Observations on the construction methods used in Soviet-era shore navigational aids in the northern reaches of the Yenisei River

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Abstract. Intense navigation in the northernmost reaches of the Yenisei River during the Soviet era produced a rich industrial heritage. Among the more conspicuous objects are the remains of shore navigational aids, particularly leading lights and beacon towers. The surviving structures offer insights into the navigation methods used in this part of the Arctic. Navigational aides were also among the last industrial structures in the Soviet Arctic to be built of wood. Besides, they are important examples of structural engineering in the Arctic, meaning that they were designed to cope with the harsh environment.

1. Introduction. The Yenisei River is a natural riverine continuation of the Northern Sea Route (NSR), which links the Arctic Ocean to the interior of Central Siberia. The river is continuously navigable for seagoing vessels to its only surviving seaport – Dudinka (69°24′N 86°11′E). For ships drawing under three meters, the head of navigation is the regional capital city – Krasnoyarsk situated over 2,500 km inland. This unique geographical feature of the Yenisei has made it an attractive transportation corridor since the 1870s, when the first seagoing steamers ascended the river for the purpose of delivering European industrial goods to Siberia. Thenceforth, thousands of vessels have navigated the vast stretches of the Yenisei making it the second busiest river shipping lane in Siberia. Thus, in 2014, vessels operating in the Ob’ and Irtysh basins transported over twelve million tons of cargo, while only approximately three and a half million tons were carried up and down the Yenisei and its tributaries. Meanwhile, the average distance this cargo was carried comprised 550 km for the Ob’ and Irtysh system, while 1,370 km was the figure for the Yenisei, making navigation distances here significantly greater [1]. Today, the intense development of oil mining on the Taimyr Peninsula has put additional strain on the riverine transportation system.

Before the arrival of modern satellite navigation systems, shipmasters relied on a system of lateral navigation aids. The history of this system in connection to Yenisei Arctic shipping marked a centennial anniversary in 2020. Its usage continues to this day in the upper and middle reaches of the river. However in the northernmost reaches, where the river widens to several (and even tens of) kilometers, the lateral system aids are now largely disused. While some beacons and leading lights towers (especially steel truss structures) continue to operate, timber towers have largely been abandoned and left to deteriorate in the harsh Arctic climate. Here it is important to note that during the last years with the increase of air temperatures in the Arctic regions followed by the subsequent melting of permafrost layers, charges in precipitation rates, and increased activeness of microorganisms threatens the existence of preserved wooden historical structures [2]. As these sites are under immediate
threat, it is important to develop a precise strategy for preserving existing industrial heritage sites located in the Arctic. Employing structural analysis provides a way to better understand original construction methods and as such is considered pivotal to the preservation and restoration of historical structures [3].

The timber leading lights towers, which dominate the landscape of the Arctic reaches of the Yenisei (north of 68°N), were built during the Soviet epoch. Some remains can be dated back to the very first beacons built during the 1920s and 1930s. They are tangible fragments of evidence speaking of the technological development of the Arctic navigation system (both maritime and riverine), paralleling the history of the sea route itself. As such, they provide a firm basis for the need to study structural evidence in the northern polar region.

In view of the aforementioned, the study of past navigation facilities should become a subject for a comprehensive study on the industrial archaeology of the Northern Sea Route. Due to the immensity of this task, in this paper, we shall narrow our focus to the structural features of leading lights towers, which remain the most distinctive anthropogenic structures on the riverbanks and islands of the lower Yenisei. This study is a presentation of a preliminary investigation of these structures, built on field data collected by us in 2019.

Internationally, there has been but a handful of studies dedicated to historical navigational aids, among which is a descriptive essay on aids in the Mississippi River mouth [4]. There is also a paper on the history of providing safe navigation for vessels operating on the river Ob' and its tributaries during the Second World War [5], however, as with other related studies, it is based on documentary, rather than material evidence.

2. Field data, collected in 2019 and its analysis.

In 2019 during a project hosted by Reshetnev University (Krasnoyarsk, Russia), a team of researchers headed by the lead author of this paper transected a two-way water route along the right bank of the river Yenisei from Dudinka to cape Mys Muksuninskii (70°18'1"N 82°59'8"E) (Fig. 1). The usage of inflatable smallcraft allowed the team to investigate a number of historical sites, the majority of which are valuable as industrial heritage and industrial archaeological monuments. As with many industrial objects, these have largely remained neglected by professional researchers, archaeologists and historians alike. The latter dismiss such objects as being outside the scope of archaeological science, whereas the former seldom undertake extensive fieldtrips, preferring to conduct documentary research in archives.

Fig. 1. Map of the Taimyr (Taymyr) Peninsula showing the study area.

1 The present authors are responsible for all translation and transliteration on this text.
The expedition gathered data on 18 sites, including seven settlements, four cemeteries, and three leading lights towers. During the fieldwork, we were able to recover structural evidence on many of the towers, particularly those fully intact or with standing remains.

Pairs of leading (range) marks are elemental navigational aids positioned in such a manner to be aligned with one another in order for the navigator to follow the leading line on the same bearing. Following a framework of bearings, the ship is guided through the deepwater channel and kept clear of submarine obstacles. Visibility is a key factor in the design of this type of aid. In monotonous landscapes such as the Siberian tundra, any freestanding structure is highly visible. The addition of a painted (typically, black and white) dayboard to the observable side of the tower further enhances the visibility of the towers. For autumn and, from the mid-1970s, winter navigation the towers were fitted with electrical lights powered by alkaline batteries making them visible during the polar night.

Fortunately, because the construction and maintenance of the structures had been staged by centralized state organizations, we have precise and detailed data on how they were built. Preserved technical documentation enables us to conduct a detailed analysis of the structures and compare them to preserved examples. For instance in Fig. 2, the standing truss tower at Mys Krestovskii is perfectly comparable with a plan for a similar construction.

As with all industrial structures built in the Soviet Union, the construction of the towers was regulated by a series of state-issued standards, known as GOST(s). One of the latest of these documents was the GOST 16150-71 Znaki navigatsionnye beregovye. Tipy, osnovnye razmery i tekhnicheskie trebovania [Shore Navigation Signs: Types, Dimensions, and Technical Specifications] issued in 1971. This standard, in turn, provided common layout for producing specialized technical documentation such as the 1972 Project for Wooden Shore Navigation Signs (the 3.505-11 Series) by the Giprorechtrans [State Institute for Projecting Riverine Transportation]. Thereby the construction of navigation towers as well as other similar structures was regulated by a series of technical documents; thereby, standardizing them.

In the table below are shown the main structural elements and their dimensions of the 9.25 m tower.

| Component          | Material | Diameter in cm or grade | Length in cm | Unit of measurement | Amount |
|--------------------|----------|-------------------------|---------------|---------------------|--------|
| Vertical support   | Pine     | 24                      | 500           | Number per m³       | 4/1.08 |
The choice of wood as the primary material for constructing the towers was dictated both by the cheapness of this material and its availability. Besides, it was expected that these structures were to be built and maintained by riverine and maritime facilities without the need for special factories or personnel [6]. Furthermore, as seen from the choice of timber type, the tower had to be relatively lightweight so to be easily transported to the building site, possibly using manual labor. The prefabricated structure was delivered to the building site, where it was assembled on the ground as two separate trusses. These were then erected in succession using a set of winches and set into pre-excavated holes. The following procedure involved joining the two trusses with braces and building a four to five decks and ladders for subsequent tower maintenance.

An important feature of wood to consider when designing structures having a potential buckling instability is its orthotropic properties. It is known that wood is better at resisting loads such as compression, shear and tensile stress in the direction of the fiber growth rather than in transversal directions [7]. Due to this the towers were constructed as three-dimensional lattice rigid structures. Lattice towers are known to be very effective at withstanding both dynamic and static loads, notably those from the environment [8]. The greatest loads for the wooden towers in the Arctic are exerted by winds blowing across the open tundra and creating pressure on the dayboard. The load is reduced by assembling the dayboard with wide spacing between the planks and resisted by adding a substantial arsenal of structural elements such as collar beams and braces.

The field work has revealed that many of the Soviet-era towers remain standing today despite their age varying from fifty to seventy years. This suggests that these structures were more or less efficient, despite being intended as temporary structures that could be easily replaced using both prefabrication and, if required, built on-site with any available local materials.

It is suggested that the weak spot of the timber towers is their foundation. While the later standards regulate this detail of the structure, proposing the usage of concrete pillars and soaking the supports in creosote, it is likely that this procedure was omitted during the construction of the first navigation aids during the 1920s and 1930s due to material and labor shortage. The ruins of towers discovered at mys Krestovskii (Fig. 4) and mys Muksuninskii (Fig. 5) reveal that these structures collapsed due to the disintegration of the foundation elements and main structural members that were attached to them.

| Vertical support | Pine | 14 | 700 | 4/0.60 |
|------------------|------|----|-----|--------|
| Collar beam      | Pine | 20 | 600 | 4/0.92 |
| Collar beam      | Pine | 16 | 440 | 7/0.73 |
| Collar beam      | Pine | 16 | 300 | 3/0.33 |
| Knee brace beam  | Pine | 20 | 600 | 3/0.69 |
| Knee brace beam  | Pine | 16 | 460 | 3/0.34 |
| Diagonal brace   | Pine | 14 | 730 | 2/0.32 |
| Diagonal brace   | Pine | 14 | 520 | 2/2.20 |
| Brace            | Pine | 15x2.5 | 230 | 3/0.03 |
| Planks for dayboard | Pine | 20x2.5 | unspecified | m³ | 0.76 |

Fig. 4. Collapsed tower at mys Krestovskii (dated 1930s).
Despite the damp conditions of the environment, the ironmongery remains largely intact, while the wooden members as a result of decades of decade have deteriorated. As seen from the last two figures, the earlier towers were built of roundwood, not beams, as this material was much cheaper (though harder to work with).

3. Conclusion

Navigation on the Yenisei during the twentieth century heavily relied on aids to navigation such as those described in this paper. While many towers continue to stand, most of the Soviet-era structures have collapsed and are rapidly deteriorating. Using primary sources such as the GOST 16150-71, we have been able to classify the tower at mys Krestovskii, though it seems that this structure had been built before the publication of the aforementioned document, which suggests that the later Soviet technical documentation was based on earlier regulations, perhaps composed during the 1950s. The remaining two towers, mentioned in this paper, were built outside the technical regulations of the 1970s and belong to an earlier period. The comparable inexpensiveness and efficiency of wooden structures explains their perseverance into the late twentieth century, when materials such as steel and concrete became available in sufficient quantities.

This paper was not intended as a detailed study on the history of aids to navigation in Arctic Siberia. It merely touched upon a new topic in the field of industrial archaeology and Arctic industrial heritage in order to test its relevance to these fields. The amount of field data collected by the authors of this paper, coupled with scattered data from other expeditions to parts of Arctic Siberia, both professional and amateur, has revealed the importance of this topic to the understanding of maritime and riverine navigation along the waterways of the Northern Sea Route and its adjacent rivers. We hope to be able to produce more comprehensive studies on this matter in the nearest future.

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