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MONITORING OF MARINE ENVIRONMENT DURING BRIDGE CONSTRUCTION – PELJEŠAC BRIDGE CASE STUDY

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Abstract

The construction of the Pelješac bridge has been one of the most significant infrastructural endeavours in Croatia in the last several decades. Due to the type of the project, according to the EU and the national legislation it was subject to environmental impact assessment, which provided a framework for the environmental monitoring plan. To fulfil the requirements related to the monitoring of the marine environment the unique monitoring system was set up consisting of three modules: (i) two autonomous measurement buoys providing continuous near-real time data on water quality and meteorology with alarm function; (ii) measurements of water quality parameters in broader project area every two weeks; and (iii) monitoring of biological parameters. The measurements on buoys included water quality parameters on surface and 4 depths. The measurements on 8 stations in broader project area were performed by a multiparametric probe for measurements of water quality parameters on surface and at every 5 m depth up to the bottom, as well as measurements of optical characteristic of water. Monitoring of biological parameters included analyses of composition of the phytoplankton community, macroalgae (CARLIT method), Posidonia oceanica (POMI index) and benthic invertebrates, including invasive species.

Keywords: environmental monitoring, marine environment, EIA, monitoring system, infrastructure, sustainable development

1 Introduction

Pelješac bridge is the main component of the project ‘Road connection with southern Dalmatia’ [1]. It enables a direct road connection between the greater part of Croatia and the South Dalmatia, which is separated from the rest of Croatia by the Neum Corridor (Bosnia and Herzegovina). The project also includes construction of series of connecting and access roads. The Pelješac bridge connects the mainland near the settlement Komarna with Pelješac peninsula. Its length is about 2.5 km. The bridge spans Mali Ston Bay, which was designated as a special marine reserve in 1983 (Fig. 1).

Mali Ston Bay is an area rich in diverse natural characteristics. It stands out for the presence of shallow bays and coves that are important habitats for many marine organisms. The bay abounds with various plant and animal species, including endemic and protected species. All this makes it critically important to ensure the preservation of marine habitats and ecosystems to maintain unique ecological features and natural processes. Also, the area is marked by traditional fishing and shellfish farming, which represent an important part of the local heritage [2]. Obviously, the nature of the project required compliance with EU and national legislation related to the environmental impact assessment, which consequently, among other requirements, prescribed the implementation of the environmental monitoring plan.

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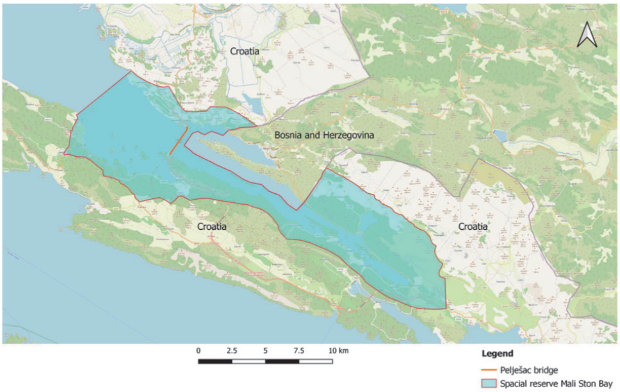

Figure 1 Location of the Pelješac bridge in relation to the Special reserve Mali Ston Bay. The map contains OpenStreetMap data https://www.openstreetmap.org/copyright

This comprehensive monitoring plan, among other components, involved the monitoring of marine environment. To fulfil the monitoring requirements the monitoring system was developed which consisted of three modules, each serving a specific monitoring purpose:

1: Two autonomous measurement buoys providing continuous near-real-time data on water quality and meteorology, along with an alarm function.

2: Manual measurements on wider project area - 8 measurement stations were established in the broader project area (Fig. 2), where water quality parameters were measured every two weeks and 24 hours after driving the first pile at each pier.

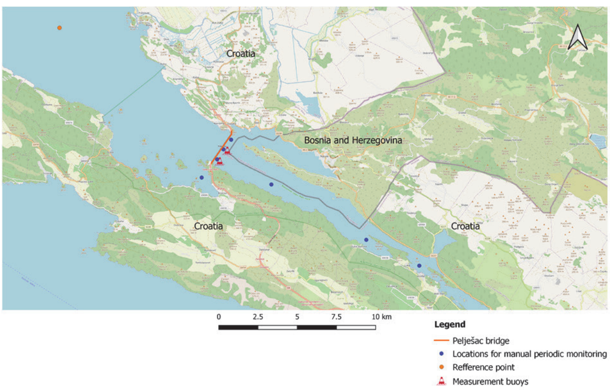

Figure 2 Measurement locations.

3: Monitoring of biological parameters involved comprehensive analyses aimed at understanding the ecological impact of the construction activities. This included the evaluation of the composition of the phytoplankton community, assessment of state of coastal waters, and the assessment of benthic invertebrates including invasive species.

In the next chapter the legal framework for the environmental impact assessment for the Pelješac bridge project is outlined. In the chapter 3 marine monitoring system implemented to accomplish the requirements of the environmental monitoring action plan is described in detail. In the chapter 4 integration of data and reporting system is presented. Finaly, in chapter 5 a summary and a conclusion are given.

2 Legal framework for environmental impact assessment (EIA) and its application to Pelješac bridge

2.1 EU and national legal framework related to EIA

The EU EIA Directive is a legislative instrument to ensure that potential environmental effects are considered before certain public and private projects are approved. The primary purpose of the directive is to promote sustainable development by integrating environmental considerations into the planning and decision-making processes for projects that are likely to have significant effects on the environment. The Directive also establishes requirements for public participation allowing the involvement of the public and relevant stakeholders in the decision-making process.
The EIA involves the identification, prediction, and evaluation of the likely significant effects of a project on the environment. It also requires the consideration of reasonable alternatives and the mitigation of adverse impacts, as well as the monitoring and management of environmental effects.
EIA Directive is implemented into Croatian legal system. The respective legal act contains a list of projects which is subject to EIA. This list includes construction of highways and motorways and thus applies to the Pelješac bridge project.

2.2 EIA and monitoring program for Pelješac bridge

Pursuant to the obligation to assess environmental impacts of the project, an EIA for the bridge and the access roads was developed in 2015. In the same year the competent ministry issued the Consent on acceptability of the project for environment, which included obligatory environmental protection measures and the environmental monitoring action plan. The environmental monitoring action plan included the monitoring of: (i) biodiversity and ecological network, (ii) noise, (iii) state of waters (marine and freshwater), (iv) wind and (v) soil. Regarding the marine environment the monitoring plan included activities before the start of construction, during the construction, and after the start of the usage of the bridge. Based on the requirements regarding the environmental monitoring, detailed methodology, time plan and monitoring system were developed and implemented. This monitoring system is described in the next section.

3 The monitoring system

The monitoring system consisted of the following components:
a) Two identical measurement buoys
b) Manual measurement of physical, biological, and chemical parameters on wider project area
c) Assessment of biological parameters.

3.1 Measurement buoys

The locations of two measurement buoys were defined to be close to the construction area, but not to pose a safety risk for the construction activities and maritime transport and to be representative for the parameters to be measured. Each measurement buoy (Fig. 2) contained a meteorological station on its top, a set of instruments in its body and a set of four probes, positioned each 5 m along the string below the buoy. The instruments were powered by photovoltaic mounted on the buoy.

Meteorological station provided the following data: average and gust wind speed and direction, relative humidity, and air temperature.
The buoy body housed a doppler current profiler sensor, and a multiparameter sonde containing sensors for temperature, salinity, oxygen, chlorophyll, and turbidity. The current profiler measured sea currents with 2 m spatial resolution, from 4 m depth to 22 m depth. Finally, the probes positioned at the measurement string were equipped with sensors for temperature, oxygen, chlorophyll, and turbidity. The system was set up to log the measured data at the central data logger located in the buoy body and send the data to the remote database (at Dvokut-ECRO premises) every 15 minutes using GPS network.
The measured data stored in the database were processed using a set of Python programs developed in-house specifically for this monitoring program. According to the regulator requirements, selected set of data was checked for given thresholds and in case of exceeding the limit values alarm email messages were sent to authorised persons. Also, the data was checked for integrity and in case of missing data or other unwanted events (e.g. error messages, warnings) the so-called service-email message was sent to Dvokut-ECRO data operator, who immediately undertook corrective actions. Additionally, a web-browser application programmed in Python was developed for continuous monitoring of all relevant data. The view included position of buoys on the map based on real-time GPS data from the buoys, last measured data shown numerically and graph of past data (with selectable time frame) for each buoy, current and past meteorological data and configuration of alarm functions. Any malfunction (e.g. missing data) was clearly highlighted, so that the operator could act immediately to eliminate any problem.

Figure 3 Measurement buoy with construction activities in the background (Photo: Alan Blažeković).

3.2 Measurements on wider project area

As it was concluded in the EIA for the project, during the construction works sediment particles can reach the water column and be carried by sea currents to the highly sensitive area of Mali Ston Bay, which is known for shellfish farming. Therefore, periodic monitoring has been established during the construction of the bridge on a larger project area in the region of shellfish farming.
Measurements within the regular environmental monitoring, which took place every 2 weeks, as well as the monitoring conducted 24 hours after driving the first pile at each pier, were carried out at 8 locations. Three of these measurement points were located at about 200 meters from the planned bridge route towards Mali Ston Bay, three locations were within the bay, one on the west of the bridge (between the islet opposite the village of Luka Dubrava on Pel-

ješac), while the reference station was located near the town of Ploče, where no impact from the bridge construction works was expected. The reference point was used to assess if a possible measured anomalies were caused by construction activities or were of natural cause.
The measurements were performed using a multiparametric probe with sensors for temperature, conductivity (salinity), total suspended solids (calculated from measured turbidity), chlorophyll and dissolved oxygen. Additionally, attenuation of photosynthetically active radiation (PAR), i.e. radiation available for photosynthesis, was measured using underwater radiation sensors.
All measurements were performed in the surface layer (0.5 m depth), and (depending on the maximal depth) on 5, 10, 15, 20 and 25 m depths.

3.3 Monitoring of biological parameters

The CARLIT (Cartography of littoral rocky–shore communities) method [3, 4] is based upon the mapping of mid-littoral and upper infralittoral species and communities of rocky shores that are considered good descriptors of the environmental water quality. It is based on a visual observation of the geomorphological features of the coast and an assessment of the presence of certain types of algae in the upper sublittoral zone along pre-defined parts of the coast. For each investigated part of the coast, dominant algal communities, each of which has its own, predefined level of sensitivity (SL) and information on coastal morphology (based on predefined 9 categories of geomorphological relevant situations - GRS) are recorded. This divides the coast into sampling transects or homogeneous sectors, both in terms of community and geomorphological characteristics of the coastline. The result is expressed as an Ecological Quality Ratio (EQR) value which is used to assess the ecological status and presented in geographic information system (GIS). The CARLIT method was implemented in a total length of 8 km, 4 km on the land side and 4 km on Pelješac side around the bridge.
Posidonia oceanica is a seagrass species that is endemic to the Mediterranean Sea. It forms large underwater meadows that are an important part of the ecosystem. The POMI (Posidonia oceanica multivariate index) [5] is a multivariate index that contains information about the entire ecosystem, from physiological processes in the plant to data on the state of the population and the entire community. An in situ analysis of density and coverage is carried out by scuba diving. The density of shoots is determined by counting shoots using a 40 cmx40 cm square. The coverage of the meadow is determined using 4 transects of 10 meters each, and on these transects, the length of the meadow and the length of the damage (the so-called “dead matte”) or parts of the substrate that have not been overgrown with Posidonia are measured. By combining this data, the coverage index is calculated. For the purposes of morphometric analysis, several shoots are taken, and the leaves are separated from the rhizome. The length, width and length of the necrosis present are measured with the leaves. Posidonia oceanica meadow was monitored at one location on the side of the Pelješac peninsula.
The main method of surveying benthic invertebrates, including invasive species and marine habitats, was the visual census method. It is a non-destructive and non-invasive diving research method that collects data on the number and composition of the species and habitats present by direct observation underwater. During the dive, notes are taken on the diving plate about the target parameters of interest, which are digitized after surfacing. Monitoring was done through two research transects, from 0 to 40 m deep on each side of the bridge.

4 Reporting

The reporting included several types of reports:
- report on initial state,
- monthly reports integrating continuous measurements on measurement buoys and measurements on 8 locations on wider project area,
- report on the state of environment after the construction,
- reports on parameters exceeding given threshold values ("alarms") on measurement buoys,
- reports on unexpected values or malfunctions on measurement buoys ("service alarms").

The first report included analyses of the initial state of the environment with respect to termohaline characteristics, optical characteristics, suspended solids, dissolved oxygen and concentration of chlorophyll a, as well as assessment of ecological quality of coastal waters using CARLIT method, assessment of ecological status of seagrass ecosystems using POMI index, and assessment of benthic invertebrates including marine habitats.
Monthly reports integrated results of the monitoring using instruments on measurement buoys, two regular monthly measurements on wider project area (eight locations), and additional measurements on the same eight points that were performed 24 hours after driving the first pile at each pier.
After the construction had been finished the assessments of ecological state of the coastal waters (CARLIT method), the ecological state of seagrass ecosystems (POMI) and the benthic invertebrates within marine habitats were performed, as well as measurements of the concentration of chlorophyll a on eight measurement locations.
Apart from the above mentioned reports whose delivery frequency was defined in advance in the environmental monitoring action plan, two types of reports were generated and sent by email automatically. One is the so called "alarm" – information that certain parameters measured on instruments on buoys exceeded given thresholds. These alarms were sent to the appointed persons of project owner. The monitoring parameters were the east (bay-ward) component of the sea current, concentration of chlorophyll a and oxygen saturation. Another type of automatically generated report was the so-called "service report". It contained information on unexpected values or malfunctions on measurement buoys. The service reports were sent to operators in Dvokut-ECRO who took necessary activities to enable continuation of error-free operations.

5 Summary and conclusion

The environmental monitoring plan resulting from the EIA for the Pelješac bridge project aimed to assess and mitigate the potential impacts of construction activities on environment, including the marine ecosystem. To accomplish the requirements related to the monitoring of the marine environment the complex monitoring system was set up, containing three main modules: autonomous measurement buoys providing continuous near-real-time data on water quality and meteorology, measurements of water quality parameters in the broader project area every two weeks, and monitoring of biological parameters. The system utilized advanced technology to collect data on various parameters at different depths and locations, ensuring comprehensive monitoring of the marine environment. Regular monitoring and reporting, including initial assessments, monthly reports, and post-construction evaluations, were conducted to track changes in water quality, biological communities, and ecological status. The system also incorporated alarm functions to alert authorized personnel in case of threshold exceedances or malfunctions, ensuring prompt corrective actions.

The successful implementation of the monitoring system for the Pelješac bridge project exemplifies best practices in environmental management during infrastructure development and serves as a guide for future marine environment monitoring projects.

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