repeated three or four times to be finally executed. In this regard, we had the support of the main designer, engineer Pipenbaher, who did not give in but demanded that every detail be done in an approved manner.

Design supervision

Design supervision actually means clarifying the project where the contractor has certain doubts or the supervisory service has noticed a problem. We also worked on coordinating specialist projects, for example, a cathodic protection project with a construction project. Some of the designer's ideas needed to be further interpreted during construction, including additional blueprints or additional budget. We reviewed all the plans and calculations of the implementation phases, with the provision that we changed something, that is, gave some solutions that are in line with applicable standards. For example, these are cross-section reinforcement solutions at the point where the segment accepts the crane during manipulation.

The most complex part of the bridge

The joint of the superstructure and the pylon, that is, the connection between the concrete and steel structure is certainly the most complex detail on the bridge in terms of shape, design and execution. In the design phase, this solution was criticized due to the complexity of the design, however, all these joints were made according to the project, without major difficulties. With such a solution, the designer achieved an efficient connection of the pylon and the superstructure in a frame with rigid joints but with relatively flexible elements, so he achieved an integral structure by combining two materials. It should also be said that fixed joints of steel and concrete beams in bridge construction are not an innovation, some bridges are made in such a way. When we say that there are no special innovations in the concept of details and joints in the construction of the Pelješac Bridge, it should be understood in a positive sense, because experimenting on a building of this size and importance would be inappropriate. Not a single detail on the bridge is unknown, it is about the joints and construction elements that we teach here, at the Faculty of Civil Engineering, University of Zagreb. Their sizing, connecting and shaping as a whole is what gives the Pelješac Bridge originality in relation to other crossings of similar obstacles.

Integral bridges

All conceptual designs of our team envisaged the installation of bearings between the superstructure and the piers, and in the end an integral structure was built. Integral bridges have the characteristic that their superstructure is rigidly connected to the supports. This significantly reduces the displacements at the ends of the structure, which are mainly due to thermal stretching, but increases the forces in the bridge elements. Our experience says that all bridges shorter than 80 meters should be designed as integral. The savings on bearings are not so important, but the benefits resulting from simpler maintenance. Interruptions in bridge constructions are always weak points, so we believe that the takeover of greater forces (those arising from prevented displacements) is justified by maintenance savings. On the Pelješac Bridge, the integral unit consists of 6 central pylons with a structure between and adjacent spans, so we have a beam 1800 meters long, which became a frame by connecting with the pylon piers. Such a large integral structure, which also contains inclined stay cables, is unique. However, when it comes to preventing displacements from heating and cooling the structure, it should be borne in mind that the pylons, strange as it may seem, are actually flexible, so the horizontally fixed point is about 50 meters below the carriageway structure. We can estimate that any displacements that would result from stretching and shrinking the beam to half a meter in size are actually completely acceptable in this bridge.

In other words, the slender piers allow the displacements that will occur due to the change in temperature and the designer took care of all this, finding very elegant solutions.

Another issue related to the integral structure of large bridges relates to earthquake behaviour. The bridges in earthquake zones in the USA are designed and built with a large number of bearings and dampers, while in European practice in countries with pronounced seismicity we find both solutions, a bearing system with bearings and dampers and a system containing fixed connections.

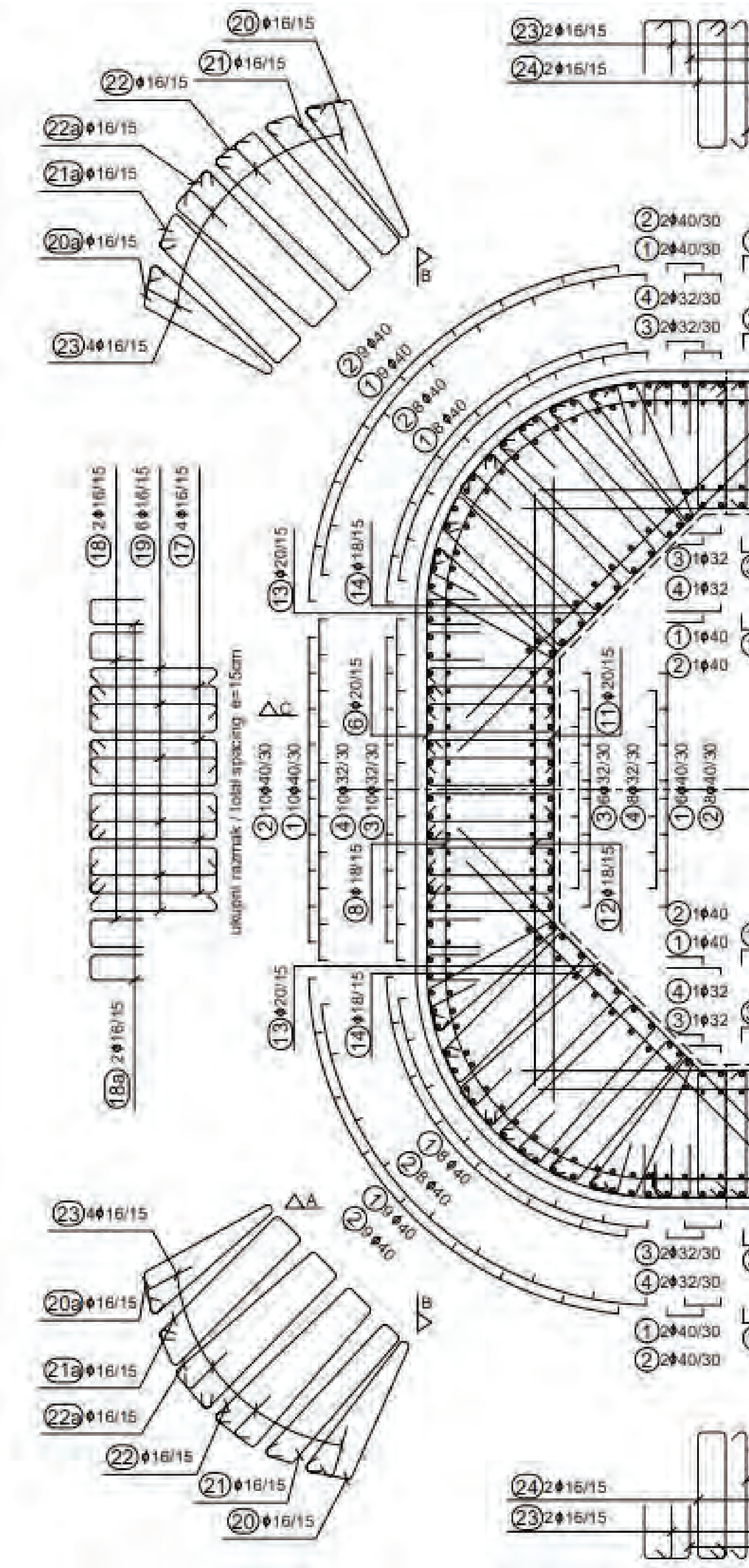
If the designer measures the dimensions of the supports correctly, that is, if they realistically estimate the distribution of forces in the event of an earthquake, both solutions are good. However, we can emphasize that the bridge without a bearing looks more elegant, and it is expected to be easier to maintain.

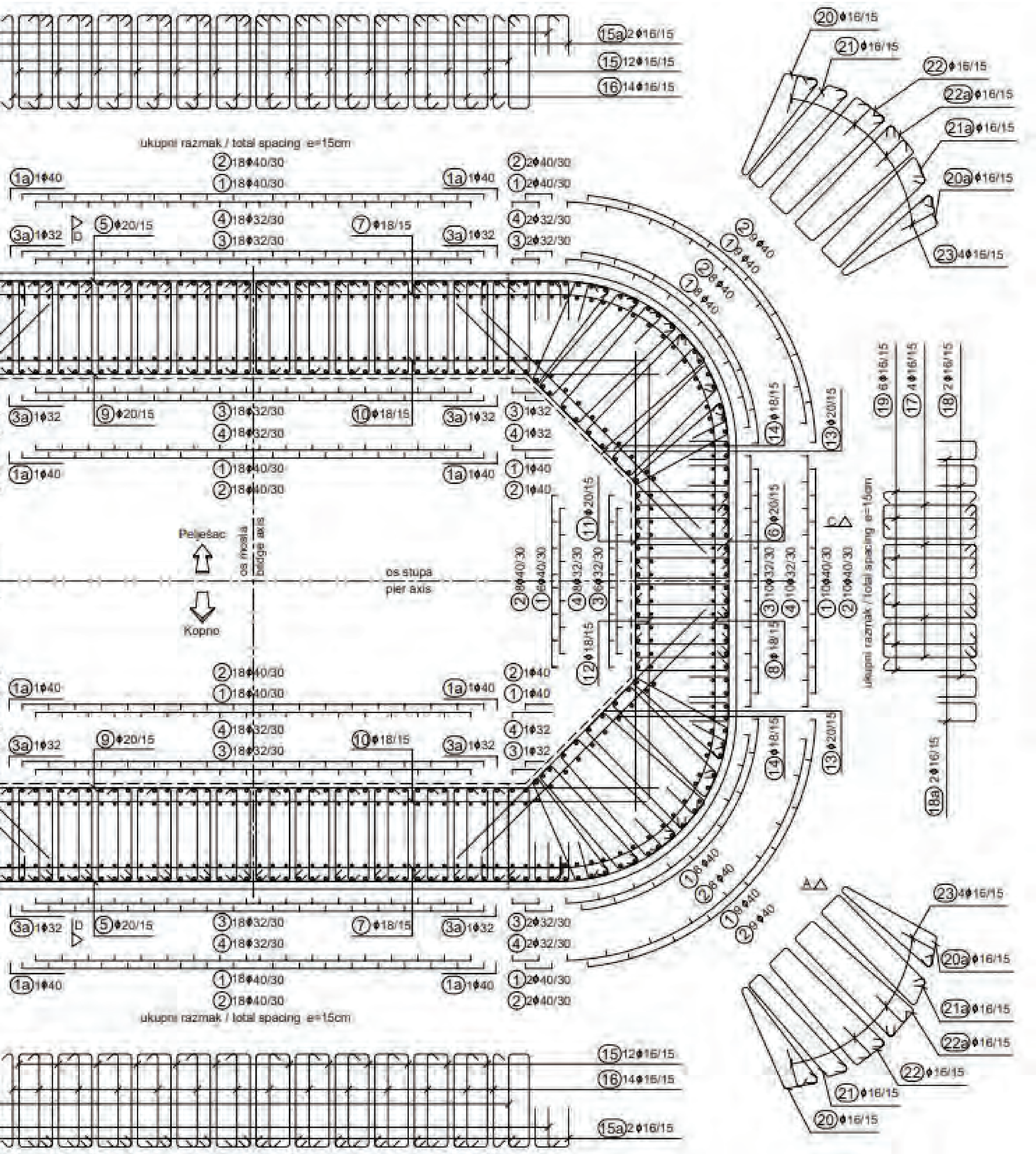
Reinforcement of concrete elements

The details of the reinforcement on the Pelješac Bridge are different from what is usually seen in the formwork of concrete elements of our bridges. The reinforcement of the pile caps, piers and pylons is denser than on any bridge we have worked on so far. In addition, rods of large diameters, 40 mm and more, were used. Continuing the reinforcement by overlapping in such conditions is questionable, so the contractor used patented extensions. A layer of stainless steel mesh reinforcement is also installed in the thick protective layers. We were lucky with the Chinese reinforcement workers, they were very tidy, which is important since it was difficult to place such amounts of reinforcement into relatively thin cross-sections.

Croatian team for large bridge projects

In Croatia, there is certainly a group of engineers who have the knowledge, experience and technical prerequisites for the design of a large bridge with advanced concept. However, for the creation of a serious bridge project, a team of about ten people who work together continuously is needed, and for now, we do not have such a team dedicated exclusively to bridges. On the other hand, engineer Pipenbaher has created a significant team that designs bridges exclusively. Specialization, experience in working on large projects, working with specialist tools, with a leader who has a respectable international reputation makes them competitive in third markets. We would like such a team to be formed in Croatia one day. At the time of the extensive motorway construction, there were several teams designing bridges, some bridge projects for foreign clients were realized, for example in Bosnia and Herzegovina and Kosovo, but with the decline in domestic orders, the teams scattered and some colleagues began to engage in the design of other structures. A bridge like Pelješac cannot be designed by someone who is not deeply committed to the science, the craft and even the art of designing bridges.





A detail of the reinforcement design of the pier reveals a very dense reinforcement

Reinforcement cage on the pier before concrete works

A thousand-ton crane, hired for the construction of the Pelješko bridge.

Marica Cikoja-Ratkovski, civil engineer and employee of Hrvatske ceste, with twenty years of experience in public procurement in the field of construction, led a team that conducted a long and complex public procurement procedure for works and expert supervision of the construction of the Pelješac Bridge, as well as public procurement procedures for the remaining elements of the CPJD Project. The so-called two-stage procurement procedure for the construction of a bridge worth over two billion kuna lasted for two years, with a number of difficulties and delays common to the fact that the current regulations do not recognize the specifics of procurement of large infrastructure projects in relation to procurement of conventional works and services.

3.4

PUBLIC PROCUREMENT AND CONTRACTING

Launching the procurement procedure

Hrvatske ceste formally began the public procurement procedure for the selection of contractors for the construction of the Pelješac Bridge with the publication of invitations to interested economic operators in the electronic Public Procurement Classifieds of the Republic of Croatia and in the Official Journal of the European Union on June 21, 2016. However, the extensive preparations for the procedure began much earlier.

Hrvatske ceste is one of the largest contracting authorities in the Republic of Croatia, but the experience of previous procurements of great value was not enough to prepare all aspects of the selection of contractors for such a complex building. The aim was to select a contractor who will have the necessary capacity and knowledge to perform very complex specialist works within the deadlines set and determined by the Operational Plan for absorption of funds. Tender documentation was prepared at Hrvatske ceste with the support of the interdepartmental working group established for the implementation of this strategic project and in consultation with external experts for certain areas (Croatian Chamber of Civil Engineers, State Geodetic Administration, Directorate for Public Procurement). Tender documentation passed additional control of the competent authority prior to publishing (Intermediate Body, that is the Ministry of the Sea, Transport and Infrastructure) and was complied with the recommendations.

Two-stage procedure

For the implementation of this procurement, a limited public procurement procedure was selected, which is carried out in two stages. It is especially important to mention the complexity of the moment in which the procedure was initiated, because the Public Procurement Act was in force (OG 90/11, 83/13, 143/13, 13/14 Decision of the Constitutional Court) with the mandatory application of the provisions of Directive 2014/24/ EU of the European Parliament and of the Council of 26 February 2014 on public procurement, the implementation of which into the new Public Procurement Act was only in the consultation phase. All those who were engaged in public procurement in the Republic of Croatia at that time know how challenging it was for the contracting authority to initiate such a complex public procurement procedure in such a legal framework, because at that moment there was no relevant experience of any contracting authority nor any legal practice of competent bodies in implementation.

During the first stage of the restricted procurement procedure, the contracting authority amended the originally required eligibility conditions to allow for the widest possible competition as follows:

a) the period of acceptance of references (a condition that states how old acceptable references can be) was increased from 15 to 20 years,

b) one expert with experience in the construction of suspension bridges, experience of deep-water foundation on steel piles and experience of contractor representatives in managing the contract according to the rules of the FIDIC contract was originally required. The condition was changed in such a way that instead of one person, the condition could be proven by several experts, a maximum of three.

The long periods between individual steps of the public procurement procedure were in fact filled with significant activities by both the investor and economic operators, as can be seen from the numerous requests for additional clarifications, mainly from foreign economic operators. Regardless of the fact that the procedure and documentation were, in the described circumstances, well prepared, in the implementation of the first stage of the procedure, 3 appeals were filed against the tender documentation. The level of expertise of the tender documentation is confirmed by the fact that two appeals were rejected in their entirety, and in the case of the third appeal, out of ten appellate allegations, only one allegation was assessed as well founded. The duration of the appeal proceedings resulted in the 98-day long suspension of the procurement procedure.

First stage of the procedure

'''Day D1'' - deadline for submission, 12 requests for participation:

1. Consortium: Bechtel International Inc., US and ENKA Insat ve Sanayi A.S., Türkiye
2. Consortium: Astaldi S.p.A. and IC ICTAS INSAAT SANAYI VE TICARET A.S., Türkiye;
3. Consortium: Bouygues Travaux Publics S.A.S., France and Viadukt d.d., Republic of Croatia;
4. Consortium from China: China Road and Bridge Corporation; CCCC Highway Consultants Co. Ltd.; CCCC Second Highway Engineering Co. Ltd. and CCCC Second Harbour Engineering Co. Ltd.;
5. Consortium: TEIXEIRA DUARTE-ENGENHARIA E CONSTRUCOES, S.A., Portugal; TOTO S.p.a., Cooperativa Muratori&Cementisti-C.M.C. di Ravenna Societa Cooperativa, Italy; J&P-AVAX S.A., Greece
6. STRABAG AG, Austria;
7. Consortium: Sinohydro Co. Ltd., China and SRBG Sichuan Road and Bridges (Group) Corporation Ltd., China
8. Consortium: AKTOR SA, 25, Greece; Rizani de Eccher S.p.A., Italy and Daewoo E&C, South Korea;
9. Consortium: EIFFAGE GENIE CIVIL, France and STFA INŞAAT A. Ş., Türkiye;
10. Consortium: CIMOLAI S.p.A., Italy and SAIPEM Limited, Great Britain;
11. Consortium: COMSA S.A., Spain, ACCIONA INFRAESTRUCTURAS S.A., Spain and GS ENGINEERING&CONSTRUCTION CORP, South Korea;
12. Consortium: OBRASCON HUARTE LAIN S.A., Spain, SK Engineering&Construction Co.Ltd., South Korea and IHI Infrastructure Systems Co.Ltd., Osaka, Japan.

According to the number of received requests for participation, it is evident that the contracting authority has ensured fair competition in the conditions prescribed in the public procurement procedure, even in the case of such a complex subject of procurement.

In the continuation of the procedure, it was necessary to review, clarify and complete in detail all twelve requests, which is approximately forty files of documents, originals and translations from various languages. A particular challenge was the control of documents submitted for the purpose of proving the right to perform the activities of individual economic operators, verifying criminal record for economic operators and responsible natural persons, the absence of tax debt, all within the legal regulations of the country of business establishment.

Figuratively speaking, it was necessary to determine the manner of proving a clean criminal record for legal and natural persons and the absence of tax debt in Osaka in Japan, Seoul in South Korea, Dongcheng District in China and other countries from which competitors come, and to determine relevant data on eligibility conditions and their records. The client had to seek help from the Croatian embassies and diplomatic missions of foreign countries in the Republic of Croatia.

During the arduous review and evaluation of the requests for participation, we learned how many impressive bridges have been built for example on the Bosphorus, in France or in China, wind farms in the cold North Sea and other buildings around the world.

During the review and evaluation of the requests for participation, it was often the case that foreign competitors did not understand our requests for clarifications and/or completion of documentation, getting angry with "excessive bureaucracy and pettiness", not knowing that every wrong word, expression in a foreign language, an insufficiently precise reference, may be the reason for their rejection. Out of the twelve requests for participation received, eight were assessed as valid, and the conditions for the start of the second stage of the procurement procedure were made.

Second stage

On May 31, 2017, the candidates who submitted valid requests were sent an Invitation to submit the tender with the accompanying documentation, and the remaining candidates were sent the Decision on inadmissibility of participation.

During the second stage of the public procurement procedure, a Grant Agreement was concluded for the Road Connection to South Dalmatia project, which enabled the project financing. Furthermore, the contracting authority increased the amount of advance that the contractor will receive from 10% to 15% of the contracted amount. This was done in the expectation that a larger advance would reduce the financial risks to the contractor, which should have the effect of reducing the bid price.

The scoring criteria have also been changed, that is, the prescribed duration of the warranty for the elimination of defects within the warranty period has been reduced from 20 years to 10 years. This amendment sought to reduce the bid price, in order to avoid increasing the risk in relation to the quality of work performed because the main project strictly prescribes the minimum quality requirements for the construction of the bridge from which cannot be deviated. Also, efforts were made to enable wider market competition with the aim of obtaining a quality and experienced contractor and a realistic price for the works.

By "Day D2" - the deadline for submission of tenders, September 15, 2017, three tenders were received, reviewed, and evaluated in accordance with the selection criteria as follows:

- Consortium: Astaldi S.p.A. and IC ICTAS INSAAT SANAYI VE TICARET A.S., Türkiye; with tender price of HRK 2.551.512.924,09 (VAT excluded) and which was rejected because the Consortium failed to submit a guarantee in line with the Tender Documentation.

- STRABAG AG, Austria, with a tender price of HRK 2.622.856.184,45 (VAT excluded), with deadline of 42 months and a duration of warranty of 120 months – the tender got 84.84 points.

- Consortium China Road and Bridge Corporation; CCCC Highway Consultants Co. Ltd.; CCCC Second Highway Engineering Co. Ltd. and CCCC Second Harbour Engineering Co. Ltd with a tender price of HRK 2.081.608.270,72 (no VAT), with deadline of 36 months and a duration of warranty of 120 months, which gave it a maximum of 100.00 points and was evaluated as the most economically advantageous tender according to the bid selection criteria.

Both candidates whose tenders were not selected appealed against the Selection Decision, but they were rejected as unfounded by the decision of the State Commission for the Control of Public Procurement Procedures, which made the Selection Decision enforceable. The contract for the construction of the mainland – Pelješac Bridge with access roads was signed on April 23, 2018.

Completion of the procedure

The execution of the Procurement Decision completed the procurement procedure for the construction of the mainland – Pelješac Bridge with access roads, which was only the first phase of the Road Connection to South Dalmatia project, but also an invaluable experience for all those who participated in its implementation.

The valuable knowledge gained through the implementation of this "procedure of all procedures" was used in subsequent procurement of works and services in other projects of Hrvatske ceste, and was useful to other contracting authorities with whom we shared it.

Professor Vladimir Skendrović, Ph.D.Sc. started his career as a chief engineer on the construction sites of our first motorway. He was an organizer and supervisor of works abroad, a scientist, and then a technical advisor on the most complex issues of construction projects, working for global financial institutions. He worked as a professor at the faculties of civil engineering at the Universities of Zagreb and Osijek, with advisory engagements in which he managed to raise business processes related to the construction and maintenance of roads to a higher level. He has worked on construction-related projects in more than 20 countries around the world. As an investor advisor, he made a significant contribution to contracting and setting up a management system for the Pelješac Bridge construction project.

CONTRACT FOR BRIDGE CONSTRUCTION WORKS

After the main design of the bridge was prepared, the documentation on the procurement of works was made, including the proposal of the construction contract and the documentation on the procurement of expert supervision with the proposal of the appropriate contract. Both of these contracts have their own features due to the technical solution, size and characteristics of the structure, the method of financing and the applied contract models.

The construction contract was prepared under the name "Contract for the construction of the mainland – Pelješac Bridge with access roads" and it was concluded with a consortium of Chinese companies in 2018. Since the construction was co-financed by EU funds, the construction contract was to be based on one of FIDIC's models of the Terms of Contract *(Fédération Internationale des Ingénieurs-Conseils, International Federation of Consulting Engineers)* and had to be prepared in Croatian.

Due to the characteristics of the technical solution and the complexity of the bridge construction, which primarily refers to a large amount of steel, then driven steel piles of exceptional length, and high reinforced concrete pylons, it was certain that the contractor will work on construction projects in accordance with its technology and organization. This applies in particular to the workshop drawings of the steel structure elements and steel piles, the conditions of land and sea transport, and the assembly or installation of steel span structure and piles.

Given the need for such a significant scope of design by the contractor, the question arose as to which FIDIC model contract for the construction works would be appropriate. The FIDIC *Conditions of Contract for Building and Engineering Works designed by the Employer, known as the "Red Book" and the Conditions of Subcontract for Plant and Design,* first edition 1999, known as the "Yellow Book". After a detailed discussion of the advantages and disadvantages of these models, the construction contract was prepared according to the "Red Book", using the Croatian translation of this model published by the Croatian Chamber of Civil Engineers.

The "*Red Book*" is regularly used and is primarily intended for works according to the client's projects, but its application is not excluded for contracts under which the contractor undertakes a part of the design obligation in addition to the construction. Thus, in the General Terms and Conditions of the Contract, the first sentence of the first paragraph of Article 4.1 [Contractor's General Obligations] states: "*The Contractor shall design (to the extent specified in the Contract), execute and complete the Works in accordance with the Contract ...*". However, nowhere in the remaining articles of the General Terms and Conditions is there any mention of design. Consequently, specific provisions had to be added to the Special Terms and Conditions which detail the obligations and responsibilities of the Contractor in preparing and approving construction projects, which is one of the features of this construction contract. Additionally, as is the case with any application of FIDIC's contract models in our practice, the Special Terms and Conditions contain many provisions that supplement, delete or amend the General Terms and Conditions in order to comply with our Civil Obligations Act, Construction Act and other relevant regulations, in particular as regards quality assurance, and in order to adapt to the specifics of the building.

The construction contract stipulates, among other things, the obligation of the contractor to procure appropriate software and tools and to develop, install, maintain and use Building Information Modelling (BIM – digital representation of the building) for the purpose of planning, construction and subsequent maintenance of the bridge. This is the first case in our practice that BIM has been applied to the construction of a large infrastructure building.

The contract on expert supervision was prepared under the title "*Supervision over the construction of the bridge mainland – Pelješac with access roads*" and, after the competition conducted in 2018, contract was concluded with a consortium of Croatian companies: Institut IGH d.d., Centar za organizaciju građenja d.o.o. and Investinženjering d.o.o. Since the construction contract is based on FIDIC's contract terms, this contract had to regulate not only the expert supervision services but all the services of engineers, so for the sake of precision the subtitle "*Contract for Engineers' Services*" was added to the contract name.

In 2006, FIDIC published the 4th edition of the *Client/ Consultant Model Services Agreement*, known as the "*White Book*". The book was translated into Croatian and could be used as a basis for a contract for the services of Engineers on the construction of the Pelješac Bridge. However, since this model of contract was not well accepted in international practice, and was rarely applied in our country, it was decided that it would not be used.

Due to the extreme complexity of the technical solution and construction of the bridge, one of the characteristics of this contract is that the consulting company providing services of Engineers must provide and employ as many as 12 specialized certified supervising engineers, which is a unique case in the construction of our infrastructure buildings.

In the first (unsuccessful) attempt to build the Pelješac Bridge, the contractors (in the form of a consortium) were at that time the most experienced and largest Croatian construction companies in the field of civil engineering: Hidroelektra-Niskogradnja d.d., Viadukt d.d. and Konstruktor-Inženjering d.d. All these companies later went bankrupt, so it could be expected that only foreign contractors would apply for the new tender for the construction of the bridge. Therefore, it was highly probable that the contractor would make the steel elements of the bridge abroad, so the contract on the services of Engineers regulates the supervision of the production of steel elements outside the borders of the Republic of Croatia. This supervision has also been successfully carried out in China under restrictive conditions due to the COVID-19 pandemic.

Signing of the contract for construction and supervision of works on the Pelješac Bridge on April 25, 2018
From left to right: Zhang Xiaojuan, CRBC Representative, Minister of the Sea, Transport and Infrastructure Oleg Butković, in the Government of the Republic of Croatia, Prime Minister Andrej Plenković, President of Hrvatske ceste Josip Škorić and President of the IGH Institute Oliver Kumrić

Installation of the first derrick cranes.

4.

CONSTRUCTION OF THE BRIDGE

Goran Legac B.Sc. in Civil Engineering, Hrvatske ceste d.o.o.; Project Manager of the Road Connection to South Dalmatia Project

4.1.

PROJECT MANAGEMENT

GORAN LEGAC B.Sc. in Civil Engineering.
Project management

Connection

The Road Connection to South Dalmatia project is one of the most important infrastructure projects in Croatia, a project that primarily connected people, and then separated parts of the state territory. After several attempts, the bridge between the mainland and the Pelješac peninsula was finally realized, with the involvement of a significant number of companies and a large number of people who came from all over the world. It was while working with them that we realized how important it is for us, the citizens of Croatia, to be connected and united when it comes to national interests.

I am proud that we have realized both the bridge and the access roads, that we are handing them over for use and that we have contributed to a more effective interconnection.

Role of the Project Manager

The Project Manager is responsible for achieving the specified project objectives within the set deadlines and within the accepted budget through coordination of a number of individual activities and control of the work of the project participants. To put it simply, the work may seem simple: you need to achieve what is defined by the project and stipulated by the contract documents within the set deadlines. However, in practice it is never that easy since each project is quite unique and always implemented in a new environment.

First of all, demanding documentation needs to be prepared, which results in concluded contracts through the public procurement procedure: design, supervision, construction and various specialist services. The concluded contract becomes a legal framework for open dialogue between the two parties in which through active work you must achieve the readiness of the other party to achieve its goals through understanding, establishing a control system, but also through creating an atmosphere of trust. At the beginning of the implementation, the contracting parties have different objectives in many points, sometimes even contradictory, but through continuous communication an agreement should be reached and, eventually, both parties should be pleased.

Roughly speaking, the contractor has receivables, usually aiming to reach the largest and fastest possible financial realization, time extension or technology replacement in order to do something faster and easier. On the other hand, the investor's representative is trying to complete the order to do something faster and easier. On the other hand, the investor's representative is trying to complete the construction successfully, with quality and on time. In order to be successful in this, they must be experienced and anticipate the moves of the other party and act in a way to remain focused on the project implementation: deadlines, quality and price.

A successful project manager must, in addition to extensive life and professional experience, have a range of competencies, be familiar with the legal framework and business processes as well as have undeniable technical knowledge of the project subject. It may seem that the project, the contract and the regulations in general form a system from which the solutions of all disputable situations on the project can be read, but this is often not the case. Most challenges arise and are addressed beyond what is prescribed. Here I would like to emphasize teamwork: in order for a project manager to remain focused on achieving goals, they must be able to quickly get to the heart of the problem so as to solve it as soon as possible, and must have competent and reliable associates. The project manager plans and sets goals and delegates individual tasks to the project team, which, on the other hand, solves individual daily project challenges through team activities.

The roles of project manager and construction manager are often confused. The project manager must, in addition to the project implementation on the construction site, take care of all stakeholders and the project environment in which the project is prepared and takes place. This includes a range of activities on project budget preparation, study and project documentation, procurement documentation, analysis and decision-making.

Project management cannot be identified only with one person or the project manager. In the preparatory phase, the project team includes a large number of experts of various professions and profiles. As the project moves from the preparation phase to the implementation phase, the number of in-house experts is declining in favour of experts that are more external.

However, challenges do not stop here. Through coordination of a large number of experts, we need to constantly monitor and take care of the execution of contracts, all with the aim to complete and deliver the entire project. There is a significant amount of time spent on communication with management to make decisions, public authorities in obtaining permits, as well as audit bodies in submitting evidence while justifying the costs incurred.

It can be concluded that the implementation of large infrastructure projects is technically extremely complex, the preparation is time-consuming and very expensive, and the implementation is very intensive with a significant number of activities taking place simultaneously. Taken together, this requires full commitment of both the project manager and the project team to ensure that the project is implemented and delivered to the users.

Preparation

Project preparation is time consuming and full of uncertainty, and the work of the project team and project manager is of the utmost importance at this stage. One of the most important elements of project preparation is risk analysis. Before starting work on the project, our team defined all potential risks that could slow us down or hinder us - the probable ones as well as the less probable ones. We included the expected risks in the analysis, but we could not predict the pandemic and the consequent market closure. This has not happened since the First World War. I mean, no matter how much you prepare using all your knowledge and theory and computer models, you cannot be prepared for circumstances that can affect a complex and time-consuming construction venture.

The project implementation maturity increases through procedures of financing approval, and then through environmental impact assessment and obtaining documents required for construction, all the way to preparation, procurement and conclusion of individual contracts. In the preparation phase, the project is determined in detail through specification of technical requirements, to which tenderers must respond through procurement procedures.

Project implementation - start of works

The works started in 2018, and the full intensity of the construction site was established in 2019, a year that promised very optimistic perspective, marked by records in tourism, which flourished, among other things, thanks to previously implemented infrastructure projects. Modern tourism is characterised by the mobility of guests, and this requires motorways and airports, projects in the implementation of which I myself have previously participated. Funding was provided, we had the support of all state institutions, the contractor was competent to intervene, we established supervisory and control mechanisms, so it seemed that nothing stood in our way. Then came 2020, when the difficulties caused by the pandemic overshadowed the project development. Work on the construction of parts of the structure in China was temporarily suspended from February to May. The successful resumption of work followed immediately after the abolition of hard closure measures, the so-called lock-down, because there was a strong will of all stakeholders to move forward despite logistical difficulties and subsequent price increase.

A complex project

The Road Connction to South Dalmatia Project is a very complex project in terms of the number of stakeholders, the price, the work invested and the special achievements, and in terms of somethings that we did for the first time. This kind of project implies a wide range of very specialist knowledge and skills, as well as experience in leading technological construction processes. Along with the investor staff and the supervisory service, we were lucky that the construction was supervised by the designer, Mr Marjan Pipenbaher, who has vast experience in design and design supervision. By this I mean situations in which certain risks are anticipated in advance and prevented from occurring. Without his commitment to work on this project, the bridge would have been much more difficult to realize.

Unique works

During the project implementation, we came across works that have never been performed in our country before. For example, concrete installed in the bridge, in huge quantities, has properties that have never before been realized in the Croatian construction practice. Prior to this project, the concrete required by technical specifications for the bridge was made only in laboratories, in experimental quantities, and this is just one of the special segments that make the bridge exceptional. There are the longest piles ever driven in one piece, 150 piles in total, balanced cantilever assembly with 6 pylons at once, segments weighing 800 tons installed at once and also other complex works that needed to be performed, controlled and documented.

Relationship with the Chinese contractor

For a project like this, it is important that the contractor has the capacity to implement it. During my professional career, I have had experience with contractors who got stuck in business difficulties or did not have the right resources to carry out certain works. All this is strongly reflected on the construction site. The Chinese contractors were highly resourced and motivated, but that does not mean they didn't have to be directed.

At the beginning of the implementation of a large project, there is always a certain reserve, the possibility of withdrawal or contract termination in case the risks for the contractor are too high. After that, there is a turning point, when the contractor enters the project to such an extent that it is no longer worth giving up. I would say that at that moment, the partnership of all stakeholders on the construction site strengthens.

The first turning point in the construction of the Pelješac Bridge, from my perspective, was the moment when pile installation was completed, and the second moment was the first delivery of the steel span structure to the construction site. After that there was no going back, I knew that together we would bring the project to an end. However, there were still occasional crises in the relationships, partly due to external circumstances and partly due to differences in business culture. In such moments it was important to understand the context, the circumstances in which the contractor operates and then in some way help them to overcome difficulties.

Sometimes our communication was unconventional and less formal, sometimes we needed to tighten the relationships deliberately in order to keep focus on achieving the end goal. Towards the end of the project, it was necessary to ensure the elimination of minor but numerous deficiencies on the bridge and at the same time resolve all contractors' requests for additional works and costs. And it was all done fairly, but I cannot say it was easy.

Dealing with conflict

Conflict situations often occur during the project implementation, particularly at the construction site. They are inevitable but should not be seen as a negative phenomenon. I would say that in some situations people have to get out of the comfort zone in order for business operations to commence properly. In other words, conflict resolution often encourages people to get more involved and solve problems. When resolving disputes and conflicts, I am primarily guided by the provisions of the contract, but I always try to understand the partner and their difficulties, I try to help to the extent that such action does not jeopardize the interest of the company - the investor. If we have deepened mutual trust and partnership in finding a solution, then it pays off to compromise, as a new day brings a new problem.

Construction site meeting

Particularities in project management

Some of the methods and procedures of project management that we applied to the construction of the Pelješac Bridge have not been used before in infrastructure project management in Croatia. On this project, for the first time, we significantly used BIM modelling, for the first time we did the planning according to the methodology used by large foreign corporations.

However, it is important to mention a process common to the implementation of both large and small projects - building relationships between people. Relationships are a bit easier to build in circumstances where you work with well-known domestic teams, with people and business practice you are familiar with. Still, in the time before the construction began, there were major disruptions in our market, there was a collapse of large companies that could take over the construction of larger units of this project, and large international corporations came to scene, some of which started production for the first time in Croatia with the intention to carry out complex works and deliver the structure to the investor within the contractual deadlines. Therefore, the special feature of the project is that we worked with new partners, who came from other architectural but more importantly also different civilizational cultures.

Dynamics of realization and deadlines

At the beginning of the bridge construction, there was a lot of doubt about whether it would be built according to the given dynamics, perhaps due to the failure of the previous attempts to build the bridge. When the foundation slabs

Chinese workers on a ship

emerged from the sea, the perception changed. We were convinced of the technical possibility to carry out the project according to the plan because thorough preparation was made.

A good illustration for such a claim is the execution of the foundation works. Since the beginning of the project, there have been major professional disputes over the conception and construction of deep foundations. And the solution that was eventually adopted was questioned until the moment when it was successfully implemented, and that happened largely due to the fact that we did not leave anything to chance.

We initially found a certain amount of research results on the seabed at the bridge location, but we still asked the selected contractor to perform new research on the exact locations of each of the piers in the sea, as there was a change in the size of the span compared to the previous project. In this way, through thorough preparation, we achieved that the foundations of the bridge were built within the agreed budget.

The foundation works is the example I chose because it is below ground level that the biggest surprises usually happen during the construction. To be clear, the foundation works on the Pelješac Bridge had their share of surprises: at two locations of submarine foundations (out of a total of ten), the soil was not exactly what we expected based on the investigation works.

The project implementation faced great challenges during and after the pandemic due to completely disrupted supply chains and significant increases in market prices, which, consequently, through disruptions of contractors' cash flows almost jeopardized the realization of the project. A great deal of commitment was required from the project team to find a solution and eliminate disruption. In addition, the involvement from both the contractor and investor in providing additional financial resources was required.

Quality control

In order to ensure high quality of the structure delivery, the most important thing is to define and control the technical specifications through the project documentation that needs to be filled in by the contractor. Conditionally speaking, we have the same goal during the project implementation, but often with a different approach. The contractor strives to optimize the project in order to earn as much as possible while achieving the required quality. On the other hand, the designer defined all the highest standards and norms in order to make the construction as durable as possible. And this is also in the interest of the investor, in this case Hrvatske ceste, due to the maintenance costs.

When supervising the construction of the Pelješac Bridge, the investor decided to prescribe a large number of control tests and supervising engineers so that the quality of work would not be questioned.

Despite the fact that production facilities were in China and that travel restrictions were enforced during the pandemic, the supervision of production facilities was present throughout the entire production, and control was additionally performed after delivery to the construction site by another team of supervising engineers. As a result, there were two levels of quality control, in addition to the current carried out by the contractor.

Technical inspection

The technical inspection was conducted by representatives of the Ministry of Physical Planning, Construction and State Assets in January 2022. Before the field inspection, we provided a detailed preview of the documentation through the exchange of information on the BIM platform, which was especially important since the technical inspection took place during the pandemic when restrictions on gathering were enforced.

During the inspection, we demonstrated quality and documentation management on the construction site, a system that was introduced and rigorously implemented over the years of construction. In particular, the most important thing was to prove complete traceability, from the basic material we delivered to the construction site, through the procedures of installation, lifting, assembly, concrete work, welding, until the moment when load testing was performed.

We also presented a list of shortcomings that needed to be eliminated, minor interventions that do not affect the essential properties of the building. During this final test, my goal for the whole team was to create an atmosphere of trust through the management of recorded non-complia-nces that hadn't been eliminated by the time the inspection was conducted. In general, we received praise for the management of documentation and records of deficiencies that need to be eliminated in the next 90 days. The process was successfully completed with the final statements of supervising engineers on the elimination of deficiencies.

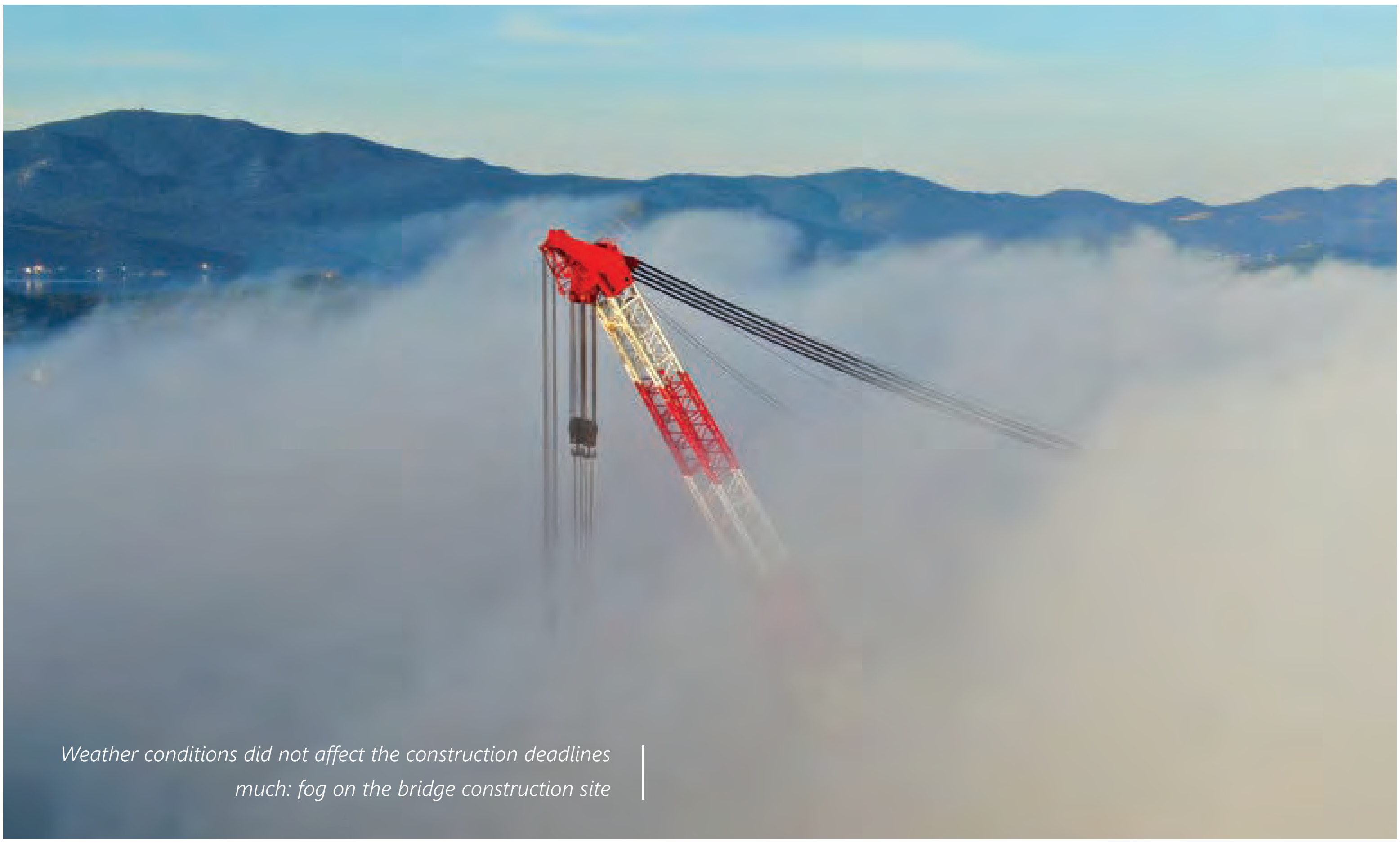
Bridge maintenance will be complex and expensive

It is common to expect that during the designed lifetime of a structure, say a hundred-year period, the structure and equipment of a bridge will be completely repaired and then replaced through regular and extraordinary maintenance. Therefore, if the construction cost two billion kuna, at least that much will be spent in 100 years on maintenance. Of course, these costs will initially be lower, and will increase later, in line with the contractor's guarantees.

Fire risk analysis

Fire is the most dangerous situation that can happen on a bridge, so a lot of attention is paid to fire protection. The worst-case scenario is one in which a flammable liquid tank leaks and catches fire. In that case, the ramps will be lowered immediately and the traffic will be stopped from the centre of remote monitoring and traffic management, where the situation on the bridge is monitored via video cameras. The Traffic Control and Management Centre is located in Zaradeže on the Pelješac peninsula, and that is where a fire brigade will be stationed.

During the construction, special attention is paid to the selection of materials and detection, as the inner part of the bridge holds many cables for various installations, optics and power supply. The inner chambers of the bridge are passable so that the bridge is accessible from both outside and inside for maintenance and inspection.



Weather conditions did not affect the construction deadlines much: fog on the bridge construction site

Monitoring bridge condition

Considering the importance of the Pelješac Bridge, the project envisages the installation of equipment for its continuous monitoring. Through it, various parameters will be monitored in real time.

A great number of devices has been installed. We will list only some: 362 optical-fibre sensors (sensors) for measuring deformations, GPS devices were placed on pylon tops to monitor their movement, a total of 153 accelerometers were installed to monitor vibrations, seismographs were installed near the abutments on the mainland and Pelješac side. Furthermore, 248 geodetic benchmarks were installed to control the displacements of the bridge during use, sensors were mounted on two piers to monitor the corrosion of concrete and risk from reinforcement corrosion, etc.

BIM in project design and management

In the last couple of years, construction stakeholders have been very interested in implementing BIM technology in design, construction and maintenance, as significant benefits are expected from this technology. However, different stakeholders have different visions or interpretations of what BIM really is.

In fact, it is about connecting and exchanging plans with an up-to-date set of structure documentation based on which stakeholders can make decisions at any stage of the construction or structure use. As already mentioned, a large number of stakeholders participate in the construction process, and they either simultaneously or with certain time shifts participate in the creation of a structure. The key thing in such a complex process is the coordination of all stakeholders. Insufficient communication and incomplete coordination is mostly the biggest cause of problems in construction processes. The existing mechanisms, based on the provision of relevant data or parts of projects on request, by e-mail, are simply not sufficient at best.

BIM technology proposes a completely different concept. It is based on the use of a storage platform that is available to all participants at all times. Such systems are stored so that they are accessible to all stakeholders.

In practice, for us BIM primarily means a system for storing all documents related to the Pelješac Bridge project, and secondly plastic, visual monitoring of construction phases in three-dimensional view and time (sometimes such a system is called four-dimensional due to links with time plans). Such a tool gives the project manager a completely new perspective on the emerging structure.

In Hrvatske ceste, the BIM technology implementation project started in 2018. A group of experts was formed with the task of applying certain aspects of BIM technology in accordance with the requirements and realistic possibilities. Initially, the implementation project was focused on the design phase. The aim of the first phase of implementation was to define the requirements for the application of BIM technology in the tender documentation. Later, through contracts on construction and design of implementation projects, an additional team of expert contractors was formed who further developed BIM models.

As a result of the conducted analyses, a platform was implemented with the task of improving and modernizing the communication of all participants in the construction process, that is, initially between Hrvatske ceste and designers, and later in the construction phase between supervising engineers, contractors and auditors. I can proudly say that the Pelješac Bridge and the entire project Road Connection to South Dalmatia is the first project in which this technology is used to a significant extent in our country.

BIM model of the Pelješac Bridge

4.2 # FOUNDATION

Preparation

Rock foundation below the seabed, under a hundred meters of slit and clay is a technical challenge that goes beyond the usual tasks of this type. To prove this right, let us just say that foundation price accounts for 25 % of construction costs in similar bridges, and in the case of the Pelješac Bridge it accounted for almost 40 %.

Data on soil layers and bearing capacity were determined by exploratory drilling. Between 2004 and 2011, 60 exploration boreholes up to 130 meters below the seabed were drilled. The project was made based on the results of these works, and the contractor was obliged to make additional boreholes, and in 2018, 17 more were drilled.

The construction sites were formed on both sides of the canal. The favourable circumstance was that the construction site and roads were prepared earlier, at the time when bridge construction started for the first time. On Pelješac side, near Brijesta, there is an operational shore, intensively used during construction.

The piles – steel pipes up to 130 meters long and weighing up to 250 tons – are made in factories in China. They are formed of sheets, mostly 40 mm thick, 3-meter-long segments, which are bent into the shape of a cylinder surface and welded longitudinally. Three sections, 1.8 or 2 meters in diameter, are welded together into a 9-meter-long pipe, then three such pipes are welded together and so on until the designed length, determined by drilling at each pier point, is reached. The piles have a reinforced bottom that is driven into the ground, 60 mm thick, and perforated steel strips are welded inside the piles, which will be connected to the reinforcement after driving. The top of the pile is specially shaped, for better connection with the pile cap. The upper parts of the piles, which will be in direct contact with the sea, are covered with anti-corrosion protection.

Intensive work on the construction of bridge parts, the structural foundations under the sea, began with the arrival of a small fleet of specialized vessels from China. The boats and barges were delivered by a special semi-submersible vessel, so that the boats can sail from the deck to the construction site itself.

Forming piles in the factory: pipe pieces are welded together to the designed length.

Production, transport, driving, filling and testing of piles

The original plan for the construction and installation of the piles was to deliver the pipes to the construction site in two parts, so that the halves could be manipulated more easily. After driving the lower part, the upper part was to be welded in place, after which the driving would continue. It turned out that the Chinese contractor has equipment with which the piles can be delivered and driven as complete elements, which is much cheaper and faster, but this had to be proven first, since piles of such length practically had not been driven in one piece anywhere before. The contractor did this under strict supervision and control by driving two long piles that did not become part of the load-bearing structure.

The piles were driven by a tower crane, with a lifting capacity of 300 tons. Like other auxiliary vessels, this one also arrived to the construction site from China, and left it, as cargo on a semi-submersible transport ship. The piles were lifted from the ship, positioned in the driving position and then driven using the equipment on this unique vessel.

The pile-driving tower of the vessel is equipped with a hydraulic hammer, one of the largest in the world. The length of the hammer assembly is 14.5 m, its mass is about 85 tons, and the maximum impact energy is 800 kNm (kJ). During the installation of steel piles for the foundation of the Pelješac Bridge, the highest energy of about 750 kNm (kJ) was used. It is interesting that the piles sank for a large part of their length into the soft soil of the seabed under the influence of their own weight, so the hammer was activated only when the pile reached the harder clay, which was up to 80 meters below the sea surface.

In March 2019, two test piles were driven in, which later were not part of the basic structures. By driving the first, shorter pile, the contractor demonstrated the ability to manipulate, position, install steel piles, drill the inside of the pile with a so-called special drilling machine, and pour concrete. The second test pile was also the longest steel pile that had ever been driven in one piece: its length was 130.3 m, and its construction finally confirmed the technology.

Prior to pile installation, the vessel with the hammer had to be precisely positioned and anchored. When the pipe driving begins, the procedure must not be interrupted until the intended depth is reached, that is, until the driving resistance indicates that solid rock has been reached.

The driving of piles of enormous mass and length was done very precisely, the final position of the top of the pier at sea level was not allowed to deviate by more than 10 cm from the designed position. Precise manipulation of the pile, which can be moved due to impacts during driving, is performed by powerful hydraulic jaws on the driving vessel. An air-release system ring (forming a curtain of air bubbles around the pile) was placed next to the pile fixed with jaws, which reduces the adverse effect of noise from driving the pile on the fauna in the work area. This is just one of the special environmental protection measures during the works, which are defined by the Environmental Impact Study.

The entire process of lifting, transporting, positioning and driving piles was monitored by a supervising engineer, a specialist in deep foundation works, along with a team that performed measurements and tests.

After driving the steel pipes of the pile, sea sediment, silt and clay remained in them, which had to be removed to the level up to which the pile will be filled with reinforced concrete. Excavation was carried out with a special machine, the so-called Reverse Circulation Drilling. It is a method of drilling in the ground that uses two pipes – an external and an internal one. Through the hollow inner pipe, the excavated material is transported out, to the surface, in a constant flow.

The piles on piers S3, S4, S10, S11 and S12 are extended by a concrete footing in the rock below the level to which they are driven, which ensures the transfer of the load into the ground. Therefore, after driving these piles with RCD equipment, the soil under them is additionally drilled, in order to pour concrete into the thus formed cavity, which will penetrate into the broken rock and strengthen the soil under the pile. These piles are completely, up to the top, filled with reinforced concrete, and are connected at the top with head beams.

The foundations of pylons S5 - S10 consist of groups of 18 or 20 piles, 2 m in diameter, which are connected at sea level by a massive reinforced concrete pile cap.

On the foundations of the pylons, central piers, that is, on a total of 94 piles with an outer diameter of 2 m, drilling was done into the sea sediment inside the piles to a level of about 15 m, measured from the level of the seabed downwards at the place of pile installation. After the drilling was completed, the inner surface and steel perforated strips for composite construction were thoroughly washed and cleaned, and a concrete plug was installed at the bottom level of the future concrete part. Only after the structure prepared in this way was inspected by the supervising engineer, the reinforcement was inserted, which was put in reinforcement cages made of longitudinal bars and transverse ties.

All the material removed from the piles was collected in ships with hatch covers (flaps) which were taken to a previously determined location for depositing, in the open sea, about twenty nautical miles from the location of the bridge. This measure was determined by environmental protection conditions, due to the sensitivity of the bay's ecosystem.

The foundations are designed in such a way that the steel pile and the AB filling of the pile should be connected into one structural unit. In order to fulfil this condition, the inside of the pile sheath and the perforated strips for connecting the concrete fill and the steel pipe of the pile must be clean. The interior of the pilot was washed using high-pressure washers.

After the piles were cast in concrete, the quality and completeness of the concrete filling of steel piles and parts of drilled reinforced concrete piles was checked. The piles were tested using the PIT (Pile Integrity Testing) procedure, which is based on measuring the wave propagation caused by the hammer blow. Measurements are made by an accelerometer on the pile head. The integrity of the concrete filling inside the steel piles of the column locations was tested using the CSL (Crosshole Sonic Logging) ultrasonic process. Each pile is equipped with four steel pipes with a diameter of 50 mm installed from the bottom to the top of the pile during the production of reinforcement baskets.

The company SLP d.o.o. from Ljubljana developed special equipment for simultaneous measurement through all four pipes. In a single pass through the piles, from the top to the bottom, the integrity of the concrete filling of the steel pile is recorded. Each probe is equipped with an ultrasonic signal transmitter and receiver, which enables simultaneous recording of the entire cross-section of the pile.

The bearing capacity of the pile to lateral force, that is, the force acting transversely on the pile, was also tested.

Piles loaded onto the ship, before departure from the Chinese factory to Croatia.

Driving the steel piles of the Pelješac Bridge: a ship with a hammer and a driving tower accepts the pile with a crane and turns it into the driving position.

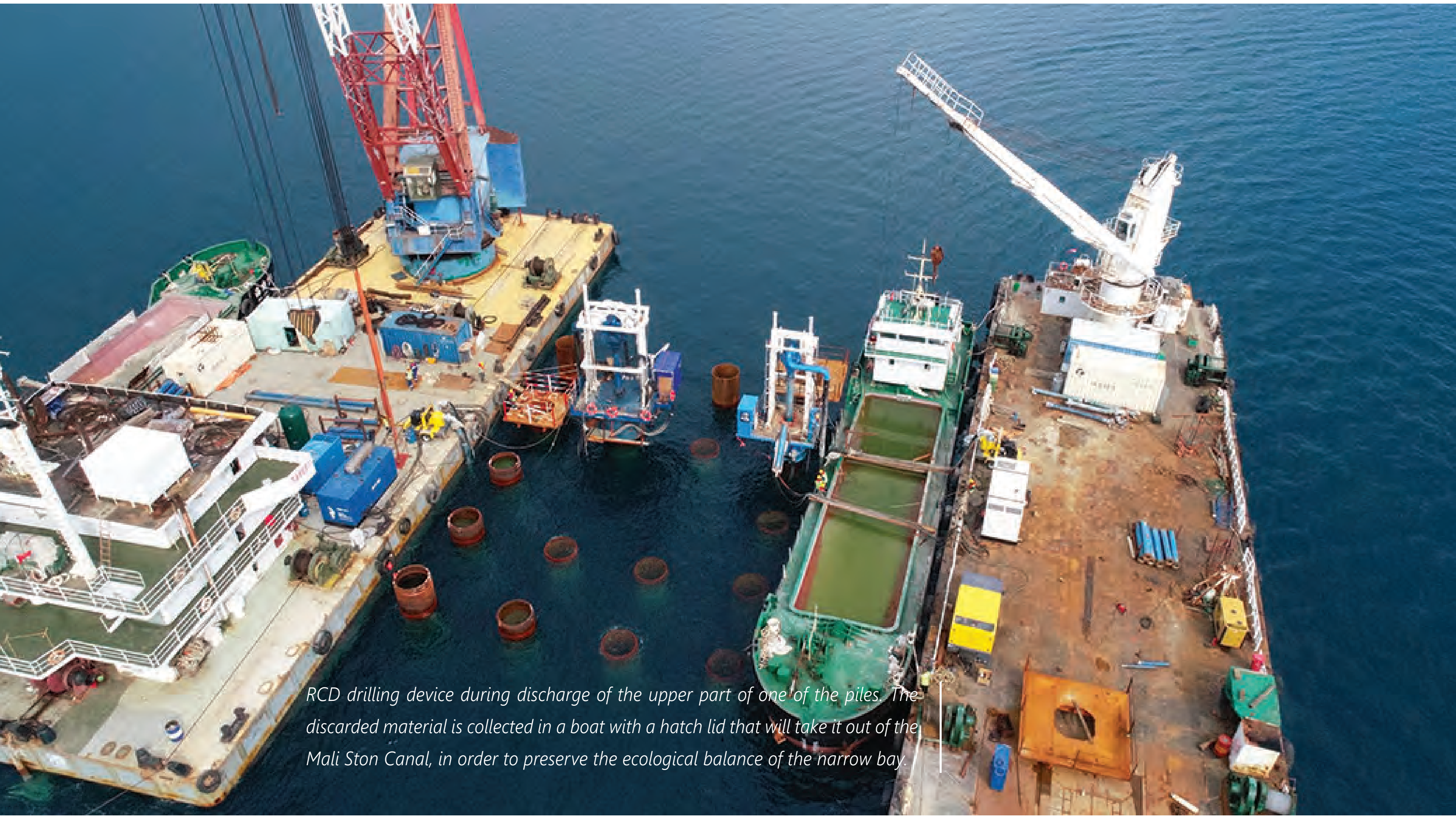
March 2019: vessels for bridge construction were delivered to the construction site by a semi-submersible naval vessel.

Pile driving

Control of works

Drilling head for RCD drilling of the material left in the pile pipe after driving.

Piles of one pier site in different stages of making concrete filling: a drilling device is working on one pile, a reinforcing cage is being lowered into the adjacent pile, and several of them have already been prepared and concrete poured to the top, temporary constructions forming a working platform are in operation on the piles.



RCD drilling device during discharge of the upper part of one of the piles. The discarded material is collected in a boat with a hatch lid that will take it out of the Mali Ston Canal, in order to preserve the ecological balance of the narrow bay.

A view of the interior of the cleaned pile into which the reinforcement has been inserted. Old gloves protect the tip of the four pipes used to test the integrity of the piles after concrete was poured (Crosshole Sonic Logging)

Casting concrete on parts of the bottom of the foundation slab (pile cap) on the operational coast near Brijesta, on the Pelješac peninsula.

Pile caps

Pile caps are the highest parts of the bridge foundation, the only visible parts of the foundation on the sea surface, and they have the role of connecting and stiffening the piles so that they together carry the load of the entire structure. The pier piles are connected at sea level by massive reinforced concrete slabs, from 4 m thick at the edge to 5 m next to the pier.

The pile caps were cast in concrete in the formwork, in boxes that had a concrete bottom and steel formwork on the sides. The bottom of the formwork boxes, in the form of a reinforced concrete slab, was made in parts on the operational coast on the Pelješac side. The openings on the foundation slabs closely surround the tops of the piles: since their position deviates from the design by an allowable distance (up to 10 cm), the slabs were precisely made after geodetic surveying of the exact position of the pile tops. Considering the large dimensions of the pile caps, the bottom is formed from several parts that were separately transported to the installation site and connected there into a whole.

The formwork of the pile caps was formed on temporary – auxiliary steel piers that leaned on the pile tops. In other words, it was made on dry land, above sea level, and only after completion was the entire hollow box lowered into the sea, into its final position, where concreting will take place (ultimately, the cap is submerged to half its height). The sides of the box are made of steel plates, which were removed later, after the concrete had hardened, while the concrete box bottom became part of the entire foundation structure.

After lowering the box to the designed depth, it would be filled with sea. The gaps between the piles and the concrete box bottom had to be sealed first, and only then the sea pumped out so that the reinforcement could be installed in dry conditions.

Concrete casting on pile caps differs from the production of ordinary concrete elements due to their massiveness - 3,000 cubic meters of concrete were installed in the largest caps. The concrete, class C35/45, was prepared in a concrete plant next to the construction site, loaded into mixer trucks, which were then loaded onto a ferry equipped with a concrete pump. The ferry would bring the mixers to the pier site where concrete was poured.

Concrete was not cast at once into the pile caps, but in layers, by height. Larger caps have three layers of concrete (the first two are 1.5 m each, the third layer is 2 m high), and the smaller ones have two layers. In order to form the inclined upper surface, the upper formwork of the pile cap was placed before the concrete works were finished. Due to the dense reinforcement of the caps, self-compacting concrete was used. A retarder was used in order to preserve the flow properties for up to 10 hours after the preparation of the concrete, which is important for long-term concrete performance.

Transport and installation of one element of the bottom of the foundation slab (pile cap) on temporary supports in the pile extension: in the first stage, the pile cap formwork is formed above sea level. The auxiliary steel structure is later removed.

The formwork of the future pile cap is lowered to the designed height. Before pumping out the sea from the box, it is necessary to seal the openings around the pile tops (March 2020).

A very demanding part of the work related to the preparation of the pile caps was performed by divers (March 2020)

Interior of the box - formwork of the pile cap during reinforcement.

After the box above the piles is sealed and the sea is pumped out of it, the reinforcement of the pile cap is installed.

Construction of the pier S13 foundation, by the sea, on Pelješac: you can see the tops of the drilled piles on top of which the foundation slab was constructed.

Foundation of piers by the sea

Pier S2 is located on the coast and is based deep on the rock on a well with a diameter of 11 m and a depth of 8 m.

Pier S13, the last one counting from the land, is located along the coast - partly in the sea. It is based on 22 drilled piles, which were driven below sea level, but in dry land, after the embankment was built and the construction pit was protected.

Concrete casting of the pile caps in the final stage - the upper formwork has been installed. The pile caps are probably the most massive concrete elements ever produced in Croatia, 3,000 cubic meters of concrete were installed in the largest pile caps.

The foundation pit of the only pier which it was built on mainland, the first one on Komarna side – S2.

Geotechnical investigation works at the location of the bridge: a vessel with equipment for drilling samples from the seabed on the day when a strong wind was blowing, September 2018.

Ivo Barbalić, M.Sc. in Civil Engineering, supervising engineer for foundation and geotechnical works on the foundation of the bridge and access roads was a role model for everybody who worked on the construction site of the Pelješac Bridge, primarily because of his attitude towards work, but also because of his relationships with people, especially young engineers to whom he passed on his experience. Engineer Barbalić was born in 1953 in Požega, he was educated in Split, and studied construction in Zagreb. He began his career in the company Konstruktor Split, and after that worked for 40 years and two months at the IGH Institute. He retired on May 31, 2020, in the midst of work on the bridge. However, he continued to work as a supervisor, working part-time as an employee of Terestrika d.o.o. Split.

SUPERVISION OF PILE IMPLEMENTATION

IVO BARBALIĆ, M.Sc. in Civil Engineering

Profession and life-long vocation

Throughout my working life as a geotechnician, I was accompanied by the thought of the famous father of soil mechanics, Professor Karlo von Terzaghi: *There is no glory in the foundation work. The success of a well-executed foundation work is forever hidden deep beneath the surface, and the failure is immediately apparent!*

I would like those who designed, built and supervised the foundations of the bridge never to be mentioned during the bridge lifetime. The absence of a mention of the people who, as I sometimes joke, "left the deepest trace in the construction of the bridge" (due to the long piles), would be our greatest recognition.

Investigation works and preparation

From the very mention of the possibility of building a bridge to the Pelješac peninsula, I began to follow the activities around the choice of construction system, and I was especially interested in the choice of the foundation concept. Through interaction with colleagues, I managed to monitor the performance of all stages of geotechnical investigation. I personally supervised the last stage of additional field geotechnical investigation works for the construction of the bridge. They started on August 17, 2018. The delivery of test equipment itself was marked by severe storms and equipment damage. Working at sea, on vessels, is always challenging. It sometimes seemed as if nature was resisting the beginning of bridge construction.

Piles of record length

One of the particularly interesting vessels is a crane with a tilting tower. The entire manipulation of piles, lifting them from the ship, positioning them at the place of driving, everything was performed with the help of 12 winches and a whole series of anchor blocks. This is not a routine work: the longest piles ever made in one piece were driven in.

The installation of piles was in full swing. The submarine geology is very variable, so the lengths of driving piles into the rock were not always achieved in accordance with the project, according to which the tops of the driven piles should be just above the sea surface. The group of piles that form the foundation of a single pier consists of piles 6 meters apart, and they are of equal length. The geological properties of the rock differed significantly at these spaces, so the neighbouring piles were hammered in some places so such a way that the parts above the surface were of different heights.

Control of pile driving

When a pile is being driven, the sensors control the parameters from which it can be concluded that the pile is completely driven. The upper part of the 20-meter-long steel pipe is equipped with two accelerometers and two deformeters. These sensors are connected to a data collection and processing device (PDA - *Pile Driving Analyser*) which controls the driving process, using a special software.

The increase in the load capacity of the pile sheet was checked using dynamic load testing (DLT - Dynamic Load Testing). SLP d.o.o. Ljubljana made a special assembly, a frame with weights weighing from 1.6 tons to 54 tons which by a controlled drop on the top of the pylon, cause strains and deformations that are measured, and after the interpretation, testify to the bearing capacity of the pile. The height of the weight drop was adjusted to the test program. Before each test, the diver would install two deformation sensors (deformeters) and two accelerometers on each pile.

One of the test piles installed before the actual construction of the bridge was until then the longest pile in the world driven in one piece, 130.3 meters long. The photo shows the pile on the shore in Brijesta. A detail of a hammer and a pile-driving platform is visible on the right.

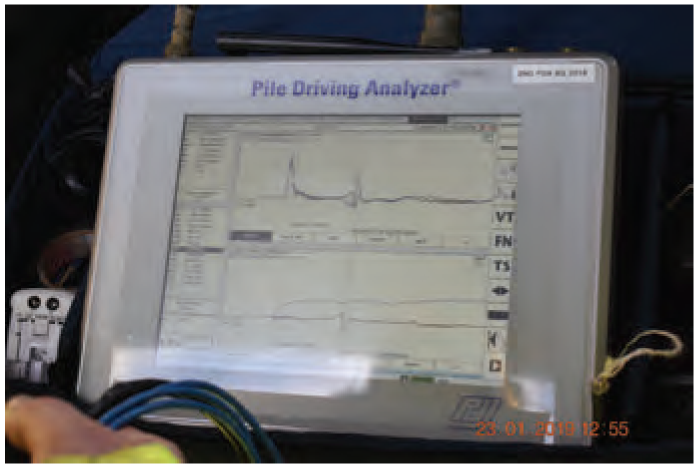
Engineer Barbalić in a 1.8 meter diameter pile, which was delivered from China and prepared for installation, at the warehouse next to the bridge construction site.

The frame for testing the pile with dynamic load contains a weight which, when dropped, causes strains in the steel and bearing capacity of the pile can be measured.

Interior control and concrete work

Pile driving was followed by excavation of marine sediment from inside the pipe, and then the inner surface and perforated steel strips had to be washed and cleaned.

After cleaning and washing, the supervising engineer went down to the bottom of the excavation and inspected the cleanliness. The depth of the descent was about 42 m below sea level. In addition to these inspections, the quality of the construction of the gravel "plug" which was performed at



Data from sensors on the steel sheet of the pile pipe to stop the driving in time, just as the pile was driven into the solid rock below the seabed and layers of silt and clay.

Sensors at the top of the pile, which monitor the driving so that it stops when the bottom of the pile reaches a solid rock under the seabed.

the bottom of the excavation was also checked. "Plug" is a layer of cleanliness before the installation of the reinforcement cage and concrete in the interior of the steel pipe of the pile. I descended into the interior of the pile, at a depth of about 42 meters, more than 220 times. The maximum depth I was at was about 65 meters, to check the finishing quality of the concrete contact surface at the level of the pile concreting break.

The examinations were performed from a basket lowered and raised by a floating crane, which means a lot of twitching and rocking. Given my modest mountaineering and speleological experiences from when I was younger, and also diving skills, descending into the piles was not a difficulty for me. There was always a Chinese worker with me who would broadcast my instructions by radio to the crane operator in Chinese. The workers did not speak English. The communication with the "other guy from the basket" took place with the help of a few poorly spoken words in Chinese and with the help of hands - pantomime!

Humidity is rather high inside the pile. Instead of a "salt room", the two of us had a "salt pipe". A kind of inhalation therapy with sea vapour. As the depth increases there is less

The basket for inspecting the interior of the pile is lowered by a crane into the cleaned part of the pipe, to the bottom of the space that will be filled with reinforced concrete. Our supervising engineer and a Chinese operator are in the basket.

and less natural light, so we had to turn on the flashlights. The temperature in the pile is about the same in winter and summer, pleasant in both seasons! We slowly descended to the bottom of the pile. I would feel the bottom of the excavation with a steel bar. I was trying to determine the composition of the soil the bottom is made of. If the sea level and the compressibility of the foundation soil allowed it, I would get out of the basket and walk along the bottom of the excavation (with the basket hanging above me), inspecting the bottom of the pile excavation in more detail. During descent I would inspect the surface and strips of half the diameter of the pile interior. In a shaky lift, I would inspect the other half, until we come out into the daylight and landed on the deck of the vessel.

The cleanliness of the interior and the perfobond strip of the steel pile pipes that were filled with sea was checked using an underwater camera on a remote-controlled underwater vehicle.

A cordial relationship with Chinese colleagues

During the works on the floating equipment, a friendly relationship was created with the workers of the CRBC company. I spent the whole working day on the vessel, so I had the same lunch as the Chinese workers: a bottle of water, a plastic box with rice, vegetables or mushrooms, pieces of meat (chicken or pork legs, dry pork skins, etc.), all seasoned with a lot of garlic and hot peppers. In the kitchen of some vessels, barges, one could get some of the many hot sauces. My biggest difficulty was mastering the technique of handling chopsticks. That was the only cutlery. If you don't want to be hungry, do your best! At first, I made my Chinese colleagues laugh, but after "training" they would praise me for being skilled.

Dried meat, dried poultry, pork, beef are also treats... The meat was air-dried, hung on ship fences. It looked bad at the beginning of drying, while it is bloody, since flies gather on it, it does not look better even when it dries because it is almost black. However, when it is cooked and seasoned, believe me, it is great!

In the restaurants on the construction site, we were served superbly prepared and served Chinese gastronomic specialties, food and drinks worthy of the best Chinese restaurants. The friendly, collegial atmosphere that was created between us through living and working together also contributed to such a good atmosphere.

Meat that is drying on a fence

For special occasions, Chinese chefs used to prepare a variety of meals from homemade ingredients with their own spices

Growing plants on a Chinese vessel stern

In addition to drying meat, colleagues on the vessels were also engaged in agriculture. At almost every stern, they placed crates of earth and formed nurseries. Seeds of special Chinese varieties of cucumbers and zucchini were sown. The characteristics of these varieties are that they have lush leaves, climb high, bear abundant and extremely large fruits. The barge crew would use steel pipes on which seedlings would climb and form shade with their lush leaves, both useful and enjoyable.

Last pile

The last pile we concreted was damaged during driving. The bottom of the pipe of that pile deformed during driving. At a depth of about 52 m, the pile knife was deformed – a 6 cm thick part of the pipe at the end. The deformation was about 160 cm long, about 60 cm high, and the deformed part entered the inner profile of the steel pipe of the pile about 40 cm. The deformed pipe made it impossible to excavate in the rock under the pilot with an RCD machine.

As the most suitable technology for removing the deformed part of the pile pipe, the supervision suggested the use of a robotic underwater cutter. It is commonly used in similar operations at great depths on gas or oil exploitation platforms.

However, the contractor proposed cutting technology using targeted cumulative blasting with high explosives. Blasting experts from the Faculty of Mining, Geology and Petroleum Engineering, University of Zagreb provided expert assistance. After many preparations and attempts, the blasting did not give satisfactory results, so the contractor changed the technology. With the advisory assistance of experts from the Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, University of Split, a combined technology of submarine "grooving" of steel pipe sheet with plasma "BROCO" electrodes and final sheet metal cutting with submarine hydraulic rotary grinder was selected.

Diving works were performed by the company Stijeg from Split, additionally teamed up with specialist divers from Zagreb, Rijeka, Zadar, Dubrovnik and Metković. A diver is allowed to do one dive a day, every other day. In the best case, five dives were performed daily. The descent to a depth of 52 meters takes about 3 minutes, the work on the bottom of the pile about 17 minutes and the ascent with a decompression stop slightly less than half an hour. The dives were done with a mixture of gases. Working with selected electrodes creates gases that become explosive when they reach certain conditions. In order to prevent such a situation, which is fatal for the diver, everything was done with extra caution. The conditions for performing the works were strictly observed, so even this technically extremely demanding and dangerous job was successfully completed. The deformed piece of the steel pipe of the pile was removed and it was possible to continue the work.

A message to young colleagues

All of us who stayed at the construction site for a long time lived the "birth" of the bridge. The windows of my study and bedroom overlooked the construction site. I woke up and fell asleep looking at the bridge. In a way, I experienced the bridge as a great connection.

The works on this construction site were marked by the presence of a large, large, number of young colleagues, Chinese and Croatian. Most of them came from college to the construction site. By hanging out with them every day, I tried to share my professional experiences with them. In addition, primarily through my own behaviour, I tried to instil in them the seed of personal motivation for approaching work: humanity, modesty and diligence.

Preparing to dive into the pilot, to a bottom that is at a depth of 52 meters.

The attempt to remove the damaged part of the pile of the S12 pier foundation with explosives failed.

Removal of the deformed part of the pile pipe after underwater cutting

Markings of abutments (U1, U14), piers (S2, S3, S4, S11, S12, S13) and pylons (S5 - S10) of the Pelješac Bridge. The height of the pylon above the carriageway is 40 m. The height of the piers between the pile caps and the pylon is 37 to 53 m, while the superstructure is 4.5 m high, which means that the highest piers S7 and S8 rise about 100 m above sea level.

4.3. PIERS AND PYLONS

Piloni

The main piers of suspension bridges are called pylons: these are piers that carry loads from stay cables into the foundation, and therefore have parts above the span structure. Sometimes only the part of the pier above the carriageway is called a pylon, so it is easy to get confused. On the Pelješac Bridge the central 6 piers, from S5 to S10, are called pylons and they surround the largest 285 m long spans of the bridge. The height of the part above the carriageway of all 6 pylons is 40 m, and the height between the head beam and the pylon is 37 to 53 m. The heights of the pylon from sea level to the top are as follows:

S5 and S10 are 85.4 m high

S6 and S9 are 93.9 m high

S7 and S8 are 100.9 high.

The parts of the pylon below the span superstructure have a box cross-section and are constant in dimension transverse to the bridge, and when viewed along the bridge they extend from the top to the bottom. The piers are quadrangular in shape, 7 m wide in side view, and the wall perpendicular to bridge axis widens from 8.1 m at the top to 11 m at the bottom. The walls of the shorter side are 80 cm thick, and the longer sides 70 cm, with the fact that in the lower part of the piers along the navigable profile they are increased to 1.2 m, due to the possibility of the vessel collision.

The parts of the pylon above the carriageway are reinforced concrete, full cross-section and contain saddles. Each pylon is fitted with 10 steel saddles that serve to anchor the opposite stay cables. The dimensions of the full part, 40 meters high, are 2.20 x 5 m at the top, while they are 2.2 x 7 meters at the level of the span superstructure.

The concrete of all pylons (S5 to S10) up to the level of the carriageway is strength class C50/60, and the part of the pylon above the carriageway is high-strength concrete C70/85 which, in addition to higher load-bearing capacity, provides even better durability properties.

The construction of the pylon began with the construction of the base in the foundation footing, along which the formwork was laid. The formwork elements were adapted to the shape of the pier - the Doka formwork system (Top 50 large-area formwork and the Doka Xclimb 60 ST hydraulic self-climbing system) was used. The so-called self-climbing formwork system contains hydraulic assemblies, which enable the transfer of all equipment from the already completed part to the next concreting cycle independently of the crane. The height of the section that was concreted in one session was 4.5 meters for the part of the pier below the carriageway structure and 4 meters for the part above the carriageway. The formwork itself consists of steel and wooden girders, and special wooden panels.

During the relocation, the entire formwork system was attached to the previously performed part of the pylon, which enabled the relocation of equipment even in adverse weather conditions. Six sets of hydraulic equipment lifting system and the same number of formwork sets were used to make the pylon.

At the top of each pylon, a concrete part of the span superstructure of the same shape as the steel beam had to be constructed. In order for the first steel segments next to the pylon to be rigidly connected to it, they were put in place before concreting the part of the structure connecting them. To temporarily support these - base - elements, heavy tubular scaffolding was erected, which rested on the pile caps.

The edge parts of the segments next to the pylons are placed in concrete so as to be firmly connected into a whole with the concrete element. In addition to the connection to the dowels, the connection between the steel and the concrete is additionally reinforced by prestressing with steel strands.

The main protection against corrosion of reinforcing steel is a protective layer of concrete elements - a layer of concrete that wraps the reinforcement and forms a smooth outer surface. The concrete parts of the Pelješac Bridge have thicknesses of protective layers from 5 cm to as much as 10 cm, which is more than on any of the bridges that were previously built along the Adriatic Sea. The additional stainless steel reinforcement is placed on the pylons in a protective layer.

After the steel elements next to the pylons are connected with the concrete part, the construction of full parts of the concrete pylons above the carriageway begins. The internal transport of concrete into these pylon segments, which were each 4 meters high, was performed from a barge using a pump concrete crane, and then with a concrete kibble, using a tower crane, the concrete was lifted and poured into the pylon formwork.

Formwork of the first block (section to be concreted at once) of the S5 pylon, December 2019, densely placed reinforcement indicated the use of self-compacting concrete.

Construction of the lower parts of the pylon in 2020: each pillar in the sea is practically a separate construction site.

The stay cable saddles at the intended heights pass through the concrete of the pylon in order to balance the forces from opposite stay cables. The scaffolding remained on the pylon tops until all stay cables were placed in their final position and tensioned.

All six pylons in a row, from S5 to S10, August 2021.

Connecting the first sections of the steel bridge structure with the pylon structure - formation of a rigid connection is additionally achieved by using prestressed cables. Construction of S5 pylon in June 2020: first steel sections along the pillar are put in place, on the scaffolding, between them, directly above the pier, concrete is being prepared.

Construction of pylon S5, April 2020. Around the lower part of the pylon, a heavy tubular scaffolding was temporarily erected, supporting two steel segments along the pylon, between which concrete will be laid on part of the span superstructure.

Construction of pylon S5, June 2020. The formwork and part of the reinforcement of the lower plate of the extended top of the pier were installed. Vertical reinforcement forms the outline of the future extension of the pylon above the carriageway. The dowels of the adjacent steel segments reveal the size of the space in which fixity of concrete and steel will be realized.

Concreting of the part of the pylon above the carriageway using a container - bucket that is lifted to the construction site by means of a tower crane. Dense reinforcement indicated the use of self-compacting concrete. According to the project, the highest concrete strength ever used for massive structure elements in Croatia was achieved.

The full part of the pylon above the carriageway during construction - the saddles of the stay cables are prepared for fixing the steel strands.

Piers

Pier S2 is on the mainland, and S13 on the embankment, right by the sea. The other piers are on driven piles which, by means of additional drilling below the level of the driven pipe, were extended several meters into the solid rock with a reinforced concrete extension.

The piers were made using a conventional procedure, in sections and in double-sided formwork that was moved by cranes.

At the top of the piers, bearings are installed that take over the vertical reactions, for example forces from the span superstructure, and transfer them to the pier. At the same time, these bearings enable longitudinal displacements of the steel beam. In addition to the bearings for vertical forces, rails are also installed. These are vertically placed bearings that prevent transverse displacements of the structure, while allowing longitudinal displacements. The rails and parts of the piers they lean on are especially reinforced in the event of an earthquake, because then significant forces are expected in the direction transverse to the bridge axis. In this case, the rails will transmit these forces to the pier tops via bearings, which are designed to transfer them safely to the ground. It has happened on several bridges in the world that parts of the span superstructure fell off the bearing during an earthquake, which is why such parts are installed.

All pylons and piers have built-in doors for the entrance to the cavity and ladders, so that the interior is accessible for inspections and repairs.

The mechanical properties and placement of concrete are significantly determined by the mixture composition, but its durability mostly depends on the process of installation and curing. If drying is too fast, a porous surface structure or cracks may appear, which significantly impair the durability of the structure as they allow moisture and salt to penetrate into the interior of the concrete element, to the reinforcement, which then corrodes. Therefore, the contractor paid great attention to the protection and care of exposed concrete elements.

Execution of pier S13, March 2020, foundation on drilled piles made on a temporary embankment, scaffolding and formwork are moved by a crane, the concrete pump pipe at the bottom of the pier is visible.

Ilija Gabrić, M.Sc. in Civil Engineering, designer of concrete composition for the Pelješac Bridge, PGM Ragusa, Dubrovnik

INSTALLATION OF CONCRETE

ILIJA GABRIĆ M.Sc. in Civil Engineering

Croatian product

The concrete installed in the Pelješac Bridge is entirely a Croatian product, which should be especially emphasized considering that the design of the bridge required concrete features that far exceed the characteristics of concrete common in our construction practice. The construction of the reinforced concrete structure of the foundations, piers and pylons of the bridge lasted for about 21 months – from May 2019 to February 2021.

Concrete, basically a mixture of stone aggregate (crushed stone), cement and water has been and probably will be the most used building material of the modern world for a long time. One of its advantages is that it is made of locally available materials. For the concrete of the Pelješac Bridge, the designer of the main design prescribed special features, which were achieved based on the work of local experts from the company PGM Ragusa d.d. from Dubrovnik, through the phases of designing the concrete composition, its production and installation.

Design of concrete

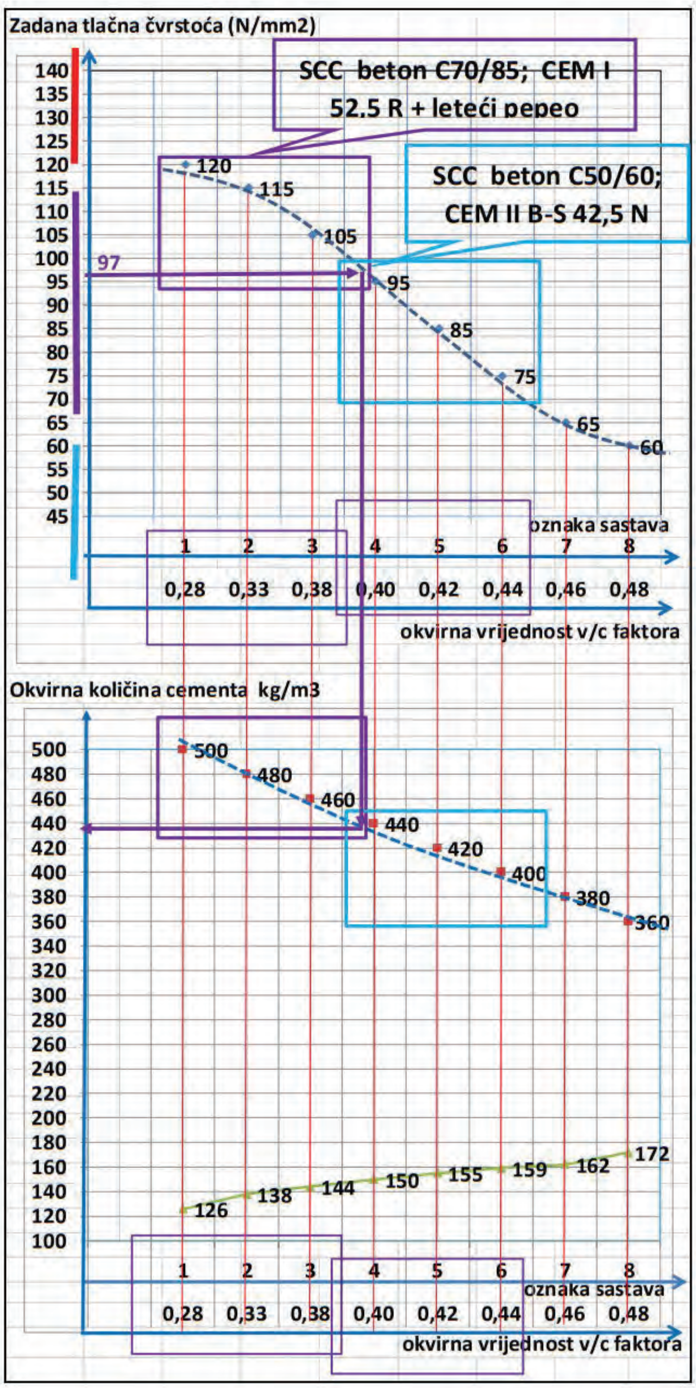
Designing concrete involves determining a mixture that will meet a significant number of different requirements, some of which are mutually opposed. Concrete components are selected so as to achieve the specified properties during the preparation and installation phase, then the specified properties of the hardened concrete, all at an acceptable cost. Proof of the required characteristics of each concrete mixture is carried out by preliminary tests.

In particular, the composition of the mixture is adjusted experimentally to balance the cohesion and flow of the concrete composition and determine the amount of superplasticizer by controlling a number of parameters (fine particle content, volume of cement paste, etc.) and determining the amount of retardant until the required loss of consistency is achieved. The required tying time delay was more than 5 hours for piles, more than 8 hours for piers, and more than 10 hours for pile caps. The optimum content of fly ash in relation to cement is determined on experimental comparative mixtures. When the mixture was adjusted to all parameters, diagrams were made showing the dependence of compression strength and water-cement ratio as well as of water-cement ratio and the amount of cement.

The concrete installed in the Pelješac Bridge was made using cements with different proportions of mineral additives, slag and fly ash and with different chemical additives for concrete.

The pylons are fitted with concrete of a strength class not yet used in Croatia for large building elements. However, strength is only one of the required properties of concrete. The designed durability of the massive parts of the bridge of 100 years dictated the design and construction of concrete that is watertight and resistant to atmospheric influences, primarily sea salt. Tiny drops of sea carried by the wind caused significant damage to some of our bridges across the sea, so the approach to this task was meticulous.

In addition to basic properties of strength and durability, the



Design of concrete composition: results of laboratory tests of optimal mixtures for high-strength concrete (default: 97 N / mm²) and correlation with the amount of cement in concrete and the required ratio of water and cement in the mixture.

composition of concrete depends on the shape and height of structural elements and the arrangement of reinforcement in the cross section. In particular, the density of the reinforcement poses an additional challenge in the design of the concrete mix, as it disables common compaction methods using vibrators. All piers and pylons of the bridge take significant forces from the earthquake, so they are heavily reinforced. Due to this, it was necessary to design concrete of liquid consistency. The so-called self-compacting concrete was used, which, after pouring into the formwork, filled the space and included rods without significant use of vibrators.

When designing concrete, consideration needs to be taken of the time that will be required to deliver the concrete to the installation site, so that bonding does not start too early, as well as of the method of installation - in this case, concrete pumps were used for most parts.

The concrete of the lower - hollow part of the pier is of strength class C50/60, while the pylons are made of concrete

Pumping concrete from the ferry into the column formwork.

Transport of concrete to the installation site by trucks - mixers with a volume of 9 m³ and ferry equipped with a concrete pump.

Concreting the pylon, one section 4.5 meters high: the pump from the ferry transfers fresh concrete to the basket of a stable pump next to the pier, which raises it to the top of the formwork through pipes mounted on a tower crane.

of class C70/85, which classifies them as high-strength concretes.

For the production of concrete for the Pelješac Bridge, a crushed aggregate from the Visočani quarry was used, obtained from limestone fiorito and unito, the basic fractions (grain size in millimetres) 0-4 were used; 4-8, 8-16 and 16-22 mm.

Cements from the company CEMEX from Kaštel Sućurac were used, namely sulphate-resistant low-hydration metallurgical cement with a share of 66-80 % slag and 20-34 % clinker, Portland cement with a share of 65-79 % clinker and 21-35 % high-quality slag, and Portland cement with a share of 95 % - 100 % clinker.

Concrete admixtures are factory-produced chemicals that are added in small amounts to ensure the desired characteristics of fresh and hardened concrete. Certified concrete admixtures from an Austrian manufacturer were used: superplasticizers, retarders, shrinkage compensators.

For the pylon concrete, fly ash was used as an addition to the concrete manufactured by KUTRILIN d.o.o. from Zagreb. Silicate fly ash for concrete is a fine powder of mostly spherical, glassy particles and is chemically pozzolanic. Concrete containing fly ash becomes stronger, more durable and more resistant to chemical influences.

The composition of the concrete was first determined in principle by calculation, and then adjusted on the test mixtures to balance the desired characteristics, with control of a number of parameters. The challenge was to accurately determine the amount of retarder until the required time delay of consistency loss was determined within the prescribed tolerances of more than 5 hours for pylons, more than 8 hours for piers and more than 10 hours for pile caps. Delaying the time within which the concrete begins to harden was important due to possible delays in the process, which is technologically very complex since a number of machines were used until installation - mixers, ferries, concrete pumps and others – all of which were used to the maximum of their capacities.

After the properties of the mixture in the liquid state have been optimized, the properties of the hardened concrete are checked. According to the main criterion, the compressive strength of concrete after 28 days of hardening is relevant.

High-strength self-compacting concrete, used for pylon parts above the carriageway (C70/85), contains 370 kg of cement per m³, with the addition of 80 kg/m³ of fly ash, and with a water-cement factor of 0.35 (ratio of water to cement in concrete). The largest grain of the aggregate in the mixture is 16 mm in diameter.

435 kg/m³ of cement and water-cement factor 0.385 were used for the composition of pier concrete (C50/60).

Control of the essential characteristic of self-compacting concrete on the construction site: the spread of a given amount of fresh mix on a smooth surface is measured.

Quality control

During concrete works, cube-shaped concrete samples were taken in order to verify the properties of the hardened concrete by tests carried out by the manufacturer as part of the factory control and - independently - by control tests ordered by the investor. In addition to the strength of concrete samples, its water tightness, gas permeability, vapour permeability, capillary absorption, chloride diffusion, and limited long-term deformations from shrinkage and creep were checked. Tests have shown that concretes have even better features than those designed, which places them in the new generation of high-performance concretes. After the experience with the accelerated deterioration of concrete of some large bridges in the Adriatic, the issues of durability of reinforced concrete structural elements become extremely important. The concretes of the Pelješac Bridge were designed according to the demanding provisions of the project and installed with extremely strict quality control.

4.4. CONSTRUCTION MANAGEMENT

Jeroslav Šegedin M.Sc. in Civil Engineering, representative of Hrvatske ceste d.o.o. in the Pelješac Bridge project

JEROSLAV ŠEGEDIN M.Sc. in Civil Engineering

Investor's role at the construction site

The representative of the client (that is, the investor) at the construction site, as a participant in the construction, does not have a role with a clear legal framework. However, in the case of large state infrastructure projects, their duties are extensive and bear great responsibility. In short, together with the supervisory service, I controlled the execution of all works, whether they were executed in line with the project and the contract, whether the quality was at the given level and whether the monthly invoice corresponded to what was actually done.

Therefore, Hrvatske ceste, as a state-owned company and public contracting authority, appoints a representative at the construction site and assigns them several basic tasks, related to finances, quality control, contractor's claims and mediation in possible disagreements between the supervisory service and the contractor. Each invoice, or monthly statement, must be approved by the supervising engineer and the representative at the construction site. The investor's representative approves the so-called exceeded work, that is, deviations of the quantities actually performed compared to those from the contractual bills of quantities. They also control unforeseen works, the execution of which is not foreseen by the contractual bills of quantities, as well as other subsequent works.

In other words, the client's representative complements and supervises the work of the expert supervision service. At the construction site of the Pelješac Bridge, a truly high-quality team of supervisory engineers was formed, who were actively and competently involved in solving every disputed situation. I think that good cooperation between supervision and investors is essential for the continuity of work in a situation where we have a contractor who, on the one hand, is very competent in construction technology, and on the other hand, has no previous experience with our work supervision and control systems.

The Pelješac Bridge - a complex project

The construction of the Pelješac Bridge is certainly the most complex and technologically demanding project that I have managed in my long career. Basically each pier in the sea is a separate construction site that needs a competent manager, equipment, delivery of materials and a team of workers. This means that we actually had 12 construction sites on the location, two on the coast between which there is 2.4 km of sea or, if we go around, two state borders, and 10 construction sites which - until the superstructure was connected - were actually islands. A few more numbers: there was a total of 655 workers and 28 different vessels at the construction site at the moment when work was in full swing. We used to joke that the construction site was a miniature Hong Kong.

However, this was not the most difficult job I have ever done: I was the representative of the investor on the Čiovo Bridge, which was also co-financed from EU funds. The main contractor went bankrupt during the works and it was necessary to re-contract the remaining works, resolve the relationship with the bankrupt company and maintain the continuity of EU co-financing. Eventually, we managed to do that, but the atmosphere at the meetings was very unpleasant. Cooperation on the construction of the Pelješac Bridge was challenging, there were certain confrontations, but the atmosphere remained positive from start to finish.


The construction of the Pelješac Bridge required the engagement of a small fleet of different vessels. A large number of sailors participated in works.

Communicating with Chinese colleagues

I will be direct: at first it was rather difficult to communicate with the Chinese at the construction site. Colleagues from China who work for the contractor - the company CRBC, come from a system of education and work on large projects that is definitely significantly different from ours, Croatian, European. As a result, when working with them, you need to invest more effort for the same thing compared to working with colleagues from countries that are culturally closer to us. Let's face it, the Chinese colleagues have the knowledge and experience of building similar facilities at a level that I am not sure we would have achieved with European contractors. They are good engineers and hardworking workers, and the result is a bridge built with high quality and on time. However, the differences in the approach to solving everyday tasks required a disproportionately large effort on our part, and I believe also on their part.

Let me try to explain: colleagues from China follow the project implementation plan that was made earlier, far away from the construction site, perhaps at the company headquarters, and adhere to it even when it should be adjusted, because new circumstances have arisen.

On several occasions, at construction site meetings, we made reasonable and justified suggestions for improvements that were aimed at more efficient, faster or simpler execution of certain work, but the Chinese partner had difficulties accepting that. Sometimes it happened that our initiative was accepted at the construction site meeting, but then, after two weeks, our Chinese partner would return to his initial conception and the whole discussion would start again. This is why I say that working with Chinese colleagues was sometimes very challenging tiring, but the results testify that we did a good job together.

Quality control

It seems that our contractors have not previously encountered the system of professional supervision that we establish at our construction sites, on projects of Hrvatske ceste. We insist on proof of quality, especially through the implementation of control tests, and Chinese partners do not like additional control and try to avoid it. On the other hand, we have to say that the Chinese proposed new, better materials, especially in situations where they could reduce the cost of construction.

During the works, they got used to our system and accepted the more detailed control and the fact that we strictly adhere to the scope of control tests prescribed by the project. They also had the support of Croatian engineers whom they hired to work for them on this project. On the other hand, we are got used to their manner, that is, discussing the same thing more than once.

So, eventually, everything ended well, although there were sometimes loud debates typical of any construction site. For example, a certain imperfection was found on one steel element, so the supervising engineer stopped its installation until additional tests were carried out. However, the person in charge from CRBC continued to work so that there would be no delay in relation to the plans that were formed in the headquarters of their company. The situation escalated to such an extent that the dismissal of responsible persons was requested, but everything was eventually smoothed out and resolved in a way that satisfied both parties, while achieving the main goal, which is the unquestionable quality of every single part of the bridge.

Work discipline and organization of construction

The Chinese builders had a different approach to work compared to what we are used to at our construction sites, and their system has some values that should be emphasized. First of all, I would like to mention their work discipline. In this respect, it is clear that these are people who come from a completely different, probably much stricter system that characterizes their work attitude. We had the opportunity to witness this daily, in all aspects of our

Inspection of welds - review of radiographic images in the office.

Chinese workers were very disciplined at the construction site, in the picture: reinforcing the pile cap

cooperation. I would especially like to point out the importance of discipline in the fight against the COVID 19 pandemic, since it is a global event that no one could have predicted at the time of contracting and which affected all aspects of the world economy, including the construction of the Pelješac Bridge.

The pandemic started in China, so the measures to close the borders immediately affected our builders. Still, owing to discipline and centralized organization, they reacted quickly and decisively to the changed business conditions, with the aim of continuing the implementation regardless of the significantly difficult circumstances. They succeeded in that, and for that we give them credit. Parts of the steel superstructure were completed and shipped across the ocean amid the global economic shutdown, an achievement that testifies to the great organizational skills of the Chinese counterparts.

Despite all the challenges and changes in the market, the works were carried out at reasonable prices and within a deadline that was extended by agreement due to objective difficulties. When talking about the organization of the construction, one more aspect should definitely be mentioned, and that is the use of a large amount of completely new, very valuable equipment for the construction of the Pelješac Bridge. No expense was spared on the equipment for the execution of the works: 6 completely new tower cranes were installed at the construction site, 6 sets of two derrick cranes each for mounting steel segments by lifting them from the sea, 12 completely new concrete mixers, each with a volume of 9 cubic meters, and 3 new container compounds were also built to accommodate workers.

Pictures from the construction site in the midst of the execution of the superstructure testify to the effort of the CRBC to acquire a valuable reference on the Pelješac Bridge and to present themselves in the best light. This performance may be related to the company's strategic effort to enter the European Union market, but, in any case, the bridge profited from it.

Informal socializing with Chinese colleagues

On public holidays in the People's Republic of China, we were invited to festive lunches where our colleagues were really cordial hosts. However, these gatherings were actually of a formal nature and I cannot honestly say that we got closer informally. Perhaps it will take a little more than three and a half years for such a thing.

Unexpected situations

Something unpleasant and unexpected happens at every construction site. For me personally, the most dramatic event during the construction was removing the consequences of damage to one of the piles of the S12 pier, when the bottom of the last pile that was installed in the foundation of the bridge twisted and cracked. I will try to describe the situation: the divers enter a tube with a diameter of 1.8 m, filled with polluted sea, so visibility is really low, and they descend to a depth of 47 meters under the surface. There are twisted 6 cm thick pieces of steel below, which need to be cut out and brought to the surface. In addition to the diving equipment, they also have to carry equipment for cutting steel. We used several cutting techniques until we came up with an effective solution, and it all took about 30 working days. All this time we were extremely concerned about the safety of our divers, all because of the last 50 centimetres of the last installed pile. Fortunately, everything ended well, that last pile of the last installed pier achieved the specified load capacity, and everyone who repaired it is alive and well.

Construction site with facilities, site camp and operative shore near Brijesta on Pelješac at the end of 2019

The road Brijesta – Orebić is indicated on the map, and the text from the Spatial Plan of Dubrovnik-Neretva County says as follows:
Corridor Pelješac – Korčula: the planned longitudinal road along the Pelješac peninsula together with the natural continuation of the route of the Korčula D118 state road should form the backbone of the transport network of Pelješac and Korčula in the future. It is planned either as a central road that connects all centres (larger settlements and ferry ports) on the Pelješac peninsula and the island of Korčula, directly or via a network of short cross connections.
The corridor of the planned road starts in the grade-separated Brijesta junction on the corridor of the Pelješac junction (A1) – Pelješac Bridge – Doli junction (A1) and leads to the planned port of Perna for the connection to the planned port of Polačišta, from where it continues along the planned connecting state road to the intersection with the D118 state road.

Preparations for retirement

Pelješac is not my last bridge, and even less the last project I will lead. Before I retire, I still intend to complete my role in the construction of the Ston Bridge, as part of the same road, that is, of the project Road Connection to South Dalmatia. After retirement, I intend to continue managing projects somewhat smaller, personal, mostly related to fishing and the olives I grow on my island of Korčula.

The significance of the Pelješac Bridge for the future of Korčula

The 32.5 km long road project, which also includes the Pelješac Bridge, has enormous significance for Dubrovnik and its surrounding area, for the part of the county east of the Neum Corridor. The way to the port in Orebić, from where we take the ferry to Korčula, will certainly be shortened and made easier by the construction of the bridge with access roads. However, travellers who will arrive to Pelješac via the motorway system and well-maintained state roads will surely feel the shortcomings of the existing island road from the junction Sparagovići – Zaradeže to Orebić. The construction of the bridge, I am convinced, will show that there is a need to intensively plan a new road that will start at the junction of Brijesta and then via Orebić, that is, the planned new ferry port - to connect Korčula in the future. I think that it is impossible to reconstruct the old road because it has bad technical characteristics, it is a very winding road and passes through settlements in the closest vicinity of houses. This project is very demanding, due to the configuration of the terrain, the hills on Pelješac, but it is the main prerequisite for stronger development of the peninsula and Korčula. It is a project for the next generation, which is in the study phase at the time of the completion of the bridge.

4.5. STEEL SUPERSTRUCTURE

The steel superstructure of the Pelješac Bridge exceeds in size any steel bridge or building previously constructed in Croatia. 33,600 tons of steel, that is, 165 sections produced in Chinese factories, were incorporated into the construction. A favourable circumstance for the bridge was the fact that the Chinese factories where the girders were made had the capacity for such an undertaking, and the manufactured segments could be transported by sea, so the size of the pieces was actually limited by the equipment and the assembly project. Large pieces were transported by ship, so there was no need for significant consolidation of the elements at the construction site, which is good because a great deal of assembly was done in more favourable factory conditions.

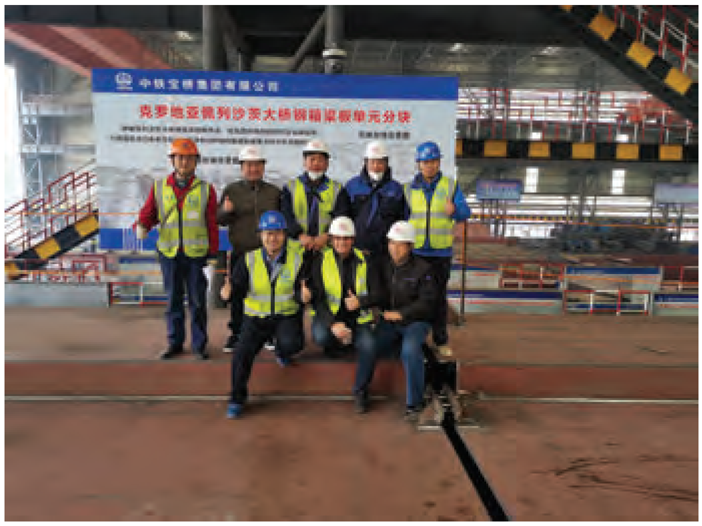
The main girder was quickly and precisely assembled from the delivered elements, owing to a qualified and skilled contractor who engaged significant auxiliary means, specifically, a floating crane with a large capacity and as many as 6 pairs of cranes for cantilever construction. The first elements on the land side were lifted to the installation site in March 2020, and the last segment was installed on July 28, 2021, so the entire superstructure was assembled in just 17 months. This achievement is even more valuable considering the fact that it happened during the pandemic that stopped many projects around the world.

Factory production of bridge segments

During the development of the implementation project, the Chinese engineers, under the control of the Slovenian-Croatian team, developed the designs of the bridge span structure into workshop drawings of steel sheets that will be cut, bent and then welded in the factory into prefabricated sections. This was followed by transport by ship to Croatia, lifting of the segments to the installation site, adjusting dimensions and setting in the correct position and finally connecting by welding into a complete structure of the bridge. This work was done with millimetre precision; prefabricated parts of enormous mass and size were connected. When the weather conditions at the construction site, work at height and other aggravating circumstances are taken into account, the undertaking becomes even more fascinating.

When we talk about sheet metal, we usually perceive thin metal sheets, but in the bridge construction we deal with thick steel plates. For example, the carriageway sheet in the area of the central cell has a minimum thickness of 20 mm and in the edge cells 14 mm and thickens to 25 mm in the areas of the connection to the concrete part of the carriageway structure. The minimum sheet thickness of the curb path is 14 mm and is thickened to 20 mm in the area of the connection to the concrete part of the carriageway structure. The lower belt of the box is a sheet of thickness 14 and 18 mm (edge part) and 20 mm (central cell), which gradually thickens to 50 mm in the area of the connection to the concrete part of the carriageway structure. The vertical web plates are 12 mm thick and gradually thicken to 50 mm in the areas of connection to the concrete part of the carriageway. The sheet metal of the vertical web plates of the inner cell is 18 and 28 mm thick in the upper part and gradually thickens to 35 mm in the area of the connection to the concrete part of the carriageway.

Production of steel elements of the Pelješac Bridge at a factory in China



Quality control at the factory showed that the bridge segments could travel to the other side of the world, to Croatia.

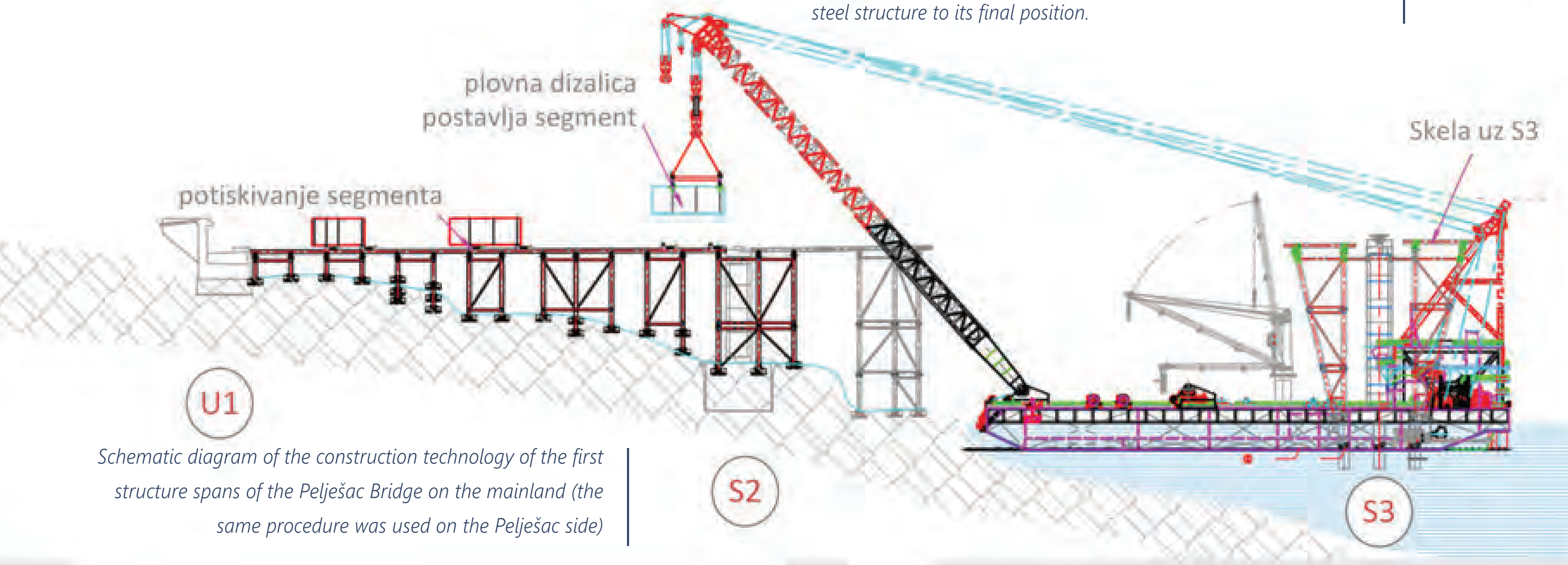
The production of steel elements in the factory began in 2019, under the control of supervising engineers from Croatia. Control tests, supervision of construction and control of welds and geometry at the construction site were among the main prerequisites for the success of this construction project. After the trial assembly in the plant, the elements were shipped directly to the construction site.

Installation of segments above the coastal terrain

The assembly of the elements of the superstructure above the coastal terrain began on the mainland, where it was not possible to put them directly in place in the structure with a crane from the sea. Because of this, heavy tubular scaffolding was installed on land, from which the segments were slid to their final position. For this, supports were placed on the scaffolding, on which the steel elements of the superstructure were temporarily placed. A floating crane placed the elements at the end of the scaffolding, which was located along the coastline, and then presses pushed them to their final position. Pushing was done on blocks that slid on steel rails - channels, which followed the curved shape of the grade line of the first spans.

After preparing the segments on the scaffolding and fine-tuning them by cutting and grinding, the circular welding platform was mounted. It is a scaffolding that covers the connection between individual elements, and from it the welders connect the elements into a complete superstructure.

Lifting the first element of the steel structure on the mainland in March 2020. The segment was placed on the blocks by a floating crane, which, pushed by hydraulic presses, will slide together with the steel structure to its final position.



Schematic diagram of the construction technology of the first structure spans of the Pelješac Bridge on the mainland (the same procedure was used on the Pelješac side)

The segments above the land are pushed by presses to their final position in the structure - parts weighing around 180 tons gradually slide, pushed by hydraulic presses along lubricated channels on the scaffolding.

Balanced cantilever construction

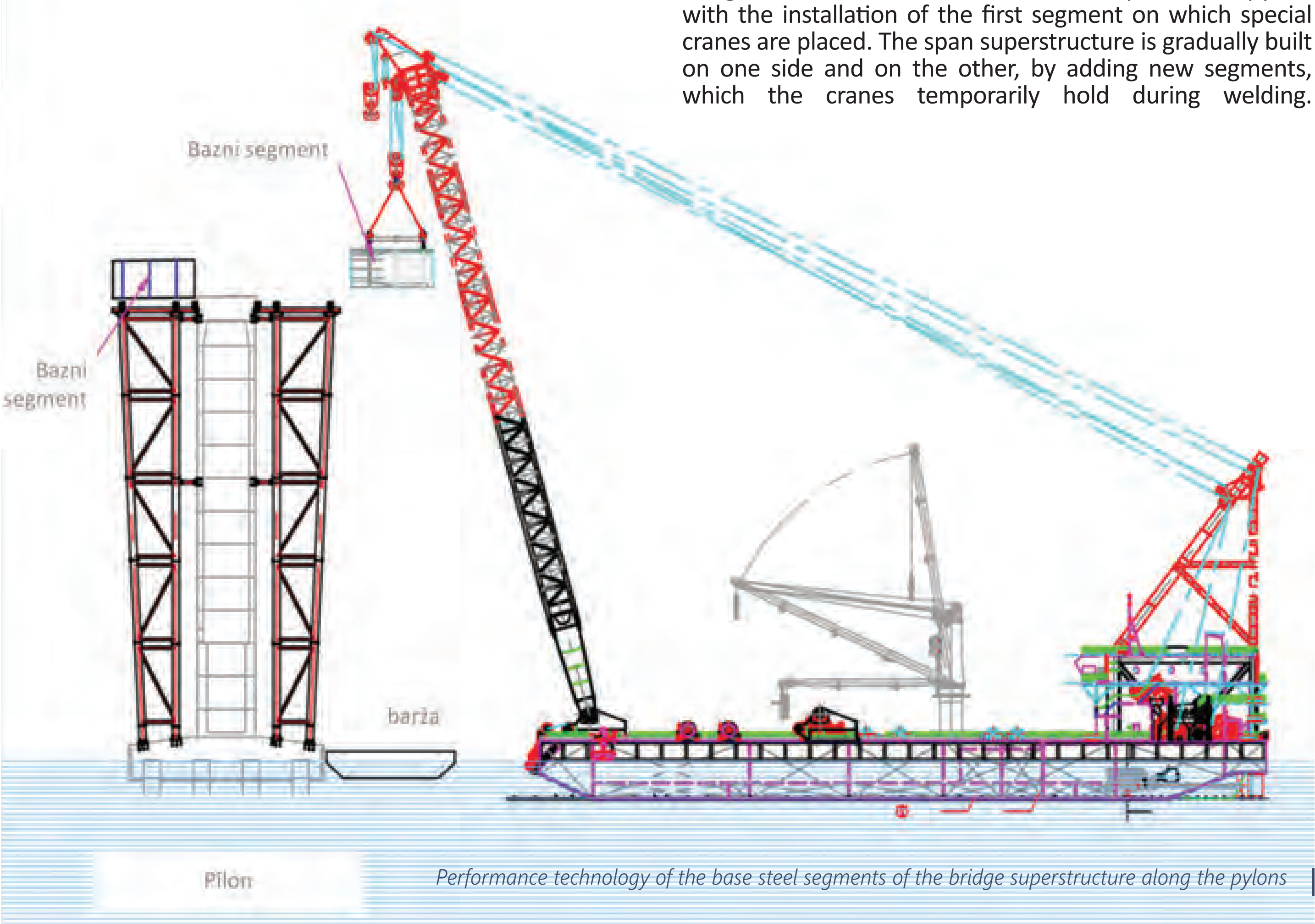
At the same time of the installation of the first sections on mainland, the first load-bearing scaffolding was also installed next to the pylons, on which the so-called base segments will rest. These are two key steel segments next to each of the six pylons, which are rigidly connected to the pylons by concreting. They are ultimately not held in place by stay cables, so they receive temporary support during installation. This is also important so that cranes can be placed on these segments, which will later lift parts of the bridge in the process of balanced cantilever construction. Scaffolding of the base segments, with a large load capacity, is placed on the pile caps and supported by the piers.

First segments of the Pelješac Bridge, on mainland, placed in their final position and prepared for welding - May 2020

First steel elements on the scaffolding next to the S5 pylon – June 2020

In the past, bridges were built in such a way that the supporting scaffolding was first built, on which the bridge parts were placed. When one span girder was completed, the scaffolding would be removed. For long-span bridges, especially over waterway obstacles, this scaffolding method would be very irrational. The process of balanced cantilever construction was developed in order to avoid the construction of huge scaffolding that serves to support the structure during the construction.

A load-bearing system containing a girder with stay cables is particularly suitable for cantilever construction, since the load-bearing structure during construction does not differ much from the load-bearing structure of the completed bridge. Construction starts from the base part of the pylon, with the installation of the first segment on which special cranes are placed. The span superstructure is gradually built on one side and on the other, by adding new segments, which the cranes temporarily hold during welding.



Performance technology of the base steel segments of the bridge superstructure along the pylons

After that, new segments are held by stay cables and thus become part of the load-bearing structure. After that, the crane is moved and the process can start again. By connecting the segments, cantilevers or overhangs, are created, that is how this method got its name. During the construction, the overhangs on both sides of the pylon must be in balance, in order to avoid unfavourable loads on the piers. For this reason, the procedure is also called balanced cantilever construction.

The process of cantilever construction cannot begin before the pylons, that is, the vertical elements above the carriageway, are built, since the stay cables that will take the weight of the installed segments are anchored in them. Before the construction of the highest part of the pylon, the sections between the base segments are cast in concrete. Their surface is identical to that of the steel girder so they are hard to notice, and the impression is that the steel girder is continuous from the beginning to the end of the bridge.

Another prerequisite for the start of balanced cantilever construction was the installation of cranes that will lift the segments from the vessel to the installation site. The so-called derrick cranes are installed symmetrically, one on each side of each pylon, and in addition to lifting, they also serve to fine-tune the position of the element of the steel superstructure and support it during welding and the installation of stay cables. When all this is completed, when a segment is welded to the previous one and when the intended force is introduced in the stay cable, the cranes simultaneously move to the end of the console with their own hydraulic devices and the process starts again, preparing the next segment for lifting. In order to meet the deadlines, the contractor procured six sets of two cranes each for every pylon. The capacity of the cranes was 250 tons per device, and the segments themselves, with a standard length of 12 meters, weighed about 200 tons each.

Lifting the first 12-meter long segments, which will be held in place by the stay cables, using derrick cranes on the base elements of pylon S7 in December 2020, the end parts of the steel saddles that will accept the stay cables are visible.

Prefabricated segments of the steel superstructure were delivered by ships and deposited on the operational shores, on both sides of the construction site. Before the final connection, the long consoles in the middle of the span are particularly sensitive to wind, so they were temporarily additionally stabilized with steel cables, which were removed after connection.

Pylon S6, balanced cantilever construction, May 2021.

Welding

All assembly joints of the steel structure on the bridge are made by welding. Welding thick steel sheets at the construction site is a significant challenge, since a strength higher than the strength of the base material needs to be achieved at the weld point. Before the welding of segments starts, they are temporarily fixed with auxiliary pieces, the edges of sheets that will be welded must be carefully prepared, and after that the welder passes several times over one joint so that the weld is eventually fully filled. Part of the preparation is the assembly of the scaffolding, which will allow access to the entire span, from the outside and inside of the box. After welding, the joints are polished, as much as 5 times per one joint, with constant monitoring of each weld. This job requires skill, which is proven for each welder individually, but also endurance for precise work that sometimes takes place in extremely difficult conditions.

Welding of the circumferential joint of the bridge segments from below.

Semi-automatic welding devices were used to partially make the joints on the carriageway slab, the welds are filled, while most of the welds were made manually

Installation of stay cables

Stay cables consist of individual ropes - strands of wires, and each rope is separately tensioned and anchored. The rope is pulled into the pipe to pass through the anchorage heads, where it is fixed by the anchors. The ropes are delivered to the construction site wound on reels, and protective tubes of stay cables are installed before installation. Part of the stay cables was formed by pulling into the protective tubes from above, from the pylon, and part from below, from the carriageway slab.

Stay cables are installed symmetrically, in pairs, as the construction segments are installed. The stay cable pairs are anchored in the pylon at the same height, but on opposite sides of the concrete tower. At that point, where the forces from the opposite stay cables are transmitted, saddles are installed in the pylon through concrete. Saddles are specially made steel elements that connect the stay cables to each other. These elements are made in the factory.

Important parts of the stay cables are anchorages at the ends, with which they are attached to the pylon, that is, to the span superstructure. The anchors at the ends of each stay cable are not the same: one is passive, fixed at the end of the stay cable, and the other is active, which means that it can be adjusted later. By subsequently adjusting the tension of the wires, they can be tightened or loosened, in order to achieve the force prescribed by the project in each wire. If there is a need for it during the use of the bridge, the active anchorage can be removed so that the stay may be replaced.

The passive anchorage, that is, the one that remains fixed, is located on the pylon, in the steel saddle, whereas the active anchor, that is, the one on which the tensioning of stay cables is done, is located in the box of the steel superstructure. Each rope is tensioned separately, with a hydraulic device, a press, which stretches it until the given force is achieved in the ropes. The force is continuously measured, and when the prescribed value is reached, the rope is fixed into the anchorage and the procedure starts

Production of pylon saddles in the factory

Installation of the protective tube of the stay cable, there are visible spiral protrusions that serve to prevent oscillations in special circumstances again, on the next rope, according to the predetermined protocol. The process is repeated until all the ropes are tensioned to the default forces, then the stay cable assumes its role and the cantilever construction process can move on.

On the Pelješac Bridge, the stay cables were immediately stretched to full force during the construction of the segment, and there was no subsequent tightening. Force corrections in the stay cables are possible during the use of the bridge, if an unplanned event occurs.

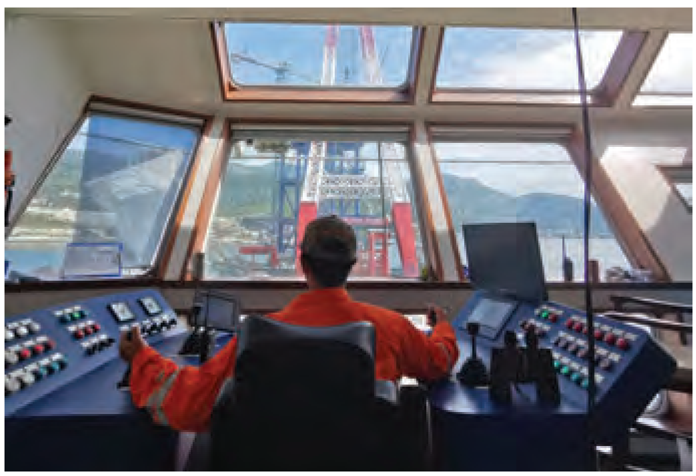
Pulling the rope into the protective tube from the carriageway – the strand of wires forms an inclined stay cable

Construction of the access, girder part of the bridge

Simultaneously with the progress of the cantilever construction of the suspended part of the superstructure, the installation of large segments of steel girder on the access parts of the bridge also progressed. After the spans over the land were constructed, the girder sections were first placed over the piers and were temporarily supported by the scaffolding. Then connecting sections were placed between these elements, which were temporarily supported by the already installed parts using large connecting girders. These are the heaviest elements that were built into the bridge at once, the largest had a mass of around 800 tons.

Tensioning of the inclined stay cable is performed using a compact hydraulic press, according to the given protocol, until the desired force is reached. Force is measured on the instrument in the centre of the image.

Installation of the girder segment on the S3 pier, October 2020



The control station of the crane with a capacity of 1,000 tons, which was used during the assembly of the largest bridge segments.

Complex girder geometry

All phases of construction took place according to carefully developed protocols, since each action causes certain deformations in the structure. The designer's task was to foresee all the changes in the construction during the execution in such a way that in the end the girder shape originally imagined by the designer was realized. Considering a large number of stages, this task is extremely complex, and its realization depends on strict geodetic monitoring of each step.

The final confirmation of the design assumptions was obtained during the assembly of the final segments, connecting the consoles into a whole. The final step, the joining of the last segment of the structure, took place at midnight, between July 28 and 29, 2021. The late hours were chosen because the daytime heat in July causes the steel to stretch, so the opening into which the last prefabricated piece needs to be fixed becomes too narrow. When the previously produced parts cooled down a bit, it was possible to wedge the last segment into place, even though a bit of sanding needed to be done, since the temperature did not drop below 30°C even at midnight.

Lowering the segment of the steel girder to the installation location in the part of the assembly that is not suspended, the huge girders are used to temporarily support the structure, which weighs about 800 tons, during welding.

Grade line – the basic line of the Pelješac Bridge construction is a complex spatial curve, achieved by careful adjustment during the construction

Installation of the last girder segment

A ceremony was organized to mark the connection of the bridge, which, in addition to the Prime Minister of the Republic of Croatia, Andrej Plenković, was attended by a large number of the highest state officials, as well as designers, builders and a large number of those who participated in project implemen- tation.

After the steel superstructure of the bridge was connected into a whole, the bridge was far from being a completed structure. However, it can be said that the most difficult part of the work was done with quality and within the deadlines that were slightly extended due to reasons beyond the control of the project stakeholders.

A number of details on the construction still needed to be completed, which were extremely important for the durability of the bridge.

The ceremony of assembling the superstructure of the Pelješac Bridge into an uninterrupted whole, the night of July 28 to 29, 2021

The Prime Minister of the Republic of Croatia, Andrej Plenković, with government officials, bridge builders, the main designer and representatives of investors at the ceremony of connecting the Pelješac Bridge into a whole.

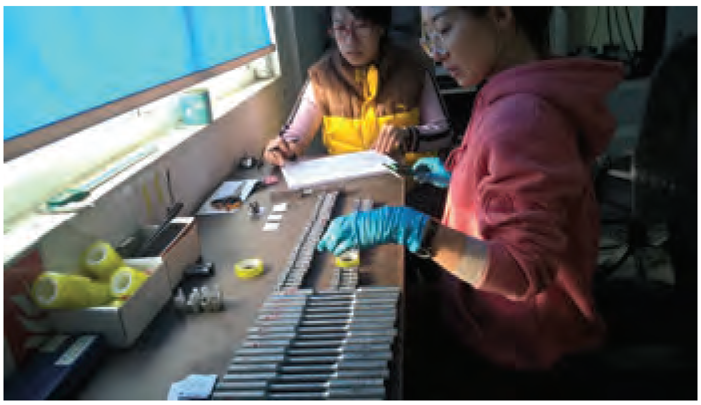
ASSEMBLY OF THE STEEL STRUCTURE

Z O R A N   T R O G R L I Ć M.Sc. in Civil Engineering

Zoran Trogrlić, M.Sc. in Civil Engineering, IGH Institute; supervising engineer for steel structure assembly on the Pelješac Bridge construction project.

Steel - the main structural material of the span superstructure of the Pelješac Bridge

Even though all structural steel came from the Chinese factories, it is exclusively the material with appropriate certificates according to valid European standards. This means that the factory production control has been checked according to the norms valid in the European Union, and the certification was carried out by European and Chinese companies with appropriate authorization. Furthermore, the quality was also confirmed by numerous control tests. In total, around 34,000 tons of steel were installed in the bridge.



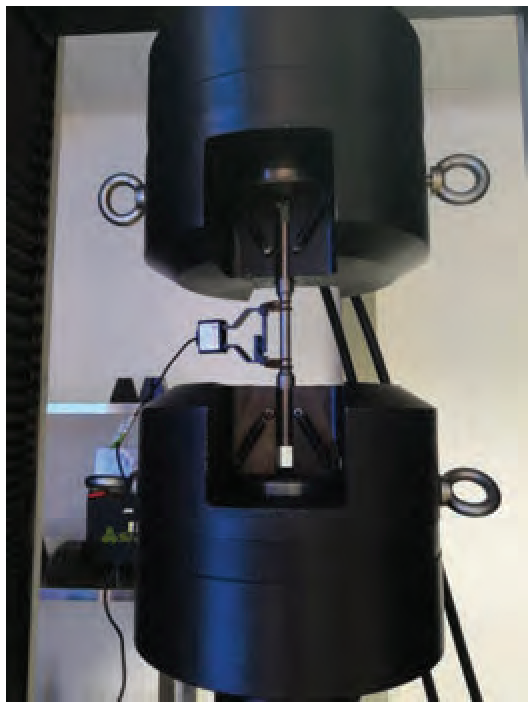
Preparation of steel samples for testing in the Chinese factory - the tests were monitored by the supervisory service from Croatia

Welding

Welds are joints on which the overall load-bearing capacity and quality of the construction depend. In workshops and factories in China, 462,500 meters of welded joints were made. These are the joints of prefabricated elements, and the length of prefabricated welds on the construction site was 26,720 meters. Of this, circumferential welds account for 9,440 meters, and trapezoidal welds another 17,280 meters.

Welding was done only manually at the construction site, using the so-called MAG process, with the use of semi-automatic welding for some types of welds on horizontal surfaces. All welds on inclined and vertical surfaces are done by hand.

All the main assembly welds, that is, those performed at the construction site, are controlled along their entire length.



Steel sample in the testing press

Other welds are controlled within the scope defined in the designed quality class and significance in the construction. The following non-destructive testing methods were used, in an appropriate combination: visual, ultrasonic, radiographic and magnetic.

Inspection of welds with an ultrasonic device inside the bridge.

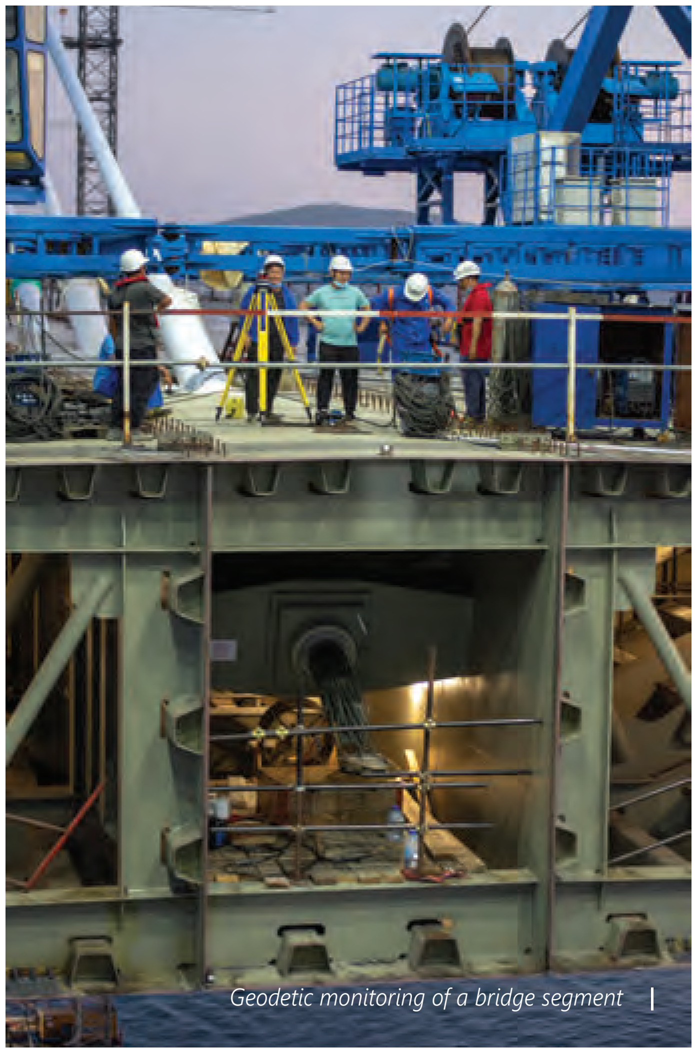
Assembly of segments and control of bridge geometry

The largest segment that was made in a factory in China, delivered and installed in the bridge had a mass of about 800 tons and was 56 meters long. The standard prefabricated elements, 12 meters long, that is, those with stay cables, weighed 180 to 200 tons. A special, very extensive set of construction site documentation, the so-called camber protocol, was created to control the geometry. It is a detailed calculation of the position in which certain points on the structure must be located at each stage of the bridge construction, so that the structure ultimately takes on the exact designed shape. At the construction site, the performance is monitored by surveyors, who check the accuracy of the position, especially the height of certain points, with the given tolerance, that is, the permitted deviation from the calculated position. I can say that we are very satisfied with what was achieved, because there were no major deviations of the derived geometry beyond the designed tolerance limits. Such precision required the constant presence of surveyors on the bridge, who followed all phases of the installation of the segments, from placing them first in the given position by the cranes, then tensioning the stay cables, which took the load from the segment in order to move the cranes into position for raising the next segment.

Precise assembly of the steel superstructure

The final shape of the girder line is achieved after the stay cables are tensioned. The stay cables were tensioned to a predetermined calculation force, and then after that the geometric shape, that is, the exact position of the support part, was checked, depending on the accuracy of the camber calculation. This geometric protocol was created for each of the 84 stages of assembly and contained a camber calculation, that is, the height at which the segments should be during installation. As a result, only after the assembly is completed, when the entire structure is deformed by its own weight, the given shape is achieved. It means that the deformations of the structure are also calculated and based on them the points are calculated by which the installation of individual parts is monitored. Each phase was tracked geodetically, that is, in each phase we knew the coordinates within which the segment must be placed. After the segment that was installed last was set in its position, the previously installed segments were checked again. With a lot of effort, checks and adjustments, we achieved a very precise geometry of the bridge, in accordance with the designed shape.

The implementation protocol of the camber and girder deformations of the Pelješac Bridge was done by a Chinese specialist, an expert who simultaneously performed the same task on two other bridges on different sides of the world. Furthermore, his budget was additionally controlled by the designers of the main bridge project and the auditors of the implementation design.



Geodetic monitoring of a bridge segment

Installation of the final segments of the bridge

We know that steel stretches under the influence of temperature, and the steel structure was completed during the very hot days of the summer of 2021. The last segments that are installed in each span of the bridge are called gap segments and they must exactly fill the opening between the two cantilevers. All fitting pieces are produced some 15 to 20 centimetres longer than the openings in which they are installed, in order to be precisely cut at to the exact size of the openings they have to enter, into which they have to fit. After that, they are held with auxiliary beams in the exact position until everything is checked and prepared for welding. After the last gap segment was installed, on the night of July 28, 2021, the final grade line, that is, the central line of the bridge was checked, and I can say that it blended in really great, that is, it has matched the line foreseen by the designer.

The most interesting moments of assembly are precisely those that precede the welding of the last, connecting segment in each span of the bridge, because their millimetre fit into the structure gives the final confirmation of the quality of our work on all previously installed segments. The fitting was done during the hottest days of summer, so the final insertion of the last segment was done at night, when it is cooler than during the day, in order to reduce the effect of stretching. One night the segment would be prepared, tailored and cut, and the next night it would be erected and installed. However, the timing of these works coincided with nights during which the temperature did not drop below 30°C, so for one segment the procedure had to be repeated and patiently waited for the installation conditions to be met.

Fine-tuning of the position of the bridge segments before the final connection

It should be known that a few degrees of difference in relation to the expected values causes centimetre long discrepancies. In addition, you should know that during hot days, the upper surface of the segment heats up to more than 50°C, while the lower one remains significantly colder, so the bridge element is additionally deformed. The key to the success of the implementation was continuous checks and controls.

It is also interesting how the height of the opposite cantilevers is fine-tuned in order to align them before mounting the gap segment. Usually one cantilever is a little higher than the other, so they need to be aligned. This is done by placing

The lifting of the gap segment between the two cantilevers in June 2021. At the end of the cantilever on the left, water tanks are visible that are being filled to bring the cantilevers to the same level, that is, so that the element that connects them fits correctly.

water tanks or some other temporary cargo on the higher cantilever, usually about 80 tons of water was placed on one side. On the night of July 28, 2021, the final segment, the last missing element, was joined. The ceremony was organized with several hundred guests who were waiting for the moment of union. That number of people represents about twenty tons of additional load on one side, on one of the two cantilevers. Such a load would upset the balance and lead to deviations that would actually have to delay the connecting process. To prevent this situation, all guests had to wait at the end of the bridge until temporary connections were made, after which the ceremony could begin.

Fitting in the girder at night

Stay cables

The total length of all stay cables installed in the Pelješac Bridge, of which there are 120 in total, is about 10,000 meters. It should be known that the stay cables consist of individual strands made of spirally twisted wires of high quality steel, of which each strand has an effective diameter of 1.5 cm2. Stay cables contain different numbers of strands, from 55 in the thinnest to 109 in the thickest stay cable. The total length of the installed ropes is 934.1 kilometres

Testing the thickness of anti-corrosion protection of the piles of the Pelješac Bridge, the default thickness is 850 µm

Corrosion protection

Anti-corrosion protection is crucial for the durability of any steel structure. The size of the areas to be protected is fascinating: the outer exposed surface with the carriageway is 120,000 m2, and the inner surface of the box is 226,000 m2. The anti-corrosion protection on the Pelješac Bridge was designed to last more than 25 years on bridge external surfaces and over 40 years on the inner part, and a standard epoxy-polyurethane system was used. Cathodic protection was applied to the piles and the reinforcement of the pile caps. The protection of some of the piles that are inside the sea is interesting: they have a triple system of anti-corrosion protection. The first component of the system is static protection, made by thickening the pile wall by 2.4 to 3.0 millimetres. The second is a protective coating that is applied in three layers with a thickness of 850 µm and finally there is the cathodic protection.

The Chinese engineer notes the conversation on the bridge in Chinese script, the language of communication is English

Language barriers

The construction of the bridge was accompanied by a large amount of construction documentation; each stage of the construction is accompanied by a detailed description, that is, the methodology approved by the main designer and supervision. All of this documentation was prepared in Croatian, prepared and downloaded using written forms in line with the procedures set in advance through the Quality Management System. In daily communication with Chinese colleagues, we used English. The documents were translated from Croatian to English and then from English to Chinese. We had no insight into how accurate the translation was in relation to the original and how clear it was; I believe that was the cause of frequent disagreements at the beginning of the works.

4.6

SUPERVISION OF CONSTRUCTION

ĐURO MIHALIĆ M.Sc. in Civil Engineering

Đuro Mihalić, M.Sc. in Civil Engineering, Institut IGH; head of expert supervision on the Pelješac Bridge construction.

Lead supervising engineer

The role of the lead supervising engineer on the Pelješac Bridge construction project includes everything that is performed in accordance with the Construction Act, as well as part of the Engineer's tasks according to the FIDIC guidelines, and is precisely regulated by the construction contract. The FIDIC Engineer is primarily responsible for the control and realization of the contract, while the expert supervision acts as a legally authorized person in the process of supervising the construction process. Expert supervision takes care of the compliance of the construction with the issued permits and applicable laws, but also enables the elimination of any obstacles encountered during the execution of the works, using their engineering and proactive approach. In this particular situation, I had the opportunity to help both the contractor and the investor in a formal and substantive sense, by managing the documentation and making sure that the project is realized according to the agreed specifications.

Working with Chinese contractors

The construction of such a complex structure requires a large number of skills, competences and special knowledge. Our partners from China had some of them to a greater extent, and some to a lesser extent. For example, they are much more skilled with steel than with concrete works. Nevertheless, I would like to emphasize their willingness to learn and, although they were reluctant at first, to accept and adopt new knowledge and skills. They tried to do everything efficiently, and in this respect we achieved good cooperation. I would also like to mention that the team members were young, and sometimes their lack of experience was compensated by will and discipline.

Establishing a documentation management system was much more difficult than starting the bridge construction work itself. Colleagues from CRBC were not used to the system of supervision and control that we regularly establish at our construction sites, and the client tried to ensure that the controls on such a project were even stronger than what is normally implemented. Such a situation caused a lot of problems at the beginning, we had to help them a lot, we worked hard on tasks that are trivial to our engineers, and the Chinese were lost in the procedure. When this did not work out, they employed some experienced Croatian engineers at the construction site, so with a lot of help from us, the supervisory service, shortly after the works started, everything went well in the administrative sense as well. Eventually, we now have very neat construction site documentation and archives, which is proven by the positive findings of bodies that monitor the spending of EU funds, such as SAFU (Central Agency for Financing and Contracting) and ARPA (Agency for the Audit of the European Union Program Implementation System).

Supervisory service

At any given time, there were 20 or more experts at the construction site and at the time of the highest intensity of work there were 25 of us from three companies that got the job as a consortium: Institut IGH, Investinženjering and Centar za organizaciju građenja (Centre for Organisation in Construction (COG d.o.o.). In addition, we engaged subcontractor specialist services, also Croatian companies. Members of the supervisory team took turns at the construction site, depending on the phase of work. It should be emphasized that we also had an accredited laboratory at the construction site for certain testing of material, which was carried out excessively.

Pile driving

Prior to driving, the piles had to be manufactured and checked in factories in China, then delivered to Croatia, to the construction site, and only after that they could be driven. This was carried out very neatly and precisely, partly thanks to the team's experience, and partly thanks to the powerful equipment, which enabled the manipulation of steel tubes up to 130 meters long and weighing up to 200 tons. I am not sure of the exact figure, but I believe that the rental of a hammer crane for driving piles costs about 100,000 euros per day.

The driving took place within the given deadlines, huge tubes were driven within the limits of the given precision (a deviation of up to 10 cm from the designed position) and everything went smoothly until the last pile, which was part of the pier closest to the shore. It was damaged at the bottom, so we had to fix it.

Let me remind you that the rock under the bottom of the piles close to the shore was additionally drilled using a special technology in order to insert the extended part of the reinforced concrete pile into it. There were a few problems with this technology of drilling through a tube previously driven to the bottom, but they were also overcome within acceptable deadlines.

This was followed by the extraction of material from the upper parts of the piles, their sealing at the given depth, and the removal of silt from the upper part of the piles. The supervision strictly ensured that all silt was disposed of in the prescribed manner, that is, that it was transported and dumped far out into the open sea. Before conducting concrete works of the upper part, our colleague Ivo Barbalić descended into the prepared pile in a basket and carefully inspected the inner surface before allowing the reinforcement and concrete works. Ivo was 65 years old at that time, so he retired during the project implementation, but all project stakeholders, the investor, the supervisory service and the contractor, requested that he stay until the project was completed. He is a real example of a man committed to his vocation, an engineer who consistently advocates for the profession but in a way that he is ready to help and explain, and for all those reasons he earned our tremendous respect.

Construction of concrete pile caps

The quality of the concrete produced at the construction site was not questionable, but the installation procedures had to be worked out, since these are unusual elements, of large volume and small surface area. For example, the pile caps of the largest piers contain 3,000 cubic meters of concrete each. There, we helped our colleagues from CRBC in the development of technology, because the locations at sea required good preparation. In the end, we poured 1,000 cubic meters of concrete at a time. Three ferries were used for large-scale concrete works, and three trucks, mixers with a volume of 9 cubic meters of concrete each, were loaded onto each of them. The ferries arrived at the installation site one after the other and continued to do so until the end of the installation of the planned quantity, without stopping.

There was one supervisor at each concrete-mixer truck and at each concrete installation site, for this job we hired an engineer from the supervisory service, two engineers from the laboratory and two more technicians. I would like to emphasize that only in the case when supervision is constantly present at the concreting site, we can conscientiously confirm that everything was carried out according to the project and the rules of the profession.

Special concrete

On heavily reinforced elements, mechanical compaction of concrete during installation is difficult, so the so-called self-compacting concrete was used, a material that completely bypasses the reinforcement and fills the formwork without the use of vibration devices. High-strength concrete was also used to make the upper parts of the pylon. I think that the C70/85 concrete class has not been used in Croatia for massive concrete elements, that is, in such large quantities. Reinforcement with a thickness greater than usual, up to 50 mm in diameter, was also used. It is interesting that for the extension of thick rods, threaded extensions were used - joints that were specially tested and certified.

Supervision controlled and approved all works - before concreting part of the pylon (above) and before laying the reinforcement in the formwork of the main girder

Technological advances in concrete required a large number of control tests, which were duly carried out as part of the supervisory team work. As far as the concrete quality is concerned, it is very good, strengths higher than those designed were achieved, and a small number of defects on the surface of the concrete were repaired. These are minor defects on the joints of the formwork, nothing important for the safety of the bridge.

Detail of the pile installation: the drilling device first extracts the material left in the tube after drilling on the previously driven pile of the S3 pier foundation, and then additionally drills the rock under the bottom of the steel part of the pile in order to carry out a reinforced concrete extension.

Welding of steel segments

After the installation of piers, it was time to assemble steel. The first elements were delivered from China, placed in place in the superstructure, and welding began, making assembly welds at the construction site, work that was largely done manually. That required highly skilled workers - welders. It should be said that large-scale welding work started in the second half of 2020, when the borders were closed due to the COVID pandemic, when the arrival of skilled workers from China was significantly hampered. At one moment we noticed that some of the welders are not working as they should. There is no need to talk about the importance of welding joints for the integrity of the superstructure - they are the most important joints in the construction. The situation did not improve after the warning, so in December 2020 we temporarily banned construction welding work. After that, a certain number of our experts were hired, and the Chinese welders received additional training. After that, there were no more problems with welding.

Challenges in achieving quality

Some works were carried out almost flawlessly, while some that required fine-tuning called for a lot of additional work with the contractor. An example is the construction of the central reservation on the bridge superstructure: test sections were made, and the work was approved only after the fifth test attempt, when we were convinced that the final execution was sufficiently neat.

I wouldn't like to be too critical, but I have to stress one very strong point of the cooperation with our Chinese colleagues, and that is mutual persistence which eventually always led to positive results. It should also be noted that all construction products came to the construction site with prescribed documentation, and we had no significant problems with that.

It should also be said that during the works we had the help and support of the bridge designer. The main designer, Marjan Pipenbaher, participated in the creation of the implementation design and was very engaged during the construction.

Final assessment of cooperation with colleagues from the Chinese company CRBC

I don't think we would have done the bridge this well with any other contractor. It was not easy, especially until the moment when our partners recognized our authority, but after that we found a way to come up with the best solutions for the construction site, even if it required much more conversation and meetings than was objectively necessary. Personally, it seems to me that the lack of initiative from our partners stems from their education in which authority figures are probably firmly followed, and that was the biggest challenge. The final rating of the collaboration would be a solid B.

Regarding the structure itself, there is a warranty period to reveal hidden defects, but I am convinced that the bridge, in terms of technical quality, in all its parts and as a whole in line with the project, is a perfect A.

Concrete works on the central reservation on the bridge superstructure

The production of piles in the Chinese factory was certified according to the EU regulation, therefore the manufacturer was able to put the CE construction product mark on them

The preparation of the carriageway surfacing for the laying of waterproofing begins with grinding the welds, the maximum permissible deviation of the flatness of the steel plate is only 2 millimetres.

4.7

BRIDGE EQUIPMENT

Bridge equipment consists of all parts necessary for comfortable and safe traffic on the bridge, as well as bearings, which transfer the load from the upper to the lower structure.

Bearings and transitional devices

There are no bearings on pylons S5 - S10, that is, on the suspended part of the bridge, since it is an integral frame construction. The vertical compressive forces of the approach part of the superstructure on piers S2, S3, S12 and S13 are transmitted to the lower structure by spherical bearings that move in all directions. These are devices that transfer the weight of the superstructure to the piers, enabling the structure to rotate in relation to the pier and its movement in all directions. Abutments and piers S4 and S11 are regularly subjected to compressive forces, but tension forces can also occur, that is, uplift reactions, so the bearings must transfer this component as well. Horizontal actions on abutments and piers S2 to S4 and S11 to S13 in the transverse direction to the bridge are taken over by longitudinal rails. Strong horizontal rails are welded to the elements of the span superstructure to transmit transverse forces from the span superstructure to the supporting structure.

Transitional devices with movable steel bars and rubber inserts are installed only at the edges of the bridge.

Carriageway and waterproofing

Waterproofing and carriageway surfacing are the most important parts of the system's protection against corrosion, and also an important factor in the safety and comfort of traffic. Waterproofing is multi-layered, made of reactive resins. The protective layer over the waterproofing is made of cast asphalt 4 cm thick, and the upper, wearing surface is of the same thickness and made of asphalt - concrete. The preparation of the surface for laying the waterproofing, the details of the insulation joints of the insulation and surface along the curbs edges and gutters were made carefully, according to the detailed instructions from the project. The discipline of the Chinese workers in performing these jobs was particularly evident.

Bearings and rail at the top of pier S3

Delivery of transitional devices to the construction site

Completion of the span superstructure on abutment prior to the installation of transitional device.

Laying of waterproofing on carriageway surface, October 2021

Cleaning of carriageway surface prior to laying one layer of waterproofing.

Entry into the bridge structure: door made such as those in ships, produced in the Radež shipyard, on the island of Korčula.

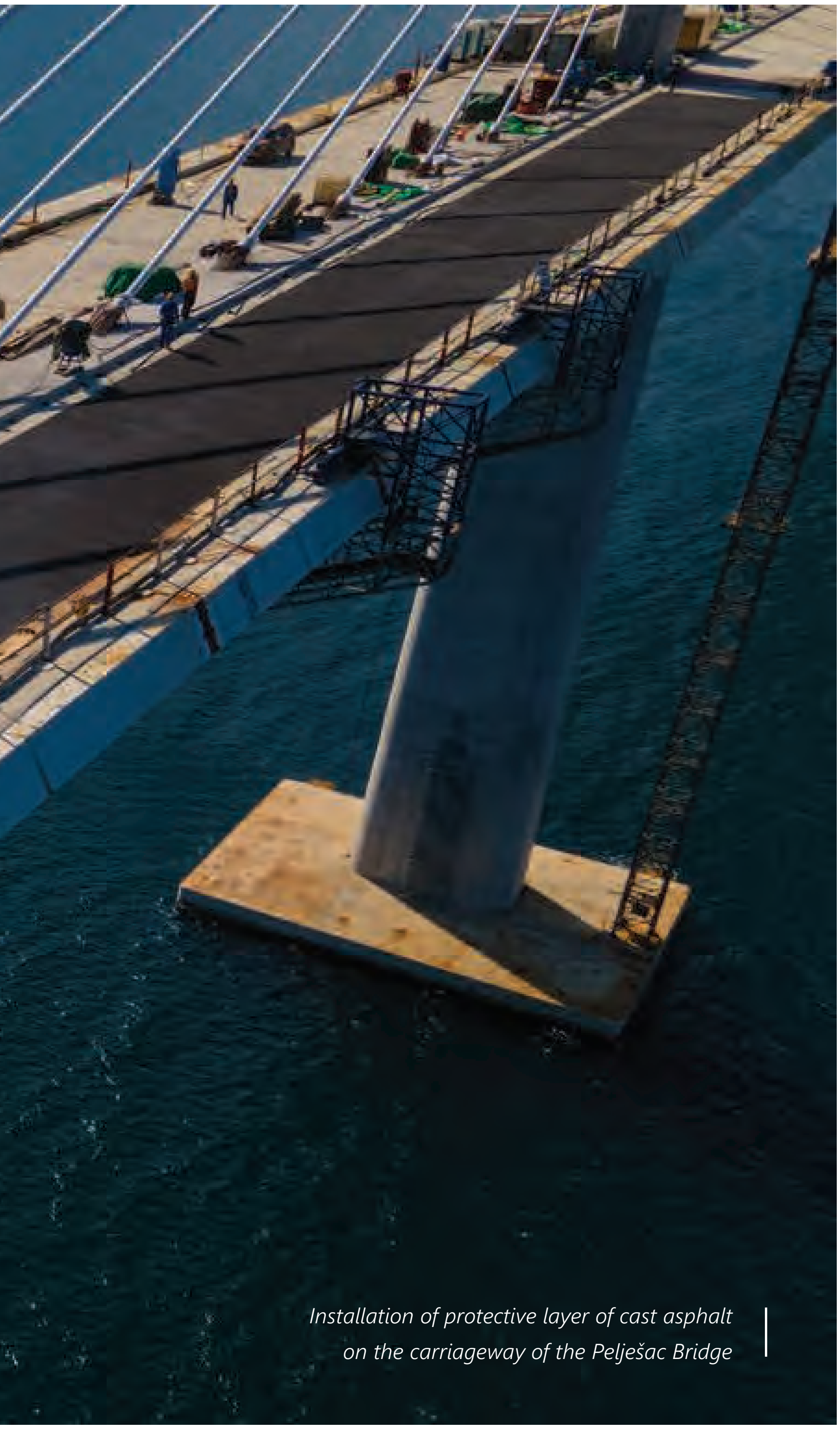
Inspection paths, ladders and doors for entering the structure

All hollow parts of the structure and piers must be accessible for inspection and maintenance. Therefore, inspection paths, ladders with platforms and doors for entrances to the structure are built into them. All these elements of the bridge are made of steel and produced in Croatia, in the company Radež d.d. from Blato on the island of Korčula, which produces marine equipment for domestic shipyards and foreign clients. A total of 552 tons of this equipment was produced and delivered for construction of the Pelješac Bridge.

Drainage pipes from the carriageway inside the superstructure.

Drainage

A closed drainage system has been installed on the Pelješac Bridge. That means that all water from the carriageway is drained in a controlled manner to the purification system outside the bridge and then discharged in a controlled manner. In the transverse sense, the gutters are located at the lowest points of the carriageway surface, and their longitudinal arrangement is determined according to the longitudinal fall of the bridge level. Thus, in places with the greatest longitudinal slope, the gutters are at a distance of 20 meters, and in places with a horizontal grade line- at 4 meters. The pipe system inside the structure is equipped with inspection windows that allow the system to be cleaned.



Installation of protective layer of cast asphalt on the carriageway of the Pelješac Bridge

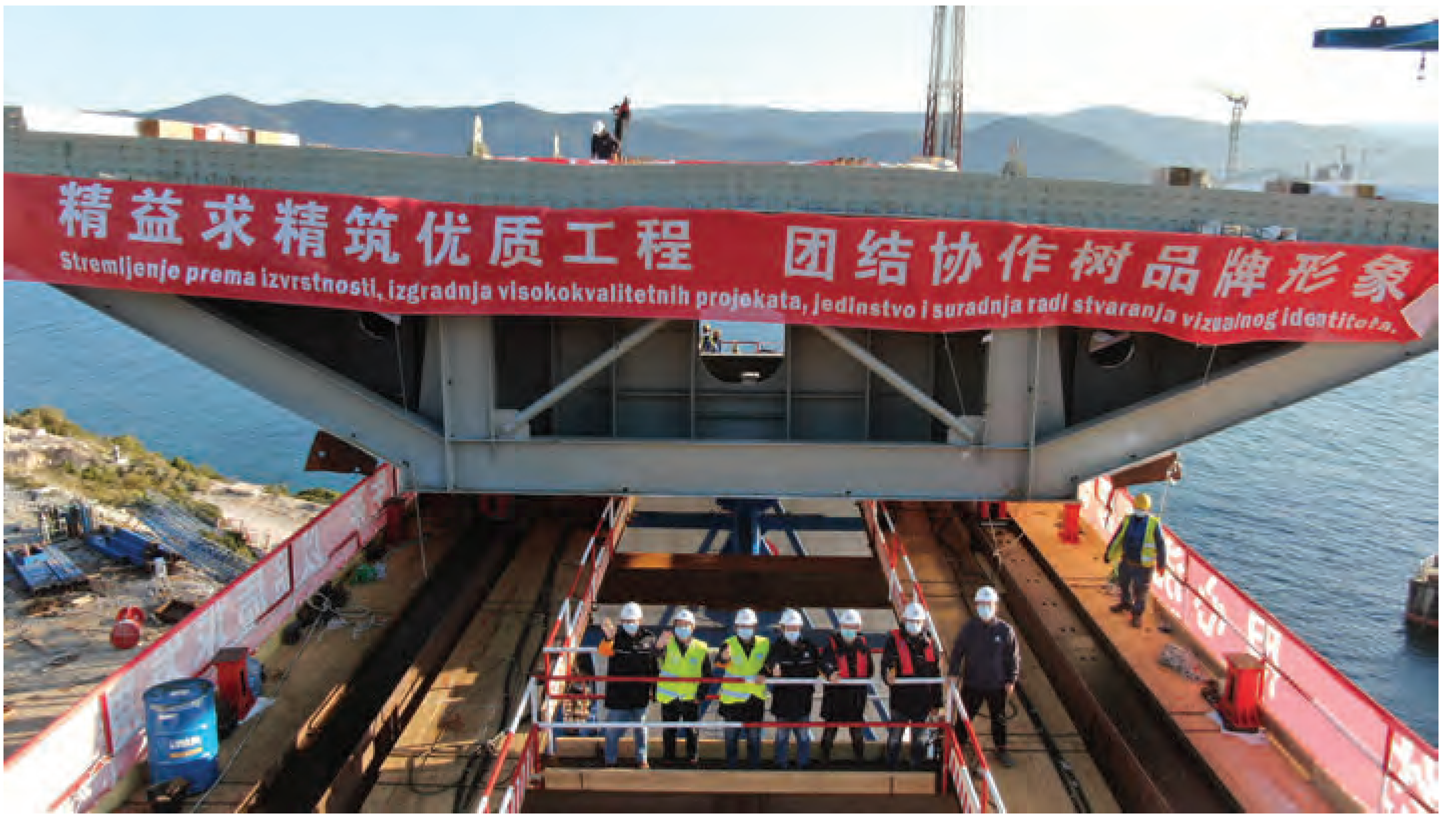
Bridge monitoring

Constant monitoring of both the bridge and traffic conditions will be performed by built-in sensors from the Traffic Control and Management Centre in Zaradeže. The system contains 362 sensors made of optical fibres for measuring deformations, based on which strain is determined, in piles, piers, pylons and steel superstructure. A total of 143 sensors measure the temperatures in the elements, and 6 GPS devices are installed on their tops to monitor the movement of the pylons. Accelerometers are sensors that monitor vibrations on stairways, pylons, superstructure and stay cables, and there are a total of 153 of them. The force in stay cables is controlled by 60 sensors. In the event of an earthquake, seismographs were installed near the bridge on both sides, the mainland and the Pelješac side. There are 248 permanent geodetic benchmarks installed to monitor and control displacements. Furthermore, sensors are installed on some pylons to monitor the process of concrete corrosion and corrosion threat to reinforcement.

Additionally, two anemometers for measuring the direction and speed of the wind were installed, also a meteorological station and a system for monitoring the number and mass of vehicles traveling on the bridge.

Wind protection barrier and lightning

Delivery of transitional devices to the construction site



The leadership of the team for the construction of the Pelješac Bridge of the Chinese company CRBC under one of the characteristic banners marking each successfully completed phase of the works.

4.8

CHINA ROAD AND BRIDGE CORPORATION:

CHINESE CONSTRUCTORS IN CROATIA

Basic information

The China Road and Bridge Corporation (CRBC) was formally established in 1979 in Beijing and included construction companies that had been operating since 1958 under the Foreign Aid Office of the Ministry of Transport. Today, this state-owned company has over 1,400 employees in the central office in Beijing, and in addition there are subsidiaries in about 60 countries in Asia, Africa, Europe and the Americas, mostly in developing countries.

CRBC is actually a subsidiary of a larger Chinese company, China Communications Construction Company (CCCC), which has been among the 500 companies with the highest annual revenue in the world for more than a decade. It is a conglomerate of companies that operate on the international market on a profit basis, but at the same time promote the political interests of the owner - the People's Republic of China.

The main business activity of CRBC is the construction of motorways, railways, bridges, ports and tunnels. In addition to construction, the company also deals with project development, financing and management of transport infrastructure.

The company's annual revenue in recent years has been around EUR 3 billion.

The construction of large bridges is among specialties of CRBC, and their references include buildings significant on a global scale.

• Surabaya-Madura Strait-crossing Bridge in Indonesia, linking Java with a smaller island, 2.1 km in length. It is a cable-stayed bridge with the 434 m long main span. The pylons are 140m in height.

• Bridge Maputo – Katembe in Mozambique, state in the south of the African continent, is part of the motorway connecting Maputo, the capital of Mozambique to the border of South Africa. It is a suspension bridge with the 680 m long main.

Bridge across the strait Surabaya – Madura in Indonesia, contractor CRBC

Bridge Maputo – Katembe in Mozambique, contractor CRBC

Interview with responsible persons at the Pelješac Bridge construction site, led by Lead Engineer Zhang Dong

• How was the decision made to apply for the construction of the Pelješac Bridge?

We have experience, qualification and skill in constructing cable-stayed bridges similar to the Pelješac Bridge, which gave us certain advantage in the procurement procedure.

• Is the procurement procedure in Croatia more complex than in other countries you have experience in?

The procurement procedure is fair, just and transparent. It is not more complex than in other countries.

• How does it feel to work so far from home? Have you got used to working in Croatia?

A few CRBC employees answered this question.

Ms. Chen: My family is in Shaanxi, a region in the northwest part of China. Although the construction site is far away from home, the Croatian people are very hospitable and the project colleagues are also very kind. Even though I sometimes feel homesick, the overall situation is generally good.

Mr. Liu: I graduated from university in 2019. This is the first time I am so far from home and it was not easy to get used to it. Now I feel better. I like the scenery of Croatia and the kindness of the local people.

Mr. Sheng: I have been working abroad for many years. Croatia gives me a different feeling from other countries. I feel good and comfortable here. . Once the Pelješac Bridge is completed, I will go home to take care of my parents, and then I will travel to Croatia again, but as a tourist this time.

• How do Chinese workers live in Croatia?

The Construction site management places great importance to the daily life of workers. The construction site conditions are set out in line with the regulations of the Croatian

Ms. Chen with her husband who is one of the construction managers

Liu, one of the young experts who got a chance to broaden his experience in Croatia

Sheng

Ministry of Labour, Pension System, Family and Social Policy as well as in line with the union policies. Food and accommodation conditions were carefully elaborated. The workers are satisfied.

• Have the workers mastered any Croatian?

To avoid risk of COVID-19 and devote more effort to work, workers go out relatively rarely. However, they manage to communicate with the local people by means of simple Croatian words such as: hello, goodbye, thank you, etc.

• What were the biggest surprises concerning who Croatian people work and live?

The biggest surprise of coming to Croatia is that the people are warm and hospitable, the scenery is beautiful, and the average temperature is such that it sometimes feels like being in China.

• *What is the greatest number of the CRBC staff at the construction site at once?*

During the period of high-intensity works there was a total of about 600 on-site construction personnel, including ordinary workers, machine operators, welding workers, vessel crews, logistics and support personnel, etc.

• *What was the selection process for workers and how are they organized?*

Most of the workers have long-term cooperation with the company. The project department selects personnel with strong responsibility, strict discipline, with rich construction experience. The team leaders were particularly carefully selected; they are skilled at managing their people well, but also at cooperating with them successfully.

• *It is not very difficult to notice that the Chinese workers are extremely disciplined: is it due to cultural habits or maybe measures for awarding discipline?*

Motto of the construction site as part of the workers' compound

Official bulletin of the CRBC construction site – something similar to wall newspaper

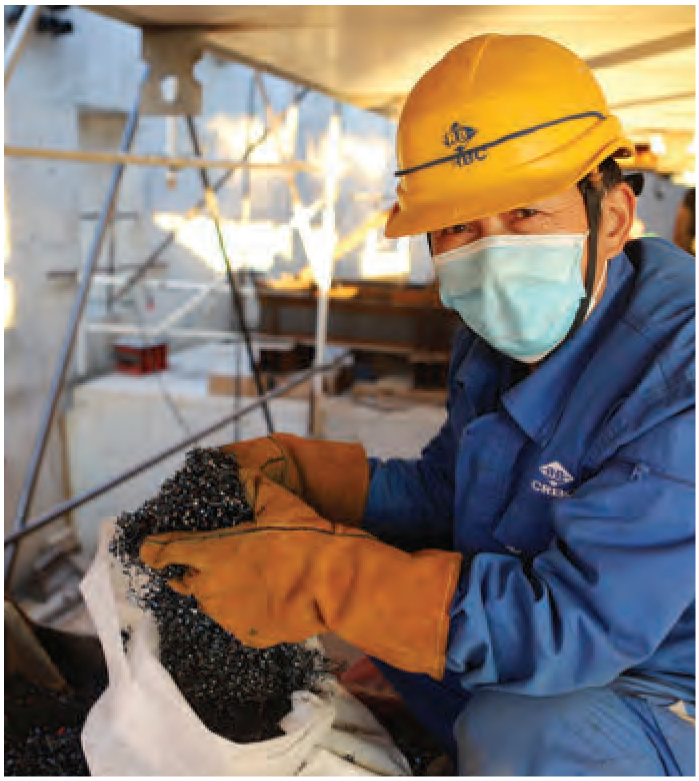
Most of the Chinese workers who come to work in Croatia are organized in the same way as in China, and they come to work as experienced teams. Before going abroad, CRBC conducts training for them, and establishes strict reward and punishment measures systems. This ensures that the workers obey the management orders during the construction period, and improves the construction efficiency on site.

• *What are the working hours at the construction site?*

The working time is 8 hours per day, and certain adjustments are sometimes made in line with the weather and actual conditions on site, all within the provisions of the Croatian Labour Law.

• *During the construction of the bridge, the COVID-19 pandemics arose and caused various measures around the world, isolation, distancing and movement restrictions, even work restrictions. What were the measures taken to fight the disease at the construction site?*

Offices at the workers' compound



Chinese workers performing usual tasks at the Pelješac Bridge construction site.

The project management established an epidemic prevention leading team and an epidemic prevention working team headed by the project manager. We managed to achieve cooperation with local hospitals. In addition, we established an epidemic prevention inspection team and a logistics support team. I could say that we managed to set up a constant prevention mechanism.

During the epidemic, the teams were divided into 5-10 people units. It was mandatory to wear face masks and to measure temperature twice a day. The personnel flow at the construction site was controlled, new passes were introduced, and access to the construction site was strictly controlled. When necessary, the workers were tested at local hospitals, and after vaccination started, our workers received vaccines in coordination with health institutions. After some time, all workers were vaccinated against the virus.

We have to emphasize that during the epidemic we did everything to make people feel as safe as possible, and ultimately we somehow strengthened our relationship with them. In terms of technical matters, care was taken to centralize the procurement of materials in order to minimize the risk for workers and all employees at the construction site.

• Were there any injuries at work? We have noticed that work safety is an important aspect of your work culture. What is the penalty for those who come to the construction site without safety equipment?

There were minor injuries during the construction process, but no major safety accidents occurred. During the work period, those who do not wear a safety helmet or not comply with the site safety regulations, are not allowed to enter the construction site. In case a worker fails to wear for example a safety helmet, appropriate fines are imposed.

• How do you organize your food/cooking? Do you use Croatian ingredients?

We have a total of 4 canteens at the construction site and the chefs in each canteen are Chinese. They come from different places in China, so we can eat different types of food. We have a local supplier of vegetables and meat.

Construction site of the Pelješac Bridge in March 2020, tidy and well organized

• *We assume that salaries for work in Croatia are greater that the salaries from the same work in China. Can you tell us what the difference is?*

Normally, the salary for working in other country is higher compared to the salary in China for the same job.

Chinese canteen at the Pelješac Bridge construction site

One of the boards at the construction site connects the development plan of CRBC with the current policy of the Republic of China with the words: "CRBC sincerely and conscientiously implements the conclusions of the 19th National Congress of the Communist Party of China, thoroughly studies and understands Xi Jinping's thought on socialism with Chinese characteristics of the new era."

A banner on occupational safety and warning related to environmental protection, with specified very severe penalty - CRBC, at the Pelješac Bridge construction site

• *What else did your company do to motivate workers to come to Croatia?*

CRBC provides all employees with labour insurance supplies and attempts to create a warm working environment for all employees. Croatia has a splendid history, social stability, and a well-developed tourism industry. The bridge construction site is located in the nature reserve, with beautiful scenery and pleasant. Finally, working abroad can increase experience and knowledge.

• *There are many slogans around the construction site: why is it so? Why are they important in the place of work?*

There are various slogans on the construction site and in the compound, a large part of which is about safety and epidemic prevention. They make workers pay more attention to their own safety at work and take various safety measures, such as wearing helmets or face masks, etc. Over time, workers' safety habits will gradually develop. To a smaller extent, some concern the significance of the project or they celebrate the completion of a certain construction phase. Such slogans motivate workers and give them a sense of purpose. These banners have an irreplaceable role, which fully embodies our corporate culture that focuses on quality, technology, and safety.

• *We often see fireworks at the construction site. Is it true that every successful stage of the completed works is celebrated with fireworks? Is it an inevitable part of the construction culture in China?*

Not really, we set fireworks only for the biggest events. Firework is not an inevitable part of the construction culture in China, the tradition and habit vary from company to company.

The banners promoting CRBC corporate culture were created without improvisation

The stands of the boards with slogans are made of steel, and the foundations are concrete, but these unusual structures did not withstand the storm. If the wind knocked down a panel, a new one was installed immediately.

Fireworks at the construction site

4.9

CHRONOLOGY OF MAJOR EVENTS

February 27, 2016
Amendment to the older Location Permit issued, which confirmed the compliance of the Pelješac Bridge project with the location conditions and spatial plan.

February 16, 2017
The Government of the Republic of Croatia adopts the Decision on the financing of the project Road Connection to South Dalmatia.

June 7, 2017
The European Commission approves EU financing of the project.

September 20, 2017
The bridge receives a Construction Permit (the effective date of the amendment to the construction permit, which was originally issued in 2007, is indicated).

April 25, 2018
A contract was concluded on the construction of the bridge mainland - Pelješac with access roads between the client Hrvatske ceste d.o.o. and the consortium led by China Road and Bridge Corporation, as well as the contract for supervision services with the consortium of Institut IGH d.o.o., Centar za organizaciju građenja d.o.o. and Investinženjering d.o.o.

July 30, 2018
Contractor induction – official commencement of works.

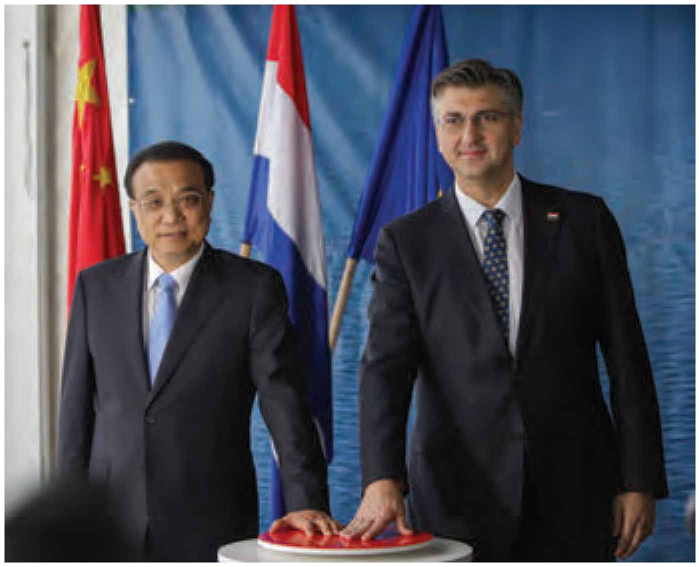
December 27, 2018
The first shipment of steel piles delivered to the construction site from the factory in China.

January 8, 2019
The first steel pile is driven. When the technology was well-established, two or even three piles were driven a day.

April 11, 2019
Premier of the State Council of the People's Republic of China Li Keqiang and the Prime Minister of the Republic of Croatia, Andrej Plenković, visiting the bridge construction site.

May 31, 2019
Driving of steel piles completed, 141 of them, the remaining piles (9) are installed by drilling.

June 2019
Concrete casting of the first piles.



Premier of the State Council of the People's Republic of China, Li Keqiang and the Prime Minister of the Republic of Croatia, Andrej Plenković, visiting the bridge construction site in April 2019.

Prepared formwork box prepared for the first pile cap, July 2019.

Construction site in October 2020.

July 11, 2019
The planned start date of the production of steel segments of the bridge structure, the start of production was postponed by 4 months due to the delay in the preparation of workshop documentation.

July 26 2019
Start of the production of drilled piles.

July 2019
The first formwork of the pile cap completed.

August 2019
Concrete casting of the foundation of the pier on the shore, concrete casting of the first pile cap (pier S8).

September 2019
Concrete casting of the first pier segment (pier S8).

November 2019
Installation of the tower cranes on pier positions. Start of the production of steel bridge segments in factories in China.

November 12, 2019
The stormy wind damaged the formwork of the pile cap of the S6 pier.

January 2020
During the construction of foundations on drilled piles, closer to the shores, material falls into the boreholes, RCD machine failures and work halts occur. The work continues with difficulties.

February 29, 2020
In the factory facilities of ZPMC and CRBBG, the production of the first segments of the steel superstructure (29 pieces) was completed, which were delivered by ship to the bridge construction site. These are the base segments of the central piers in the sea and certain segments of the steel span superstructure provided for the side part of the bridge. At the construction site, a supporting scaffolding is installed for mounting the steel structure.

March 17, 2020
Completed pier S2 on land and supporting scaffolding, the first steel element of the span superstructure on land installed.

April 2020
Installation of temporary support scaffolding for the steel span superstructure began on piers S5 and S8.

May 23, 2020
The first base steel segment of the span superstructure installed on pier S5. The base segments are 9.9 m long and weigh 267 tons each.

June 2020
Concrete casting of the joint between steel segments on pier S5, construction of the first pylon over the carriageway begins. By the end of June, 19 segments of the steel structure were assembled.

Production of steel elements of the girder span superstructure in a Chinese factory.

Construction site in March 2020.

Installation of the first base segment in May 2020.

The second ship with a steel construction in front of Komarna, October 2020.

August 2020
A large team of specialized welders from China arrived at the bridge construction site.

September 2020
The last pile completed as part of the foundation of pier S12, a drilled pile. During the execution, the steel sheath was damaged, so it had to be repaired. The welding of the segments of the steel span superstructure in the first span above the mainland has begun.

October 11, 2020
The second ship with a steel construction, with 13 segments weighing a total of 3,842 tons, arrived at the construction site.

October 2020
Installation of Derick cranes for the cantilever assembly of the steel structure on the S5 pier began. The first segment was placed on the temporary support scaffolding of the S3 pier, at a height of 30 m. The segment is 52 meters long and weighs 736 tons.

November 23, 2020
The third ship with 16 steel segments weighing a total of 4,484 tons arrived at the construction site.

November 2020
By the end of the month, 33 segments of the steel span superstructure were installed. The cantilever construction started using Derrick cranes. A segment weighing 789 tons was placed on the supporting scaffolding next to the pier S11.

January 8, 2021
The fourth ship with 16 steel segments weighing a total of 3,952 tons arrived at the construction site.

January 2021
A segment of the steel span superstructure weighing 794 tons and 52 meters long is mounted on pier S4, that is, the supporting scaffolding next to the pier. First stay cables installed. 42 segments of the steel structure installed (out of a total of 165).

February 15, 2021
The central segment between piers S2 and S3, weighing 581 tons and 52 meters long, was installed, connecting the first span above the sea.

March 5, 2021
The fifth ship with 29 steel segments weighing a total of 5,056 tons arrived to Komarna.

March 2021
On all central piers, the cantilever construction of the span structure is in progress, 66 segments have been installed, of which 42 welded. At the installation site, the central segment between piers 12 and 13, weighing 582 tons and 52 meters long, was erected.

April 14, 2021
The sixth ship with 38 steel segments arrived at the construction site.

Connecting the first span above the sea, January 2021.

The sixth ship with steel segment elements arrived in April 2021.

Installation of asphalt surface on the carriageway, October 2021.

Lifting the last steel structure segment, July 28, 2021.

Demobilization of the construction site.

Final works in December 2021.

Final removal of defects, works are coming to an end.

June 9, 2021
The seventh ship with 24 steel segments arrived at the construction site. Now a total of all 165 segments arrived.

June 30, 2021
The first final, gap element between the two cantilevers installed, span superstructure between pier S4 and S5 connected. Length of the gap element 18.6 m, weight 211 tons.

July 2021
Concrete casting of the central reservation. Connecting the span superstructure between pile piers. Length of gap segments 18.6 m, weight 211 tons.

July 28, 2021
Installation of the gap segment between piers S8 and S9, the last of a total of 165 segments, the entire span superstructure of the mainland – Pelješac Bridge is placed in the geodetic designed position.

July 30, 2021
The agreed date of completion of the works, the deadline for completion, extended to January 31, 2022. The delay is caused by the difficulties arising from the COVID-19 pandemic.

August 2021
The work on the construction of parts of the access roads next to the bridge intensified, as well as the final works on the bridge. Preparation for the installation of transition devices.

September 2021
Installation of carriageway waterproofing and transition devices, coating of piers with silane, dismantling cranes, finishing works.

October - November 2021
Installation of cast asphalt on the bridge carriageway, installation of drainage pipes in the box, installation of crash barriers and wind protection barriers.

December 2021
Works on the construction of the roadside service facility Komarna, drainage (lagoons and separators), installation of vibration dampeners on stay cables, electrical works, installation of remaining elements of the monitoring system.

January 2022
Damage on the bearing on pier S13 observed, replacement bearing ordered. Preparation for test load and technical inspection of the building.

17 to 27 January 2022
Test load of the bridge.

27 and 28 January 2022
Technical inspection of the bridge.

26 July 2022
The **Grand Opening Ceremony**
of the **Pelješac Bridge**

THE BRIDGE AS A SCHOOL OF LIFE

DAVOR PERIĆ, M.Sc. in Civil Engineering

Davor Perić, M.Sc. in Civil Engineering, Hrvatske ceste d.o.o., engineer at the construction site. He has been working in Hrvatske ceste since 2015, after his initial professional experience in his hometown of Vinkovci. At his workplace in Zagreb he dealt with regular road maintenance, and then he took the opportunity to go to our largest construction site - the CPJD project - in 2018. During the construction of the bridge, he was promoted from administrative tasks, through assistant to client's representative for contracts for power supply and equipment of the route and bridge, as well as for the construction of the Brijesta junction.

First experience with a major project

The opportunity to go to work to the construction site of the Pelješac Bridge came to me at the moment when I had no experience with large projects, and during the four years of work I experienced some things that significantly influenced my understanding of the work I do. At the construction sites of the bridge, access roads and the Ston bypass, I had the opportunity to compare the working methods of three major global companies that come from different construction cultures, namely the Chinese CRBC, the Austrian Strabag and the Greek Avax. The differences in the approach to project realization among these contractors are great, but I might stay that the Chinese are the most particular. Another important feature of the project came from the fact that for two-thirds of the total 3.5 years of construction, the construction site functioned in a special, isolated regime due to the pandemic. The CRBC representatives acted quickly and decisively even before any movement restriction measures came into force in Croatia, since they had knowledge of the seriousness of the situation in China. The works continued without interruption, despite all restrictions.

In my free time, living next to the bridge construction site, I had the opportunity to socialize with Chinese colleagues, my peers, for years. When you get to know them better, they are actually very similar to us. Very ambitious young people came to Pelješac, they like sports and going out, are they are open and sociable. They come from college with a high level of technical knowledge, and it took them some time to adapt to our supervision system, which is at a level they are obviously not used to. It also took time to adopt all the default environmental protection measures, especially those related to the vessel fleet. There were fewer difficulties with safety at work, because the workers are very disciplined and I can say that there were no serious accidents during the entire duration of the project.

Concrete casting of pile in June 2019.

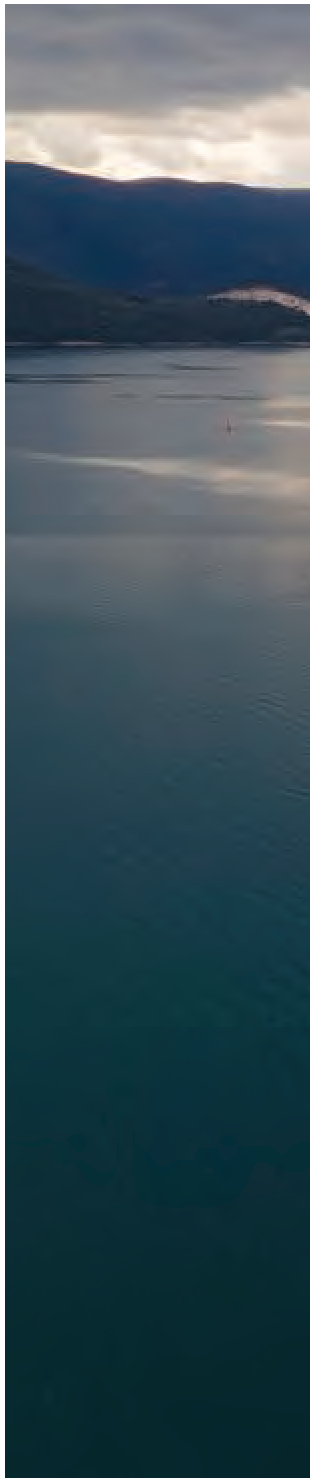
EU VIEW OF THE PROJECT

M.Sc. LOTHAR ZELLER

Lothar Zeller, Senior Transport Engineer at European Commission body JASPERS (Joint Assistance to Support Projects in European Regions) that operates in cooperation with the European Investment Bank, monitored preparations for financing and implementation of the project Road Connection to South Dalmatia.

The Pelješac Bridge, with its unique strategic, symbolic and emotional relevance is a kind of project which transport experts might only touch once in their career. The bridge including the connecting road network not only secures the integrity of the Croatian and therefore EU territory, but also provides a unique opportunity for the development of the region.

Many experts expected the bridge to become a "white elephant", with significant implementation delays and cost overruns. Instead, the project turned out to be an outstanding example of the project implementation in the European transport sector. The relevance of the bridge is even more underlined by the sad developments in Ukraine, which remind us how fragile the world we live in is.



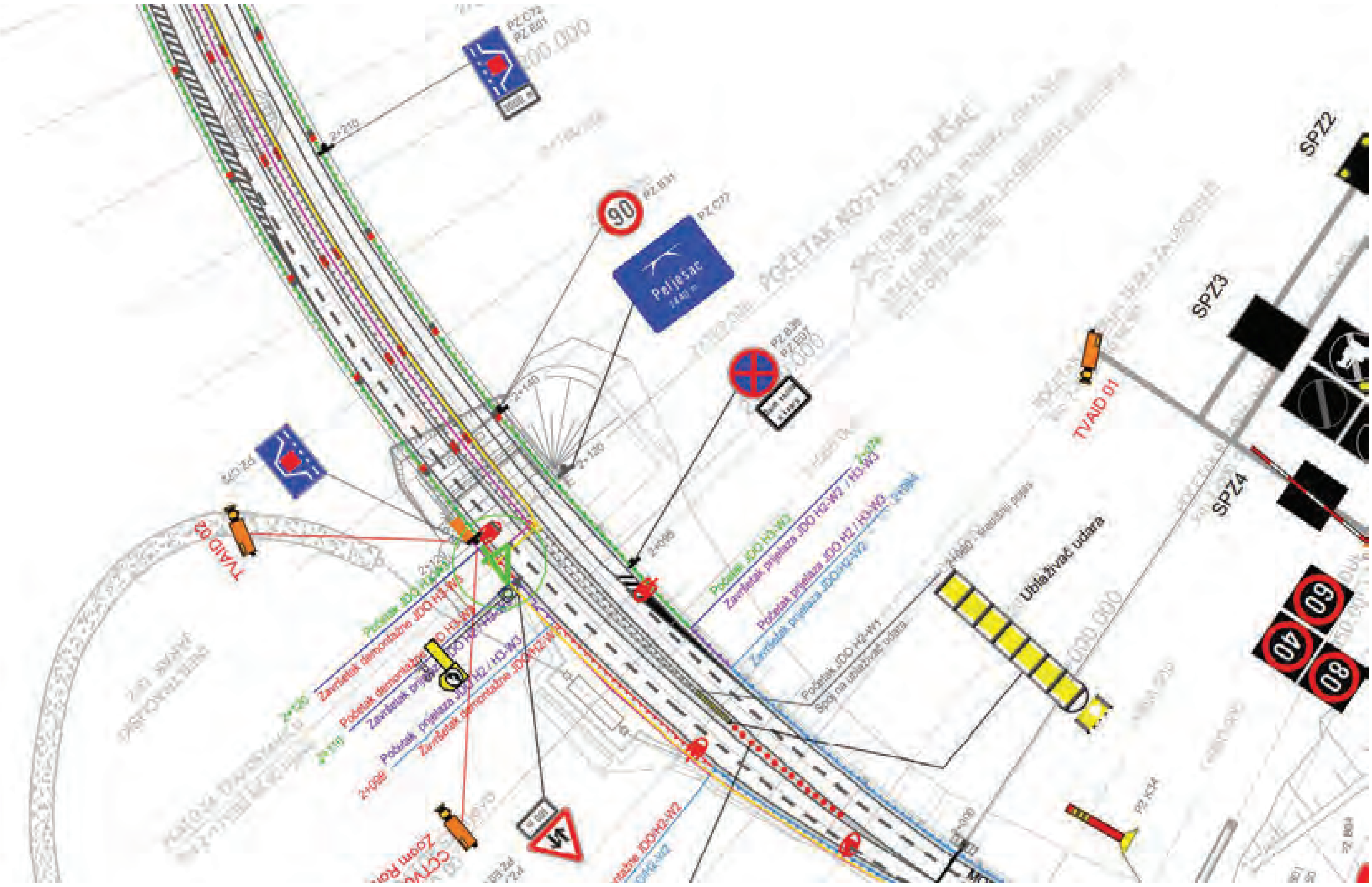
5. MANAGEMENT AND MAINTENANCE

5.1

TRAFFIC MANAGEMENT

The Pelješac Bridge with access roads is equipped with traffic signs, signalization and equipment, the purpose of which is to provide users with information on traffic conditions, to warn them of possible dangers, restrictions, obligations and prohibitions. Traffic is regulated by static traffic signalling system, but it is also managed by dynamic signalization system managed by the expert service at the Traffic Control and Management Centre (CNUP) in Zaradeže through the traffic information system. The centre covers the entire route of the road from the Duboka junction to the Doli junction, including the bridges and the tunnels. The combination of static and dynamic signalization systems ensures safe traffic flow even in the most demanding weather or traffic conditions.

The monitoring and management system automatically collects data from sensors and measuring devices in real time and then produces information from those data that describe traffic conditions: weather conditions, traffic load, incident situations and other factors. In particular, the traffic information system includes equipment installed on the road, bridge or tunnel, the transmission of signals from sensors to the remote control system in the Centre, which automatically manages traffic according to predetermined algorithms and scenarios. Such systems are called Intelligent Transport Systems (ITS). Some of them predict atypical phenomena, for example the road-weather system, because the data from the weather stations are processed in CNUP and, by means of an algorithm, the degrees of danger are determined according to which the signs and messages on the road are adjusted.



Traffic signalization on the Pelješac Bridge – from the project

The elements of the traffic information system of the Pelješac Bridge and access roads include:

o traffic system (collecting weather and traffic data and providing information)

o video surveillance and video detection system

o remote management and monitoring

o systems for monitoring the bearing capacity, usability and fire alarm

o call-in system

The traffic system is based on data collection on characteristics of traffic flows and current weather conditions on the road. The traffic is monitored by traffic counters built into the carriageway, and an automatic video detection system that enables data collection through digital processing and analysis of video recordings from cameras. The data on weather conditions are collected through weather stations equipped with sensors for measuring humidity, air pressure and temperature, wind speed and direction, type and amount of precipitation, visibility, carriageway temperature, and the thickness and salinity of the water layer on the carriageway.

The input criteria of the weather station for closing and opening the road are set in advance. So, for example, in wet road conditions, traffic for all vehicles on the bridge will be closed when the wind speed exceeds 90 km/h.

The video surveillance and detection system serves to recognize incidents on the road through a video recording that passes the detector for digital processing and image analysis. In case of such a situation, intervention protocols are activated, and traffic participants are warned about the situation through dynamic traffic signalizations.

The remote control and monitoring system includes stations for monitoring and controlling lighting, tunnel energy supply, ventilation and gas detection, pedestrian passage gates in tunnels, SOS system signalling, fire alarm system, hydrant system and connection stations towards the traffic information system and video system. Groups of stations are intended for monitoring and managing facilities on the section, and are connected to each other in local networks that are further connected to the main telecommunications line laid along the road route.

The systems for monitoring the bearing capacity, serviceability and fire alarm of the bridge consist of a system for collecting data on the structure behaviour, a system for measuring seismic activity, a system for monitoring weather impact and a fire alarm system for monitoring the interior of the bridge structure. The systems forward the alarms to CNUP in Zaradeže.

The information about the traffic situation from the bridge and access roads is transmitted in real time to the Centre for Supervision and Management of State Roads and indirectly further to the National Access Point, which is managed by Hrvatske ceste d.o.o. This enables the timely digital exchange of traffic data and information with EU member states.

Installation of surveillance cameras on the bridge

Centre for Supervision and Management of State Roads

5.2

LOAD TESTING

The bridge load testing is carried out in order to prove that the bridge in use will be able to take on the prescribed actions, and this is done controlling the accuracy of the calculation assumptions through measurements. One of the important measurements refers to the deformations of the structure under load, which are then compared with the values from the project.

The load testing of the Pelješac Bridge was carried out from January 17 to 27, 2022, using twenty trucks with an average weight of 40 tons, with 4 axles each, so a total weight of 800 tons was used. The measurements were carried out under static load - when the trucks are stationary in the given positions and under dynamic load, when the vehicles are moving across the bridge.

The testing was carried out according to the current standard, which stipulates that at least half of the maximum calculated internal force must be achieved on the tested parts of the bridge in the tested section. The efficiency of the load testing is first determined by calculation and then confirmed by measurements. So, for example, in one of the central spans of the bridge, the calculation predicted that the largest deflection (deflection in the middle between the piers) would be about 70 centimetres. Therefore, a load testing with 16 loaded trucks was determined for that part, which should theoretically create a deflection of 43 centimetres, which means that the efficiency of the testing is about 60%. When the trucks were placed in place, a deflection of 38.5 cm was measured, thus slightly less than the calculation.

During the static testing, the trucks are arranged in such a way as to cause the greatest internal forces and displacements at the observed location of a certain structural element. When the measurements are made, the

Load testing of the Pelješac Bridge by using twenty trucks of a weigh of 40 tons each trucks are moved into a new arrangement, intended to cause maximum forces and displacements in the second element, and so several dozen times. The largest vertical displacements of the span superstructure, the largest forces in the bearings, the rotation of the pylons and the span superstructure, as well as the largest longitudinal forces in the longest stay cables were measured. Displacements were measured geodetically, and forces by measuring relative deformations.

During the dynamic load testing, the displacement of parts of the structure is first determined when trucks pass through the bridge at different speeds. After that, the dynamic response of the structure when the vehicle passes over the obstacle is determined - the acceleration of the bridge part and the damping of the structure are measured. In a similar way, the influence of sudden braking on the bridge is checked. The dynamic characteristics of the bridge in the unloaded state were also determined: natural frequency, modal shapes and damping coefficient, and finally the natural frequency and damping on the stay cables were also determined

Based on the load testing, it was concluded that the measured displacement values of the span superstructure are within the expected limits, that there are no significant residual displacements after the structure is unloaded, and that the measured dynamic response of the structure is expected and realistic. After the testing, an inspection of the bearings was carried out, in which no changes were observed compared to the condition before the testing. It was concluded that the Pelješac Bridge behaves in accordance with the requirements of the project.

Geodetic equipment for monitoring displacements during load testing

5.3 MAINTENANCE

Structures deteriorate over time and due to external factors, both those that are included in the project and those that were not planned. In practice, it is shown that the concept of the structure, the design of details, the quality of materials and work are of crucial importance for the ultimate durability. In addition, the organization of maintenance and the amount of investment over the years of use have a significant impact on the longevity and cost-effectiveness of a structure. The modern design approach also includes proof of durability, which should meet the criteria set over the years. Designing for optimal durability includes consideration of maintenance already in the early stages of conceiving the structure, then through design and further through execution and maintenance until the moment the structure is removed.

The Pelješac Bridge, according to the design regulations, belongs to a group of buildings for which the estimated service life of 100 years is determined, this is taken into account in considering protection of load-bearing elements and the method of repair or replacement of parts for which it is expected that they will wear out earlier.

This is clearly defined in the project, so in relation to the mechanisms of deterioration of the material, the protective layers of concrete that protect the reinforcement, the features of anti-corrosion protection of the steel and the possibility of changing the stay cables were determined accordingly. Durability design means enabling inspection of all elements of the bridge, with the implementation of entrances, paths, climbing frames and lighting of the internal parts, and enabling access to the outer shell for paint repairs and other interventions was also considered. The maintenance manual, which is part of the project documentation, contains everything designed and executed in terms of durability, as well as a set of measures that should be taken so that the bridge truly remains in use for at least a century.

The company that takes over the bridge maintenance and management, Hrvatske ceste d.o.o., played the role of the investor during the construction, so preparations for maintenance were made during the final works. Buildings such as the Pelješac Bridge require continuous monitoring, and the team from the Zaradeže Traffic Control and Management Center is responsible for this. A favorable circumstance for

Cleaning the surface of newly completed piers and pylons is essential for the durability of the bridge, and the position of the workers indicates future challenges during inspections and maintenance.

The interior of the bridge is accessible for inspection, there are inspection paths, climbing frames and interior lighting.

the bridge is that there are also tunnels on the same road, for which European regulations prescribe constant traffic monitoring, so the equipment of the center in Zaradeže gains multiple significance.

Monitoring the bridge primarily means monitoring traffic and weather conditions, then there is the safety aspect and finally the construction aspect, that is, monitoring possible signs of damage to the building.

The key part of the implementation of the bridge maintenance program refers to the inspection of constructive and non-constructive elements of the bridge at programmed intervals and according to protocols developed depending on the periodicity. Rare bridge inspections are more detailed, and experience is very important for all levels, that is, knowledge of the structure, the construction process and indications of defects. The monitoring system automatically collects huge amounts of data from the sensors, but their interpretation, that is, the conversion of a set of data into information depends on the knowledge and experience of the engineer who ultimately makes decisions on maintenance.

The maintenance program contains regular maintenance, periodic renovation work and replacement of parts, as well as basic instructions for larger works. Repairs and reconstructions require design documentation. Regular maintenance refers to road, bridge surface and drainage cleaning works, especially equipment parts such as bearings and transition devices. Painting and restoration of anti-corrosion protection, arrangement and repair of pavement layers, fences and other parts are carried out periodically.

If necessary, repairs of mechanical damage, changes and repairs of worn parts, etc. are carried out, as well as numerous preliminary works that need to be done in a timely manner so that these works can be carried out properly.

It is known that buildings exposed to the direct influence of the sea deteriorate faster than others. The impact of the sea on some older bridges, especially on the Pag and Krk Bridges, resulted in expensive repairs, so special attention was paid to the resistance of the Pelješac Bridge to the sea action through design, construction and maintenance.

The maintenance of the bridge begins with consistent implementation of simple works; the picture shows the cleaning of the gutter on Dr. Franjo Tuđman Bridge in Dubrovnik.

5.4

COMPARISON

Lengths and spans of large Croatian bridges

The Pelješac Bridge surpasses all Croatian bridges built before it. However, it is not the longest bridge in our country, neither it has the longest span nor the highest pylons. It has certain characteristics that make it stand out among other bridges such as significance of the crossing and location, its impressive size and appearance in space, and the impression it leaves on the observer. If we want to express the features that make the Pelješac Bridge stand out in numbers, or set new records, the consumption of materials, concrete and steel come first. In addition, the new bridge contains the longest driven piles and the longest continuous span superstructure that is rigidly connected to the pylons, making it our largest integral or at least semi integral bridge.

When we say that the Pelješac Bridge contains a more complex structure than other bridges in our country, we primarily think of the concept, which combines main materials used in modern bridge construction - concrete and steel - in an unusual way. It is customary to use one material for the execution of the superstructure - steel, concrete or their combination in a connected section. On the Pelješac Bridge, the steel structure is interrupted above each of the 6 pylons by a section of prestressed concrete. By connecting steel and concrete into a unique load-bearing frame, which is additionally strengthened by stay cables, a unique structure has been created. It is important to note that the selection of the bridge concept did not come easy; years of different, sometimes polemical considerations regarding the design of this bridge preceded the final decision. The greatest influence on the design of the final structure of the bridge was the consideration of all foreseeable effects on the structure during its hundred-year lifespan. The economic and technical aspects of performance were considered, so known and proven technologies were used for the construction. And finally, the architecture of the bridge is conditioned by the aspiration that the huge structure imposes itself on the environment as little as possible.

Compared to some contemporary European bridges, the Pelješac Bridge is not a record holder for its total length, span size or pylon height, but for the way in which a rational and technically justified structure fits into the landscape of the bay and the coast.

Some comparisons with other bridges in our country will be given here, the bridges that dominate the space in terms of size and appearance and that we perceive as huge structures. When we get closer to them, in our perception, these bridges are, each in their own right, extremely large buildings, so it is interesting to make a comparison of their actual sizes in relation to the Pelješac Bridge.

Krk Bridge (Krčki most)

The bridge over the sea strait between the mainland and the island of Krk, built in 1980, contains two arches made of classical reinforced concrete, the larger of which has a span between the foundation structures of 390 metres. If we were to measure its span from foundation to foundation, which would be technically more correct, its size would exceed 400 metres. In both cases, it is a span that still holds the world record among classically reinforced arches, although larger concrete arch bridges with rigid free-standing steel reinforcement have also been built in the meantime. At the time of the construction, the larger arch of the Krk Bridge exceeded the previous concrete arch with a record span by as much as 85 metres. It was built using the technology of the balanced cantilever construction, without heavy scaffolding resting on the ground, on which massive arches were traditionally built.

The process applicable to steel bridges was developed by the designer in an original way. At the same, the designer tried to keep the element dimensions to a minimum, since the technology required a relatively light structure. The result is a magnificent achievement, but the slender structure with thin walls of load-bearing elements requires significant maintenance efforts. In the design and construction phase, certain compromises were necessary in order to achieve a record span, which came at a cost in the maintenance of the bridge.

The fact that a larger reinforced concrete arch has not been built since the construction of the Krk Bridge indicates that the development of new systems, initially bridges with stay cables, makes such structures on larger spans unprofitable for the time being.

Krk Bridge, with reinforced concrete arch with the record span of 390 metres, completed in 1980.

Franjo Tuđman Bridge (Most dr. Franje Tuđmana, Dubrovnik)

At the entrance to Dubrovnik from the west, the Franjo Tuđman Bridge was completed in 2002, with a main span of 305 metres, which is 20 metres more than the central span of the Pelješac Bridge. It is a structure that combines two systems, each starting from one coast and joining above the sea bay. The cable-stayed bridge consists of a pylon, which is 141.5 metres high from the base to the top, so it is higher than the central pylons of the Pelješac Bridge by some 40 metres. The asymmetric span construction on the western side contains a section with stay cables that stretches 244 metres across the Rijeka Dubrovačka, where it connects to a prestressed concrete beam. The prestressed structure on the east bank was carried out because the road is in a curve there, so the bridge could not be symmetrical, with pylons on both sides. The total length of the bridge is 518 metres, and the clear height above the sea is 50 metres.

Comparing the outlines of the Pelješac Bridge and the Franjo Tuđman Bridge, a difference in the height of the pylons compared to the main span can be seen; the Dubrovnik bridge is a classic bridge with stay cables and a high pylon, whereas the pylons above the carriageway are unusually low on the Pelješac Bridge. In addition, the Dubrovnik bridge has two rows of stay cables, which are fixed at the outer ends of the cross-section, whereas the Pelješac Bridge has one row of stay cables anchored in the middle. The cross-section of the Dubrovnik bridge is significantly narrower, 14.2 metres, compared to the Pelješac Bridge, which is 22.5 metres wide. The bridge across the Rijeka Dubrovačka has a composite open cross-section, with two main girders and a concrete slab on the top, whereas the Pelješac Bridge has a closed, that is, box-shaped section made of steel. The difference in the method of support is also important. The Dubrovnik bridge rests on bearings, while the Pelješac Bridge is an integral frame structure in the central part.

It is interesting that the construction of the bridge over the Rijeka Dubrovačka, similar to the construction of the Pelješac Bridge, started according to one project, but was soon suspended. Construction of the Dubrovnik bridge began in 1989, and was interrupted by the outbreak of the Homeland War. During the public procurement process before the continuation of construction, the potential contractor offered substantial savings based on significant changes to the original project. From today's perspective, it is highly questionable whether conceptual changes have resulted in a better technical solution, and the thesis about theoretically achieved savings could also be contested. However, in the circumstances that prevailed shortly after the end of the Homeland War, it was only appropriate to accept a solution that offered a lower cost.

The concept of connecting two different structures (cable-stayed bridge and concrete girder) within the main span is questionable for some experts in the context of a highly seismic area. The Franjo Tuđman Bridge and the Pelješac Bridge share practically the same seismic parameters. However, it should be said that the Croatian designer originally envisioned a different solution, with a steel structure with box cross-section in a larger span, and a concrete one in a smaller span, but the contractor offered an alternative that was supposed to bring certain savings.

Drava Bridge for motorway (Most preko Drave)

The Drava Bridge on the A5 motorway near Osijek stands out for its unusual length for a bridge over a river, as much as 2,485 metres, which means that it is about 80 metres longer than the Pelješac Bridge. In addition, this Slavonian bridge is also wider than the one on Pelješac, since it was built for a full-width motorway, with four traffic lanes and two stopping lanes, which makes a total width of 28.6 metres.

Long approach viaducts were built across the swamp area, which the river occasionally floods, as standard constructions of prefabricated beams made of prestressed concrete, which are connected by a carriageway slab. The approach viaduct on the right bank of the Drava is 1,063 metres long, and on the left bank it is 989 metres long. These structures are not special in any way, except that they lead to an interesting cable-stayed bridge over the main channel of the navigable Drava River.

The central bridge over the permanent river bed is 420 metres long and consists of a composite beam and two pylons 76 metres high, on which the beam is suspended by stay cables. The longitudinal arrangement of the bridge is symmetrical, with the main bridge span of 220 metres and side spans of 100 metres each. The traffic light is supported by a composite beam containing a steel box with three chambers, 12 metres wide. The suspension is constructed with two rows of parallel stay cables, both rows in the central axis of the bridge, in the central reservation of the motorway. The expansion of the box to the full width of the structure, required for the motorway, is carried out by cantilevered steel cross-girders, which extend through the box and then to both ends of the bridge in width. A concrete slab is attached above the box and the transverse girders.

The pylons of the Drava Bridge stand out in the Slavonic plain, only the 94-metre tower of the Osijek cathedral is higher. However, the justification of choosing such a structure can be disputed with the argument of two neighbouring bridges on the same river, with significantly smaller central spans. The upstream bridge over the Drava in Belišće, a girder structure with two steel girders in cross-section, connected by a composite concrete slab, has a main span of 94 metres. Furthermore, the downstream bridge on the western bypass of Osijek, built as a steel girder structure with a box section, has a central span of 110 metres. Both structures, upstream and downstream of the Drava Bridge, are simple girder structures, with smaller spans and significantly lower unit prices. The navigable profile for all three bridges is the same, 52 metres wide and 5.25 metres high above the highest navigable span.

All three parts of the Drava Bridge for the motorway form an impressive structure. However, this structure cannot be compared to the complexity of the Pelješac Bridge, since these are basically three separate bridges, two of which are typical structures. It is interesting that the bridge was not built using the cantilever method, which is appropriate for this type of load-bearing structure, but the beam was built by pushing it over temporary piers that were removed afterwards. The stay cables were installed after the girder was completed, which is very rare for bridges of this type. The bridge was practically completed at the time of the

Franjo Tuđman Bridge, with stay cables and a main span of 305 metres, completed in 2002.

construction of the Pelješac Bridge, but the completion of the motorway section towards Beli Manastir had to be completed before the bridge could be put into traffic.

Homeland Bridge (Domovinski most, Zagreb)

The Homeland Bridge in Zagreb is outlined here as an example of a cable-stayed bridge with low pylons. It is a wide bridge that carries a four-lane city expressway, and in the future, a light rail connecting the city centre with the airport will pass over it. The main span is 120 metres long, and the pylons are 16 metres high. It is a girder bridge, with prestressed concrete superstructure, which is suspended in the central part over the river by stay cables on two pylons, while there is a continuous border over the river flood zone. The total length of the bridge is 879 metres. In the 33.5-metre-wide cross-section, it is a five-part box. It is interesting that the first initiative for the construction of the bridge came from the Zagreb utility company, since the bridge carries large-capacity drainage pipes to the sewage treatment plant.

The comparison of this bridge with the one on Pelješac is interesting enough because of the pylon height, which are lower in both buildings than is recommended for cable-stay bridges. In the case of the Zagreb bridge, the ratio of pylon to span is 0.13, and in the case of the Pelješac Bridge, it is 0.14. For illustration, the classic cable-stayed bridge over the Drava River has a ratio of 0.27, that is, twice as much. Low pylons place these bridges in the group of special type bridges, which are quite rare in global practice. These are prestressed extradosed bridges, which actually came from prestressed concrete structures. At a time when complex calculations can be performed on numerical models, the imperative to classify the bridge among typical structures, for which theoretical calculation models have been developed, has weakened. When you observe the span and structure of the Homeland Bridge, one has to wonder why a suspension bridge was made when the common prestressed concrete beam could have done the trick. More so, prior to the construction of the Homeland Bridge, viaduct Kamačnik nearby Vrbovsko was built as a prestressed concrete girder, with a 125-metre-long span.

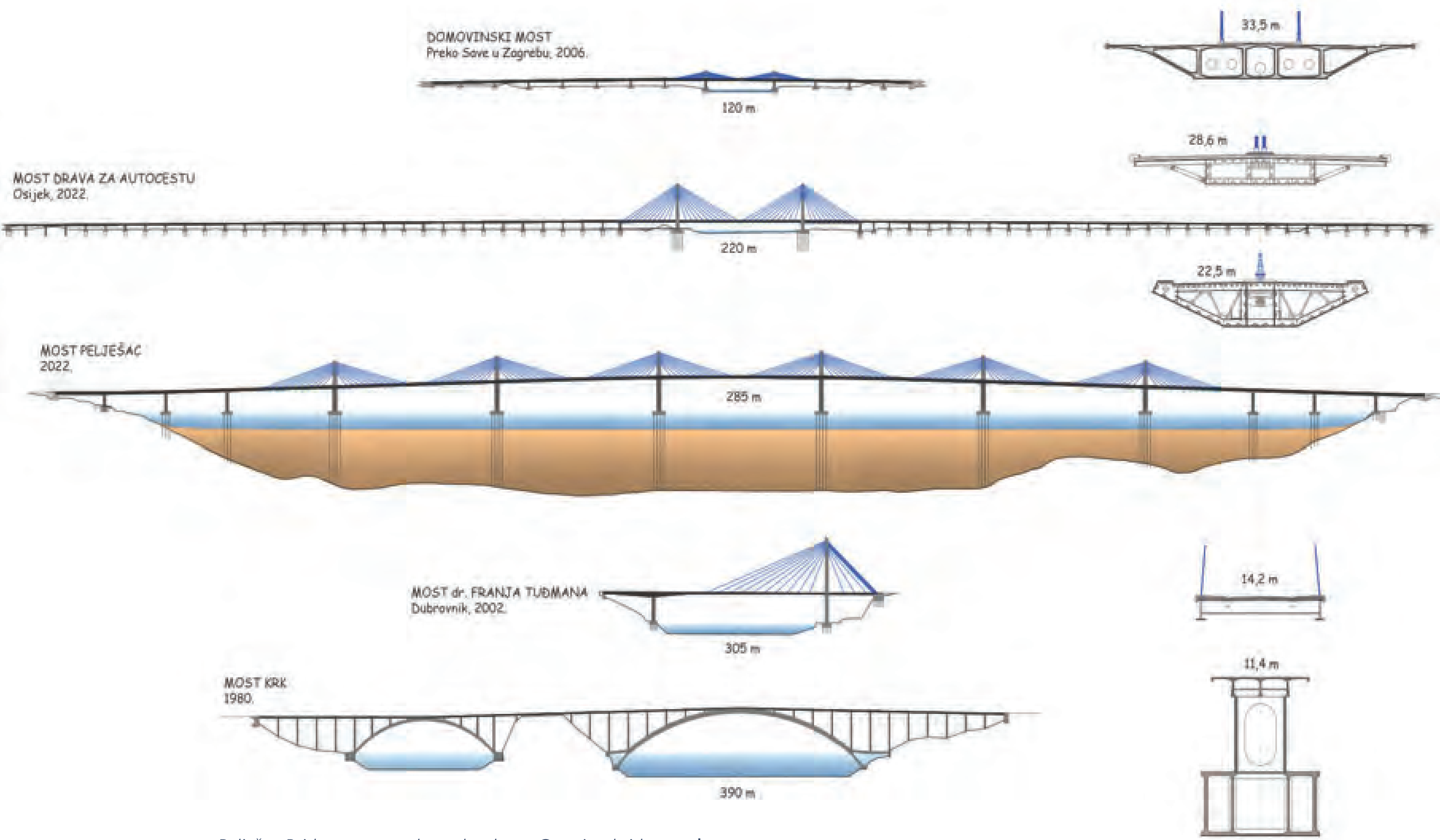
Homeland Bridge across the Sava River in Zagreb with a span of 12 metres, completed in 2006.

Comparison of span length and steel quantity

A comparison of the Pelješac Bridge and other Croatian bridges that we consider large reveals a difference which clearly indicates the engineering achievement of the peninsula crossing.

In addition to the Drava Bridge for the motorway, at the time the Pelješac Bridge was built, two more bridges were built over the Sava River, for the expressway near Stara Gradiška and the motorway bridge near Svilaj.

It is interesting to compare the total amount of structural steel for these three large and significant buildings across navigable rivers with the amount used for the construction of the Pelješac Bridge: the expenditure for all three large bridges on the continent is less than half of the total amount spent for the construction of the Pelješac Bridge.



Pelješac Bridge compared to other large Croatian bridges.

Top-down: Homeland Bridge across the Sava River in Zagreb, Drava Bridge on the A5 motorway, Pelješac Bridge, Franjo Tuđman Bridge across Rijeka Dubrovačka and Krk Bridge.

Table: Comparison of the lengths and amounts of structural steel of three bridges in continental Croatia with the amount used for the superstructure of the Pelješac Bridge.

	Pelješac Bridge	**Bridges Drava – Osijek, Sava Stara Gradiška and Sava Svilaj**
Total length of the steel span superstructure	2,404 m	1,542 m
Amount of structural steel	33.600 tons	14.950 tons

The Drava Bridge on the A5 motorway, Svilaj – Osijek – Beli Manastir, contains a 420 m long and 30 m wide composite structure in which 5,000 tons of steel are installed

The Sava Bridge near Stara Gradiška, for the expressway, has a 462 m long and 23 m wide structure in which 4,650 tons of steel are installed.

The bridge across the Sava River near Svilaj, on the A5 motorway, contains two parallel composite structure each 660 m long and 13.5 m wide, a total of 5,300 tons of steel installed.

Tall buildings compared to the Pelješac Bridge

It is interesting to place the pylons of the Pelješac Bridge, the highest of which rise around 101 metres above sea level, in relation to other tall buildings in Croatia. The record at the time of the construction of the bridge was held by the industrial chimney of the Plomin II power station, which was 340 metres tall. At the same time as the bridge, the tallest Croatian skyscraper Dalmatia Tower 2, 115 metres tall, with 27 floors, was built in Split. An antenna has been placed on top of the building, raising the total height to 135 metres.

The skyscraper has five underground floors, and it is also interesting to compare the total amount of concrete that was built into it with the amount used for the Pelješac Bridge. A total of about 70,000 m³ of concrete (170,000 tons) was installed in that bridge, of which 22,077 m³ was installed in the piles, 22,270 m³ in the pile caps, another 2,545 m³ for the prefabricated formwork of the caps, 14,135 m³ for the piers, for the base parts of the pylons installed at the level of the superstructure and pylons, 3,432 m³, for abutments and wells 2,380 m³, and for dividing belt and other 3,161 m³. For Westgate Tower 2, with a gross developed area of 33,560 m², a total of 21,220 m³ of concrete was used, thus less concrete than used only for the pile caps and piles of the Pelješac Bridge.

The difference in the amount of installed reinforcement between the bridge and the skyscraper is even more pronounced, about 18,000 tons of reinforced steel were installed in the bridge, whereas 3,367 tons were enough for the skyscraper.

Among the other tall buildings that we can compare the bridge to, there is the television tower on Sljeme, on the top of Medvednica, near Zagreb, completed in 1976. The total height of the tower, from the ground to the top of the highest antenna, is 170 m. The construction of the tower consists of a lower, concrete part with a height of 92 m and an upper, steel part with a height of 78 m.

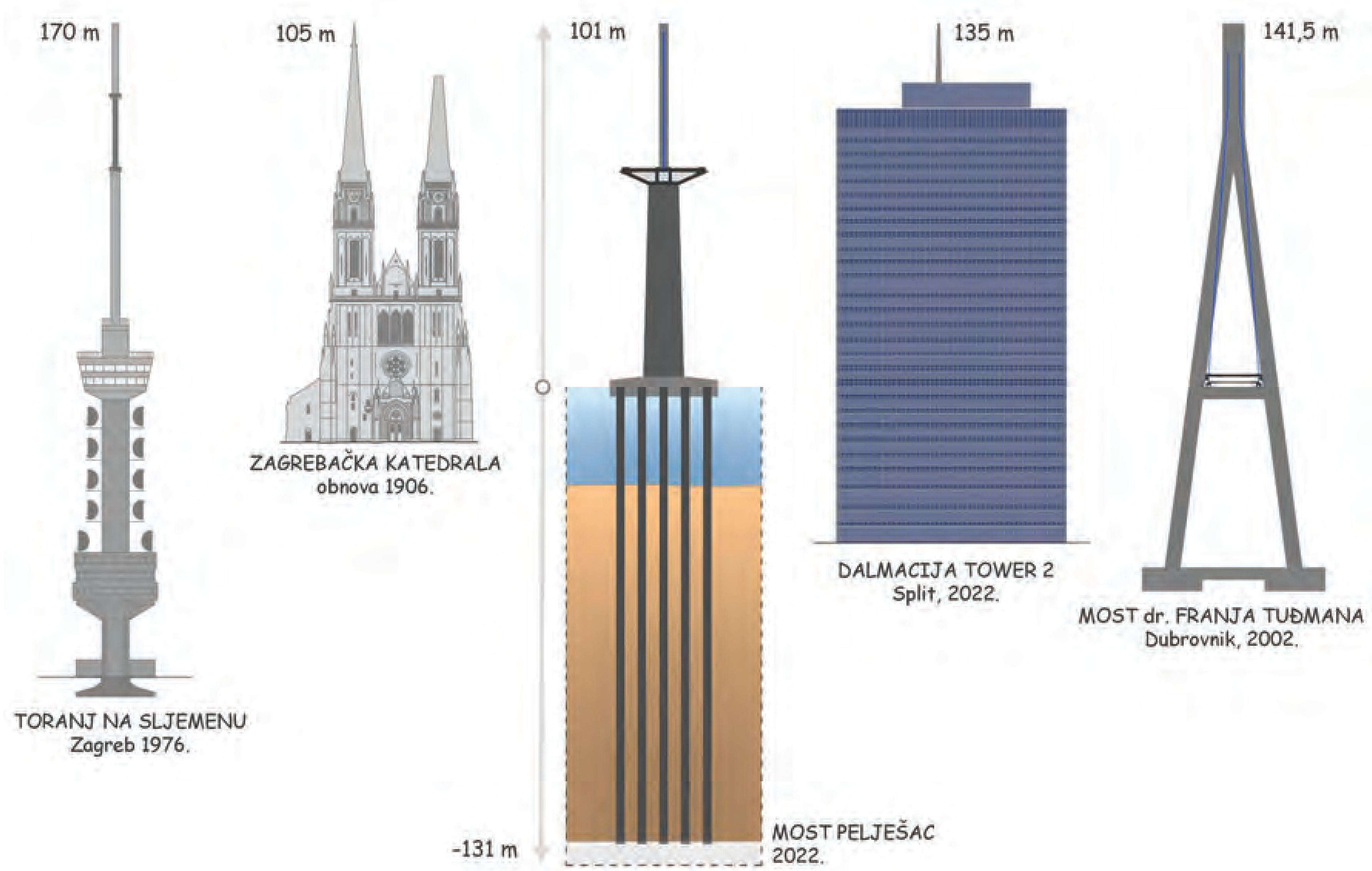
Dalmatia Tower in Split is 115 metres tall (135 m to antenna top), completed in 2022.

The Zagreb Cathedral of the Assumption of the Blessed Virgin Mary and the Kings Saint Stephen and Saint Ladislav is the tallest sacral building in Croatia. Before the earthquake that hit Zagreb in 2020 when the top of the towers collapsed, it was 105 metres high, whereas after that, at the time the bridge was completed, it was 92 metres high.

The Pelješac Bridge in the context of contemporary European achievements

Most Pelješac as compared with other tall buildings in Croatia .

We compare the Pelješac Bridge with European bridges over sea straits or navigable rivers, built in the decades that preceded the realization of the Road Connection to South Dalmatia project. The bridge across the Mali Ston Canal satisfies modern technical and technological developments, with some features that we can consider innovative. A comparison of the realized unit price of the Pelješac Bridge with other bridges over similar obstacles indicates that the investment is within the dimensions of the expected values, which for such constructions range between EUR 5,000 and 10,000 per square surface metre.



The Rio – Antirion Bridge

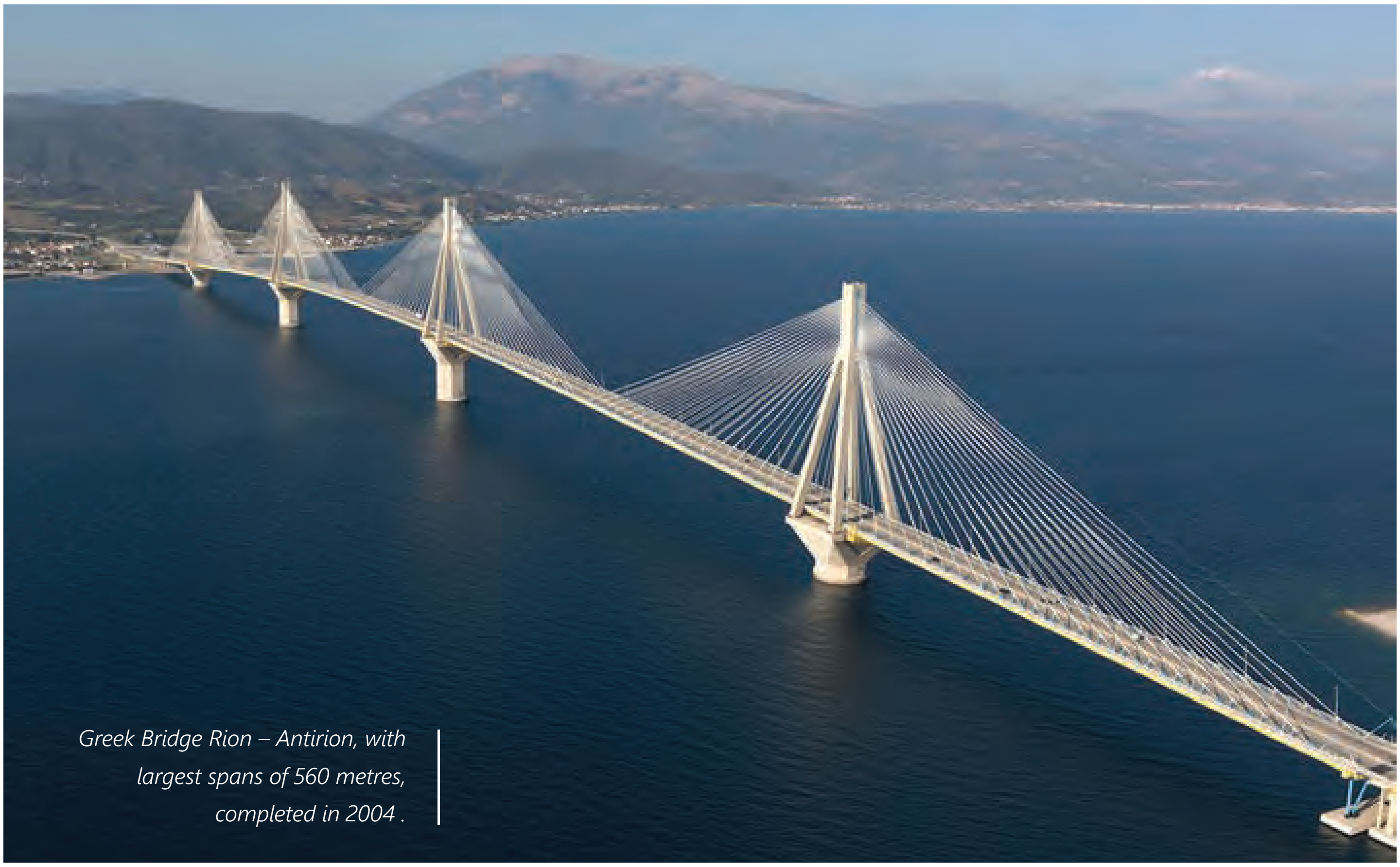
The Rion - Antirion Bridge was built in Greece and spans the Gulf of Corinth near Patras, connecting the Peloponnese to the Greek mainland.

This bridge crosses the Gulf of Corinth near Patras, linking the Peloponnese peninsula to the mainland of Greece. It was opened for traffic in 2004. Furthermore, it is located in a demanding location, where the sea depth reaches 65 metres, the seabed consists of loose sediment with low bearing capacity to unreachable depth, in an area of high seismicity (anti-earthquake design parameters are higher than those for the Pelješac Bridge), and there is also the possibility of tectonic shifts. In addition, the bridge is designed to withstand the possible impact of a large ship. It is a multi-span cable-stayed bridge, with 5 spans, and a total length of 2,252 metres, with the largest spans of 560 metres, which was extended at the ends with approach viaducts, so the total length of the building is 2,883 metres. The main structure is uninterrupted along its entire length, similar to the Pelješac Bridge.

However, this bridge is best known for its foundation, which is based on caissons with a diameter of 90 metres, which rest on the seabed, previously reinforced with 25 to 30-metre-long steel tubes, which are driven under the foundation in a dense arrangement.

The span superstructure consists of two longitudinal plate girders each 2.2 metres high and transverse girders spaced at 4 metres, and a concrete slab, the total width being 27 m. The pylons, from sea bottom to the top, are up to 230 metres tall. The spacing between stay cables is 12 metres, and the structure was built using the balanced cantilever construction, similar as was the case on the Pelješac Bridge.

There are 250,000 m³ of concrete installed in the bridge, so more than three times compared to the Pelješac Bridge, but less steel was used, since it is an open cross-section and a composite structure so 14,000 tons of structural steel were consumed. In addition, about 4,500 tons of steel were also used for the stays.



Greek Bridge Rion – Antirion, with largest spans of 560 metres, completed in 2004 .

The Constitution of 1812 Bridge or La Pepa Bridge

La Pepa Bridge in Andalusia crosses the Cadiz Bay, linking the town of Cadiz on the peninsula and Puerto Real on the mainland. The bridge is 3,092 metres long and contains the 1,180 metres-long main structure with stay cables and approach viaducts. The width of the composite span superstructure is 34.3 m, and it holds a six-lane carriageway. The main span is 540 metres long and crosses the sea strait at 69 metres of clear height.

The pylons are 183 and 186 metres tall, shaped like a diamond, which means that the pylon forks at the point where the structure passes through it, and then joins again above the structure into a single vertical from which the stay cables extend.

The main girder is a relatively shallow (3 m) box with a trapezoidal - aerodynamic shape, supported by stays at the ends. The bridge was built using the balanced cantilever construction, by assembling 20-metre-long segments, with an average weight of about 300 tons.

It is interesting that at the request of the shipyard in the bay, one of the access span superstructures was made so that it can be dismantled in case a vessel higher than 69 metres needs to pass through it. Since this will happen very rarely, the bridge is not designed as a full drawbridge.

Due to the economic crisis, the bridge construction was delayed by more than three years behind the planned deadline, and the construction costs increased twice compared to the estimated value. The bridge was completed and opened to traffic in 2015.

View comparison of sizes and investments

bridge	location	length (main structure)	width	largest span	investment	Investment per m²
		m	m	m	million EUR	EUR
Pelješac	Croatia, Dalmatia	2,404	22.5	285	278	5.140
Rion - Antirion	Greece, the Peloponnese	2,883 (2,252)	27	560	630	8.093
La Pepa Cadiz	Spain, Andalusia	3,092 (1,180)	34.3	540	510	4.809
Queensferry	Great Britain, Scotland	2,539 (1,950)	39.8	650	790	7.817
Mersey Gateway	Great Britain, England	2,250 (998)	32.9	318	720	9.726

Table: The comparison of sizes and investments for some large European bridges, contemporaries of the Pelješac Bridge. The data on the investment value of bridges should be taken with a grain of salt, because there is no information on what exactly the amount includes. For the Pelješac Bridge, the value of the construction contract was used, without VAT, without design costs and expert supervision.

The Spanish Constitution of 1812 Bridge or La Pepa Bridge in Cadiz, with the largest span of 540 metres, completed in 2015.

The Queensferry Crossing

The Queensferry Crossing crosses the Firth of Forth, near Edinburgh, Scotland, not far from the historically significant Firth of Forth Railway Bridge. The new bridge is 2,539 metres long and contains three sets of stay cables with a maximum span of 650 metres. It was opened to traffic in 2017. The cable-stayed structure is a composite 39.8-metre-wide, three-chamber, 4.9-metre-high box. The width of the bottom surface of the box is 26.2 metres.

The bridge holds a six-lane road - four lanes are intended for public traffic, and two are used only for public buses. The cable-stayed bridge contains three concrete pylons about 210 metres tall. It is an integral structure with a central pylon (thus, the girder is clamped into the pylon), while on the other two pylons, the girder can be moved relative to the pylon. The girder is uninterrupted - continuous from beginning to end, along the entire length of the bridge. It is interesting that two rows of parallel stay cables are placed in the central reservation, with a small distance between the stay cables of the same length (about 3 metres).

The bridge was built using the balanced cantilever construction, with the fact that, similar to the Pelješac Bridge, the large segments were shipped from Chinese factories directly to the construction site. The suspended girder was formed from 134 segments that weighed an average of 750 tons each.

The Queensferry Crossing is also located in a zone of strong winds, which regularly causes traffic suspension on the bridge, so 3.3-metre-high wind protection barriers are installed. The main design challenge of a bridge with three pylons is to ensure stability of the central tower. The required stiffness was achieved by extending the fan-shaped stays over the central part of the adjoining spans, so that groups of 10 cables overlap in the central parts of the main spans.

There are 35,000 tons of steel installed in the composite structure.

British, or better to say Scottish Queensferry Crossing, with the largest span of 650 metres, completed in 2017.

The Mersey Gateway Bridge

The Mersey Gateway Bridge crosses the Mersey River and canal in the English province of Cheshire, and was opened to traffic in 2017, carrying a six-lane road. It is constructed as a cable-stayed bridge with three pylons. The central pylon is lower than the other two pylons, one of which is 110 and the other 125 metres tall. The largest span is 318 metres.

The bridge is based on shallow foundations, since the solid ground is located under relatively shallow alluvial deposits. The circular foundations of the pylon have a diameter of 22 metres and are 4.5 metres tall.

The north and south pylons are made with pile caps, while the pylon in the centre of the bridge is suspended with the span superstructure. This is the only one among the bridges outlined here that has a prestressed concrete span structure which is a single-chamber box, transversely reinforced with strong beams that support the wide carriageway slab through cantilever.

The superstructure was built using the balanced cantilever construction, concrete casting of segments performed on site, on suspended formwork, in three stages. The production of each 6-metre long segment took place in a weekly cycle, in which the section was longitudinally prestressed and hung on the corresponding stay cable. the auxiliary devices with formwork for cantilever construction weighed 270 tons. The construction was facilitated by the construction of temporary supports, that is, piers in the river, at a distance of about 72 metres from the pylon.

Preparations for the construction of the bridge, which lasted three years, lasted for 20 years.

British, or better to say English Gateway Mersey Bridge, with the largest span of 318 metres, completed in 2017.

6.

APPENDIX

6.1
ABOUT THE AUTHOR

Sc.D. G O R A N P U Ž, M.Sc. in Civil Engineering,

Head of the Management Board Office of
Hrvatske ceste d.o.o.

Goran Puž was the Head of the Management Board Office of Hrvatske ceste d.o.o. at the time this monograph was written. He developed his interest in bridges at the beginning of his career, working at the Faculty of Civil Engineering of the University of Zagreb, as a researcher and assistant at the Department of Bridges led by Professor Jure Radić. From 1991 to 2004, in addition to teaching, he also worked on professional projects of the Department, on the design of post-war reconstruction of family houses, as well as on the bridge projects. One of the visionary projects of the Department from that time was the study of variants for the future Pelješac Bridge. After college, he went to work at Hrvatske autoceste, where, during the intensive period of construction of the motorway network, he was involved in the development of the management and maintenance system. After that, in 2008, he moved to a private company, Institut IGH, where he worked for several years with the road design team, and then with the team of the accredited laboratory. After leaving the faculty, he did not stop teaching, but participated in the implementation of several courses at the Department for Structures of the Faculty of Civil Engineering in Zagreb. Finally, in 2017, he moved to Hrvatske ceste, where, in addition to his daily work in the Management Board Office, he also deals with the popularization of capital transport infrastructure projects. In his spare time, he continues his career as an academic teacher at the University North in Varaždin, Department of Construction. He has published several scientific papers, mostly on topics related to the building maintenance.

The publications he published as a co-author while working at the University of Zagreb that need to be pointed out are a handbook on bridge design and a monograph on post-war bridge reconstruction entitled *The Time of Demolition and the Time of Construction*. While working in the motorway sector, he also participated in the creation of several publications that testify to the time of intensive construction particularly addressing the technical and financial aspects. Over the years, through publication of monographs, brochures, expert papers and lectures, he first dealt with peculiarities and details of individual projects, and later more and more with the role of individual projects in the development of national and even European transport infrastructure. The 2019 monograph *Transporters for the European Future - projects of the transport system of the Republic of Croatia, Roads for European future - projects of the transport system of the Republic of Croatia, achievements and plans*, connects the capital projects of the national transport infrastructure into the context of sustainable development and European perspectives.

ABOUT THE REVIEWER

Ph.D. ZLATKO ŠAVOR, B.Sc. in Civil Engineering,

Ph.D. Professor Zlatko Šavor, B.Sc. in Civil Engineering, reviewer of the monograph People behind the Bridge, is one of the most important contemporary Croatian bridge designers. He was also the author of the design solution for the Pelješac Bridge which made it to the very end of the competition, in direct competition with the project according to which the bridge was eventually constructed.

In his rich career, Zlatko Šavor was a professor at the Faculty of Civil Engineering and Architecture of the University of Zagreb, a researcher-scientist and a teacher, but above all a designer of bridges, mostly of exceptional spans or particular design range. His projects have always had a personal touch and followed the worldwide trends in the bridge construction. As an auditor and professor in subjects related to bridges, he influenced the activity of the bridge construction as well as the wider field of construction in Croatia, always striving to raise the profession to a higher level.

Among the bridges built in Croatia, for which Dr. Šavor is the designer, the following stand out:

- New Maslenica Bridge for A1 motorway (1996)
- Bridge mainland – island of Pag (2000)
- Kamačnik Bridge (2000)
- Bridge across the Drava River nearby Belišće (2002)
- Bridge across Rijeka dubrovačka (2002)
- Bridge across the Sava River in Martinska Ves (2002)
- Bridge across the Krka River Most on the motorway near Skradin (2005)
- Viaduct Mirna (2005)
- Reconstruction of the bridge across the Sava River in Jasenovac (2005)
- Rječina Bridge on the Rijeka bypass (2007)
- Overpass Mucići (2008)
- Bridge mainland - Čiovo (2018)

Dr. Šavor is the author of many scientific and expert papers, an active member of numerous Croatian and international professional associations. He received several recognitions and awards for his scientific and professional work.

From the review:

In the monograph entitled People behind the Bridge, a detailed overview of various aspects of preparation, design and construction of the Pelješac Bridge is provided. Important project stakeholders gave their contribution, and the photographs are extraordinary. All this gives the reader an opportunity to see the majority of challenges that stood in the way of this magnificent project. In a technical sense, I would like to emphasize that the Pelješac Bridge belongs to the so-called extradosed bridges (suspended bridges with low pylons). There are less than 200 such bridges in the world, mostly built in the Far East with a span superstructure almost exclusively made of concrete.

Only three Japanese bridges from the beginning of the 20th century (Ibi River Bridge, Kiso River Bridge and Korror Babeldoap Bridge) with main spans up to 275 m have hybrid span structures where the steel cross-sections are longitudinally rigidly fixed to concrete. Such a solution was also chosen for the Pelješac Bridge, which is logical, because it was necessary to reduce its own weight to a minimum due to the extremely poor soil and high seismicity of the location. The construction of the bridge is very demanding, 100-meter-long driven piles, pylon concrete C70/85, reinforcement profiles up to 40 mm, longitudinal connection of concrete box plates on pylons with steel aerodynamically shaped box sections of the superstructure, etc. Therefore, it is good that the book describes the structure in such detail. In terms of the length of the main spans (285 m), the Pelješac Bridge is, in the competition with bridges of the same type, second in the world.

People behind the Bridge is also a thank you and a congratulations note to all stakeholders in the construction, the designer, the contractor, the supervisor and the investor, for all the great effort they had to put in to complete this magnificent bridge.

In conclusion, the Pelješac bridge embodies all the Vitruvius criteria: firmitas, utilitas, venustas, (strength, purpose, beauty), it can handle all budgetary actions, it is functional, and in my humble opinion, from an aesthetic point of view, it is the most beautiful extradosed bridge in the world.

Photo: Milan Sabić / Pixell

LIST OF COMPANIES THAT PARTICIPATED IN THE PROJECT CONSTRUCTION

Road Connection to South Dalmatia

1. Project: Construction of the Pelješac Bridge with access roads

Consortium:
China Road and Bridge Corporation
CCCC Highway Consultants Co. Ltd.
CCCC Second Highway Engineering Co. Ltd.
CCCC Second Harbour Engineering Co. Ltd.

Subcontractors:

1. GEODETSKI URED VESNA KOVAČ	geodetic works
2. SLP d.o.o.	construction works
3. STIJEG d.o.o.	underwater works
4. MONTAŽA BAĆINA	construction works
5. ASCON d.o.o.	concrete testing
6. GEOEXPERT d.o.o.	concrete testing
7. VSL INTERNATIONAL	consulting service
8. PUNDT d.o.o.	NDT testing
9. CROATIAINSPECT d.o.o.	NDT testing
10. HARMONY TRADE d.o.o.	NDT testing
11. TPK d.o.o.	NDT testing
12. UNIS - TELECOM d.o.o.	construction works
13. DEGAL TEHNIKA d.o.o.	construction works
14. MONTERRA d.o.o.	construction works
15. L.Z. PROJEKT d.o.o.	construction works
16. ADRIACINK d.o.o.	construction works
17. PISMORAD d.o.o.	electrical works
18. SPELEOLOŠKO DRUŠTVO ŠPILJAR	construction works
19. IMOTEHNIKA d.o.o.	electrical works
20. REPLY TOOL d.o.o.	work equipment maintenance
21. TRAG d.o.o.	construction works
22. ĆOSIĆ d.o.o.	construction works
23. ADVENTURE OMIŠ d.o.o.	construction works
24. KALAUS d.o.o.	construction works
25. SPEGRA d.o.o.	construction works
26. C4 d.o.o.	construction works
27. GUSTIN ZIDINE d.o.o.	construction works
28. ELEKTROENERGETIKA d.o.o.	electrical works
29. ZAGREB MONTAŽA d.o.o.	construction works
30. GRAĐEVINSKI FAKULTET ZAGREB	load test
31. PRIJEVOZNIČKI OBRT BRDAR	transportation
32. PRIJEVOZNIČKE USLUGE MARKO BOŠNJAK d.o.o.	transportation
33. GRBIĆ d.o.o.	construction works
34. KOSINAC d.o.o.	electrical works
35. INERO d.o.o.	electrical works
36. ANAFORA d.o.o.	waterproofing testing
37. ANTE INŽENJERING d.o.o.	waterproofing testing
38. ENERGO PLAN d.o.o.	electrical works
39. UNELPO d.o.o.	electrical works
40. POMIJA d.o.o.	construction works
41. KARABIT d.o.o.	mining
42. PA-EL d.o.o.	cathodic protection
43. MATO LD d.o.o.	construction works
44. T-REKLAM d.o.o.	billboards
45. DUAL CONCEPT d.o.o.	construction works
46. SITAL d.o.o.	construction works
47. GABRIĆ d.o.o.	construction works
48. DOMGRAD d.o.o.	construction works
49. COLAS HRVATSKA d.o.o.	construction works
50. TELEGRA d.o.o.	electrical works
51. PROMEL d.o.o.	electrical works
52. TRITEGRAL d.o.o.	electrical works
53. NEOS d.o.o.	electrical works

2. Construction of access roads to the Pelješac Bridge, section: Duboka – Sparagovići/Zaradeže

Consortium: **STRABAG AG (Zagreb subsidiary, STRABAG d.d.) and STRABAG d.o.o. Zagreb**

Strabag group subcontractors:

1. CML CONSTRUCTION SERVICES d.o.o. za savjetovanje u vezi s poslovanjem
2. STRABAG BMTI d.o.o. građevinski strojevi
3. STRABAG BRVZ d.o.o. za usluge
4. STRABAG d.o.o. SARAJEVO
5. STRABAG d.o.o. BEOGRAD
6. POMGRAD INŽENJERING d.o.o. za graditeljstvo
7. TPA održavanje kvaliteta i inovacija d.o.o.

Other subcontractors:
1. ADLSTRUKTURA d.o.o.
2. ADRIA DRILLING d.o.o.
3. ADRIA WOOD INDUSTRIES d.o.o.
4. ADRIACINK TRANSPORT d.o.o.
5. ALFA ATEST d.o.o.
6. ALFATHERM d.o.o.
7. ALLIANZ ZAGREB d.d.
8. ALUPLAST – OBRT ZA ALU I PVC STOLARIJU
9. AMIBLU ROMANIA SRL
10. ANTONINI d.o.o.
11. ASCENDUM GRAĐEVINSKI STR
12. ASCON INSTITUT d.o.o.
13. ASN-GEO d.o.o.
14. AUDAX d.o.o.
15. AVESCO AG
16. BARUNO INTERIJERI d.o.o.
17. BASF CROATIA d.o.o.
18. BAUSYSTEM GROUP d.o.o.
19. BELFRY UT KFT.
20. BEST OBRT ZA CESTOVNI PRIJEVOZ ROBE
21. BESTRENT d.o.o.
22. BETON LUČKO RBG
23. BIJUK HPC
24. BIM-ING d.o.o.
25. BINĐO d.o.o.
26. BRAĆA RADIĆ – OBRT ZA ISKOPE
27. BRKIĆ BAU d.o.o.
28. BRODOMETALURGIJA d.o.o.
29. BS TELECOM SOLUTIONS d.o.o.
30. CAR-MERKUR d.o.o.
31. CEMEX HRVATSKA d.d.
32. CHROM INTERIJERI – OBRT ZA BRAVARSKE RADOVE
33. CMC GROUP d.o.o.
34. COLAS HRVATSKA d.d.
35. COMET d.o.o.
36. CONRAM d.o.o.
37. CONTENDO d.o.o.
38. CRIVAC d.o.o.
39. ĆOSIĆ GRADNJA d.o.o.
40. D&J d.o.o.
41. DIORIT d.o.o.
42. DIORIT GRADNJA d.o.o.
43. DOKA HRVATSKA d.o.o.
44. DRONE 4 DESIGN d.o.o.
45. DSI UNDERGROUND AUSTRIA GmbH
46. DUBRAVICA d.o.o.
47. DUBROVNIK CESTE d.d.
48. DUNAV-DRAVA CEMENT d.o.o.
49. DVD PUTNIKOVIĆ
50. EKSPLO-PROMET d.o.o.
51. ELEKTROTEHNIKA DIZAJN d.o.o.
52. ELLABO d.o.o.
53. EL-ZAP d.o.o.
54. EPIROC CROATIA d.o.o.
55. ERA COMMERCE d.o.o.
56. FEROTERM d.o.o.
57. FERRO MO d.o.o.
58. FRUHWALD d.o.o.
59. G.O. EMANUEL
60. GEA TIM d.o.o.
61. GEFYRA d.o.o.
62. GEOMATIKA d.o.o.
63. GEOPROJEKT d.d.
64. GEOTECH d.o.o.
65. GEOTEHNIKA-KONSOLIDACIJA
66. GEOTEST d.o.o.
67. GIP-CESTOVNI PRIJEVOZ ROBA
68. GISPLAN d.o.o.
69. GNJEČ PROMET – OBRT ZA CESTOVNI PRIJEVOZ
70. GRAĐA d.d.
71. GRANDIS d.o.o.
72. GRBIĆ d.o.o.
73. GRGA
74. GROTEL d.o.o.
75. GROUND ZERO d.o.o.
76. GUMIIMPEX-GRP d.d.
77. HALO NET d.o.o.
78. HILTI CROATIA d.o.o.
79. HORMANN HRVATSKA d.o.o.
80. IGH d.d.
81. INA-INDUSTRIJA NAFTE d.d.
82. INDUSTRIAL ELEMENTS d.o.o.
83. INEL d.o.o.
84. INSTITUT IGH d.d.
85. INTER S.T.E.E.L. d.o.o.
86. INŽENJERING GEORAD d.o.o.
87. ISKOPI BORAS
88. JAHODA d.o.o.
89. JAKIIĆ - OBRT ZA VODOINSTALATERSKE RADOVE
90. JATA GROUP d.o.o.
91. JVP METKOVIĆ
92. KLEMM SIGURNOST d.o.o.
93. KOMARDA d.o.o.
94. KOMUNALNO DRUŠTVO STON d.o.o.
95. KONTI HIDROPLAST
96. KOTAČ GRAĐ.MEHANIZACIJA, PRIJEVOZ
97. KOTONTEKS d.o.o.
98. KOTONTEKS GEO d.o.o.
99. KREMENA d.o.o.
100. KREŠO GEO d.o.o.
101. KRIVAJA METALI d.o.o.

102. LAGER BAŠIĆ d.o.o.
103. LIMMONT - OBRT ZA LIMARSKE RADOVE
104. LION j.d.o.o.
105. M.A.K.& N. TRADE d.o.o.
106. MAGNUSOL GRAĐENJE d.o.o.
107. MANDIĆ CONSULTING d.o.o.
108. MAPEI CROATIA d.o.o.
109. MARANA d.o.o.
110. MARELO
111. MARITIM BAŠIĆ d.o.o.
112. MASTER BUILDERS SOLUTION
113. MB SPOT-SIGNALIZACIJA
114. MEDIMPEX d.o.o. SARAJEVO
115. MESSER CROATIA PLIN d.o.o.
116. METALIS d.o.o.
117. MGM PRIJEVOZ
118. MGT
119. MIAB d.o.o.
120. MONTERRA d.o.o.
121. MOUNA d.o.o.
122. MOZAIK PB d.o.o.
123. MUPRO d.o.o.
124. NARONA REZ
125. NOVI IZBOR
126. OBRT MRČAVIĆ
127. OBŠIVAČ d.o.o.
128. OCTOPUS RIJEKA d.o.o.
129. ORIOBETON d.o.o.
130. PANORAMA d.o.o.
131. PERI OPLATE I SKELE d.o.o.
132. PETROKOV d.o.o.
133. PGM RAGUSA d.d.
134. PIPELIFE-HRVATSKA d.o.o.
135. PODOVI OPAČAK d.o.o.
136. PODVODNI RADOVI KINA
137. POLIROL d.o.o.
138. POPULUS d.o.o.
139. POSSUM d.o.o.
140. PPT d.o.o.
141. PRANGL d.o.o.
142. PRAVA APLIKACIJA 2020
143. PRIJEVOZI ŠIMLEŠA
144. PRVI TREPTAČ d.o.o.
145. PUŠINA d.o.o.
146. RADIĆ&CO d.o.o.
147. RAZMJER d.o.o.
148. REGENERACIJA d.o.o.
149. REHAU d.o.o.
150. ROYAL PRESTIGE d.o.o.
151. S.A.K.Z. d.o.o.
152. SAMOBORKA d.d.
153. SCHRACK TECHNIK d.o.o.
154. SECURITAS HRVATSKA d.o.o.
155. SEKSTANT d.o.o.
156. SIKA CROATIA d.o.o.
157. SPB INŽENJERING d.o.o.
158. STELA GRADNJA d.o.o.
159. STUDIO BASIS d.o.o.
160. SUMA MAN POWER d.o.o.
161. SVEUČILIŠTE U SPLITU – Fakultet građevinarstva, arheologije i geodezije
162. SVEUČILIŠTE U ZAGREBU – Građevinski fakultet
163. SYNTEKS d.o.o.
164. TABAK GRUPA d.o.o.
165. TEHNODELTA-OPUZEN d.o.o.
166. TEMPUS PROJEKT d.o.o.
167. TERESTRIKA d.o.o.
168. TERMO SAN d.o.o.
169. TERMODINAMIKA d.o.o.
170. TERRAKOP OBRT ZA USLUGE
171. TEXO MOLIOR d.o.o.
172. TGT PROM d.o.o.
173. TIMIS OBRT ZA PRIJEVOZ I USLUGE
174. TRANSPORTI PERVAN
175. TRASER d.o.o.
176. TRG d.o.o.
177. TRIO I d.o.o.
178. TRLIN d.o.o.
179. UNI RENT d.o.o.
180. VEKTOR INTEGRA d.o.o. GLAVNA PODR. DUBROVNIK
181. VELBOS d.o.o.
182. VENTUNUS d.o.o.
183. VETA d.o.o.
184. VIANOVA SLOVENIJA d.o.o.
185. VIATOR d.o.o.
186. VIJCI KRANJEC
187. VILJEVAC d.o.o.
188. VISOKO POTKROVLJE d.o.o.
189. VODOSKOK d.d.
190. VOLVERE OBRT ZA CESTOVNI PRIJEVOZ ROBE
191. WURTH HRVATSKA d.o.o.
192. ZANGRA d.o.o.
193. ZIDOGRADNJA d.o.o.
194. ZONA ARCHITETTONICA j.d.o.o.
195. ŽUHOVIĆ TRANSPORTI

3. Construction of the Ston bypass – new route of the D414 state road with sections Sparagovići/Zaradeže – Prapratno and Prapratno – Doli

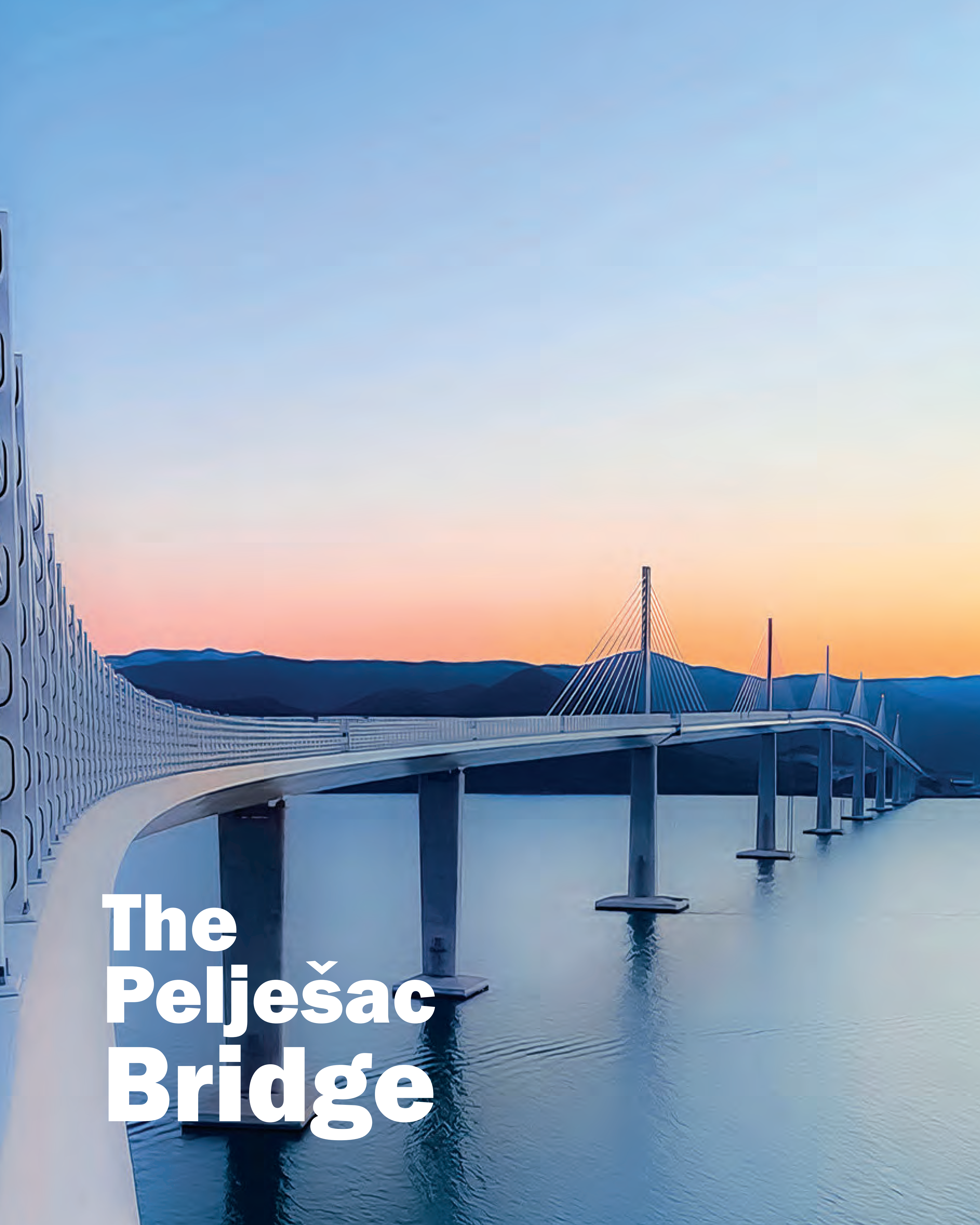
AVAX S.A. (Marousi, Greece)

Subcontractors:

1. ADRIA DRILLING d.o.o.
2. AKVAMONT d.o.o.
3. BASF CROATIA d.o.o.
4. BBR ADRIA d.o.o.
5. BETON LUČKO d.o.o.
6. BOSSIN d.o.o.
7. BRODOSPLIT d.d.
8. CALX d.o.o.
9. COLAS HRVATSKA d.d.
10. CONTECH d.o.o.
11. DELTA-INŽENJERING d.o.o.
12. DIORIT GRADNJA d.o.o.
13. DUBROVNIK CESTE d.d.
14. DVD PUTNIKOVIĆ
15. EDITUS d.o.o.
16. EKO SEVERIN d.o.o.
17. FERRO MO d.o.o.
18. FRACASSO RI d.o.o.
19. FRIEDL SOLUTIONS d.o.o.
20. GALAXY d.o.o.
21. GEFYRA d.o.o.
22. GEO LINE SYSTEMS d.o.o.
23. GEOMAT d.o.o.
24. GEOMIN d.o.o.
25. GRAĐA d.d.
26. GRBIĆ d.o.o.
27. HD USLUGE d.o.o.
28. ING ATEST d.o.o.
29. ING-JET d.o.o.
30. INSTITUT IGH d.d.
31. INŽENJERING GEORAD d.o.o.
32. IPZ d.d.
33. JOŠKO I JADRAN d.o.o.
34. JUDIK d.o.o.
35. KAPLAN PROJEKT d.o.o.
36. KARABIT d.o.o.
37. KLAKAR d.o.o.
38. KOPILOT d.o.o.
39. KRTICA 2 d.o.o.
40. L.Z. PROJEKT d.o.o.
41. LAGER BAŠIĆ d.o.o.
42. LED ELEKTRONIKA d.o.o.
43. MAKIMA, OBRT ZA GRAĐEVINARSTVO
44. MEDIUS d.o.o.
45. MIKULA MALI, OBRT
46. MODULATOR d.o.o.
47. OBŠIVAČ d.o.o.
48. OCTOPUS RIJEKA d.o.o.
49. PERI OPLATE I SKELE d.o.o.
50. PERVAN PLAN d.o.o.
51. PLOVPUT d.o.o.
52. PRANGL d.o.o.
53. PROSUM d.o.o.
54. RADEŽ d.d.
55. RAD-TROGIR, OBRT ZA METALSKE RADOVE, TRGOVINU I IZNAJMLJIVANJE PLOVILA
56. SAMOBORKA d.d.
57. SECURITAS HRVATSKA d.o.o.
58. SIKA CROATIA d.o.o.
59. SLP d.o.o.
60. STOA, OBRT ZA INŽENJERSKI DIZAJN I USLUGE
61. STROJOPROMET d.o.o.
62. SVEUČILIŠTE U ZAGREBU GRAĐEVINSKI FAKULTET
63. TERESTRIKA d.o.o.
64. TERMODINAMIKA d.o.o.
65. TRASER d.o.o.
66. V PLAN SIGURNOSTI d.o.o.
67. VARGON d.o.o.
68. VEKTOR INTEGRA d.o.o.
69. VELIS d.o.o.
70. VIKTOR ENERGY d.o.o.
71. VODA NOVA d.o.o.
72. VODOSKOK d.d.
73. VODOTIM d.o.o. SPLIT
74. ZVONO RENT d.o.o.

4. SUPPLY AND EQUIPMENT:

1. VICTOR ENERGY d.o.o.
2. TELUR d.o.o.
3. TEHNO – ELEKTRO d.o.o.
4. ELEKTROCENTAR PETEK d.o.o.
5. DALEKOVOD d.d.
6. INERO d.o.o.
7. TEB AUTOMATIKA d.o.o.
8. TELEGRA d.o.o.



The Pelješac Bridge

The Pelješac Bridge

Road Connection
to Southern Dalmatia

HRVATSKE CESTE

Road Connection
to Southern Dalmatia

European Union
together to EU funds

GOVERNMENT OF CROATIA

Ministry of the Sea,
Transport and Infrastructure

Ministry of Regional
Development and EU funds

DUBROVNIK-NERETVA COUNTY

HRVATSKE CESTE

safu SREDIŠNJA AGENCIJA ZA FINANCIRANJE I UGOVARANJE
Central Finance and
Contracting Agency

Operativni program
KONKURENTNOST
I KOHEZIJA
Operational program
COMPETITIVENESS
AND COHESION

EUROPSKI STRUKTURNI
I INVESTICIJSKI FONDOVI
EUROPEAN
STRUCTURAL AND
INVESTMENT FUNDS