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# EXTRA-LONG STEEL PILES PRODUCTION AND TRANSPORT OF BRIDGE MAINLAND – PELJEŠAC, CROATIA

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## Abstract

Steel pipe pile as one of the foundation forms has the advantage of high bearing capacity, environment protection and installation, which were widely adopted to sea-crossing bridge, offshore wind power and marine oil rig at present. With the development of project scale, the length and diameter of the piles were increasing gradually. Meanwhile, civil engineers had to face the outstanding challenges in the production and transportation of extra-long and extra-large steel pipe piles. The design parameters of steel piles were controlled under the highest and strictest execution class EXC4 B+ in accordance with the European standard EN 1090-2. Additionally, the pile length of 130,6 m set a record for entire pre-fabricated longest steel pile in the field of civil engineering worldwide at that time. All the manufactured piles were delivered by cargo vessel after long voyage to Croatia. The accumulated experience of Pelješac Bridge could be as a reference for similar projects in future.

*Keywords: extra-long, EXC4 B+, CNC, mechanized, long voyage*

## 1 Project introduction

Bridge Mainland - Pelješac is located at a marine nature protection area in the south of Croatia. It will be connecting the separated two parts of the Croatian territory. By the construction of the bridge, the local economic development could be promoted rapidly. Bridge crosses the Mali Ston Bay with the length of 2440 m including approach spans. It is a multi-span extradosed cable-stayed bridge with a main span layout of 5 x 285 m. The superstructure applied steel box girders and strand stayed cables. The navigation clearance was 200 m x 55 m, as contractually agreed with Bosnia and Herzegovina. Steel pipe piles were adopted to deep water foundation. The lengths of steel piles ranged from 36 m to 130,6 m, and the proportion of pile length over 100 m exceeded 70 %.

## 2 Pile design work

The main steel pile structure consisted of pile head, pile body and pile shoe. Shear rings were welded around pile head with the distance of 30 cm, in order to enhance the stability of connection between pile head and pile cap. Pile body was composed of standard small segments with the length of 3,0 m, the pile body was made of raw material S355NH and the wall thickness is 40 mm. Meanwhile the 2-meter-long pile shoes were made of steel S460NH with the wall thickness of 60 mm. The longitudinal stiffeners were set and welded inside for improving the stability of steel tubular piles, and also enhancing the connection between steel tubular piles and concrete inside. Piles were divided into two main types according to pile shoe characteristics in this project. One type was steel driven pile with stiffening pile shoes, which were embedded into hard rock and the upper 40 m were filled with concrete, but the other type was reinforced-concrete filled steel piles with concrete sockets instead of stiffening pile shoes stand on the hard rock. see Figure 1.

**Figure 1** Shear rings of pile head and pile shoes with stiffening pile shoes

The mean water depth on bridge site is 27 m, in order to ensure that the pile could be protected against corrosion of seawater and sludge, the upper 33,0-meter part of steel piles was painted with epoxy glass flake coating with dry firm thickness of 850μm, and the adhesion was as the requested minimum of 5,0 MPa. The adopted anti-corrosion system was consistent with the expected high durability in accordance with ISO 12944-5 [1], and the steel piles were equipped with the replaceable cathodic protection as well, so it is able to ensure the lifetime of the main structure of up to 100 years.

## 3 Preparation work of production

Before the production the selected Chinese manufactures had obtained the strict European Union (EU) and international certificates, and meanwhile gathered extensive actual valuable engineering experience of European standard EN 1090-2 [2] and international standard ISO 3834-2 [3]. In terms of personnel, the welders and the welding operators were qualified in accordance with ISO 9606-1 [4] and ISO 14732 [5] respectively.

According to approved detailed design drawings the manufacturers edited essential detailed technical documents before formal production, which were also approved by consulting engineer, such as the workshop drawings, manufacturing procedure specification (MPS), inspection and test plan (ITP), welding procedure qualification record (WPQR), etc. The welding procedure qualification test in the accordance with ISO 15614-1 [6] was organized and implemented by international welding engineer (IWE) of the manufacturers, and at the same time supervised and qualified by the consulting engineer and the third party during the whole procedure.

All of the raw materials were purchased from Chinese steel mills, which had acquired permission to produce steel plates of standard EN 10025 [7]. In the meantime, all the plates were qualified with the 3.2 inspection certificates of EN 10204 [8] by the EU notified body. The local steel mills were provided with the advantages of large plant capacity and short haul distance, so that it ensured the stable supply of steel plates during the production.

# 4 Manufacturing procedure

## 4.1 Standard segment production

As mentioned in chapter 2 the wall thickness is 40 mm and 60 mm respectively. For small diameter circular hollow section using thick steel plates was adopted. The pre-bending process was carried out for steel plate edges, and it was necessary to perform it by using a heavy CNC plate rolling machine to form the required curvature of the circular section. After that the plate was rolled backwards and forwards by the plate rolling machine to the "O" shaped cylinder and fixed with tack welding, then the curvature was checked by the templates in time. See Figure 2.


**Figure 2** Standard segment rolling and forming

In order to decrease the difficulty of rolling and improve the processing efficiency, the total pile was separated into several small standard segments to achieve sectional manufacturing. After the forming, as approved by the welding procedure specification (WPS), the longitudinal seam was welded with mechanized welding process. Afterwards the re-rolling procedure was repeated to ensure the roundness of single standard segment. In order to avoid the deformation from welding residual stress, the press of automatic plate rolling machine needed to be strictly controlled.

## 4.2 Segments assembly

The steel piles were spliced from standard segments, one after another to three large segments with the length over 30 m by mechanized welding process. After that the large segments were fit-up and welded with circumferential seams together. See Figure 3. The circumferential seams were checked with non-destructive test (NDT) after the minimum hold time. The roundness and straightness as dominating dimensions were checked strictly for the standard segment, large segment and the total length, according to experience the internally permitted deviation were limited within mm and 0,05 % respectively, which were much stricter than the corresponding mm and 0,2 % referring to EN 1090-2 Annex D 1.9 Class B [2] and EN 10219-2: 2006 Table 2 [9]. The following Table 1 shows the actual measured value of driven piles in this project. In this way the final quality of steel piles could be ensured. The shear rings and pile shoes as additional production were installed when a large segment spliced completely.

**Figure 3** Fit-up of standard segments

**Table 1** Actual measured straightness and roundness of final product

| Pile No. | Pile length [m] | Straightness [mm] | | Out – of Roundness [mm] | |
|---|---|---|---|---|---|
| | | Measured | Percentage [%] | Top | Bottom |
| S5.1 | 117,0 | 42 | 0,036 | +2 | +3 |
| S6.4 | 126,6 | 59 | 0,047 | 0 | -1 |
| S7.4 | 128,1 | 55 | 0,043 | +1 | +2 |
| S8.1 | 128,4 | 43 | 0,033 | -3 | -3 |
| S9.1 | 122,0 | 51 | 0,042 | +1 | +1 |
| TP7 | 130,6 | 34 | 0,026 | +2 | +2 |

## 4.3 Anti-corrosion protection

When the large segments were completed, the underwater 33-meter-long parts were protected against corrosion with epoxy coating before final assembly. In the field of offshore engineering the automatic rolling blasting machine with CNC system (computer numerical control) was widely adopted to steel piles instead of traditional manual sand blasting, which could greatly improve the working efficiency. The following Table 2 shows the comparison between them. The adopted CNC system in this project could treat a surface with maximum of 240 $m^2$ per hour, so that the uncoated pile could be shot blasted automatically in a total period of within 1 hour. As required the prime must be completed within 4 hours after blasting, in case the surface would be oxidized again. Except of high efficiency, the surface treatment was much more uniform than manual, the requirements of cleanliness Sa 2.5 and surface roughness 50 - 85μm could be achieved more easily.

**Table 2** Comparison of work efficiency between CNC and manual

| Item | Area [$m^2$] | Working efficiency | Blasting time | Labor |
|---|---|---|---|---|
| CNC-system | 207,35 | 240 $m^2$ / hour | 0,864 hour | 1 operator |
| Blasting manual | 207,35 | 6,4 $m^2$ / manhour | 4 hours | 8 workers |

## 5 Quality control

The execution class of steel piles was EXC4 B+, as the strictest requirement of steel structures production in the EU. Compared to class EXC3, there was a noticeable difference located in the non-destructive tests, particularly in the visible inspection (VT) of quality level B+, as shown in Table 17 “Additional requirements for quality level B+” in EN 1090-2: 2008+A1 [2]. Undercut is not allowed and must be removed for EXC4 B+, and the other visible imperfections such as weld spatter, cracks, cavities and not permitted imperfections must be removed in time and couldn’t be deposited on the further processing steps.
The NDT tests including visible, ultrasonic, magnetic test (VT, UT and MT) were performed as approved proportion by NDT inspectors of the manufacturers, who had been qualified and certified as minimum level 2 according to ISO 9712 [10]. The full penetration longitudinal and circumferential welds were adopted 100 % percentage of ultrasonic and magnetic test, which is stricter than the corresponding requirements of Table 24 in EN 1090-2: 2008+A1 [2]. In addition, both of consulting engineers and the third party checked the products randomly as well.

## 6 Logistic and transport

After the final inspection the piles were moved to storage area and ready for uploading. Usually the flat barge as best choice is used for pile transport at short distance, but for this project there are two main difficulties, which are the extra-long piles and the long voyage. The vessel departed via the route from China, passing through Strait of Malacca, Indian Ocean and the Suez Canal and arriving to Croatia.


**Figure 4** Cargo vessel with extra-long steel piles arrival on site

Facing such a great challenge the contractor considered the influence factors thoroughly. Firstly, the convenience and safety of uploading in the manufacturers and unloading on bridge site had to be taken into account. The draught on departure and on arrival should be deep enough for anchoring of vessel safely. As transport demanded, the vessel deck had enough strength to afford an approximate load capacity of 5.500 tons. Secondly, in order to minimize or avoid the rent of floating crane and other barges, the better option was for cargo vessel to be equipped with its own deck crane for up- and unloading. Thirdly, according to pile driving rate and production capacity of the manufacturers, it was necessary that the delivery time to destination be around month to ensure an uninterrupted pile driving. As a result, the vessel had to be equipped with adequate strong power. According to the mentioned comprehensive consideration, finally, the large heavy lift vessel was adopted to extra-long steel piles transport. The piles were banded and fixed on the deck with riggings and welded steel structure for safety. Meanwhile, the rubber mat and stow-wood were adopted to protect the contact areas from the damage of coating. Based on the dynamic plan the steel piles of 31.000 tons were sent to site in six batches respectively. See Figure 4.

# 7 Conclusion

In order to meet the great demand of the increasing infrastructure of sea-crossing bridges and offshore wind power worldwide, the underwater steel pile foundation has to now be developed at a rapid pace. The piles have to be longer and with a greater diameter gradually. The advanced CNC-system and mechanized welding process were used widely, on one hand it could reduce man-made effect on product quality, on the other hand, it improved the working efficiency obviously. The contractor has achieved a huge success in Pelješac Bridge Project by selecting a professional supplier of steel piles. It means that China's heavy industry is advancing forward at a global level with high-quality and efficient services.

## Reference


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