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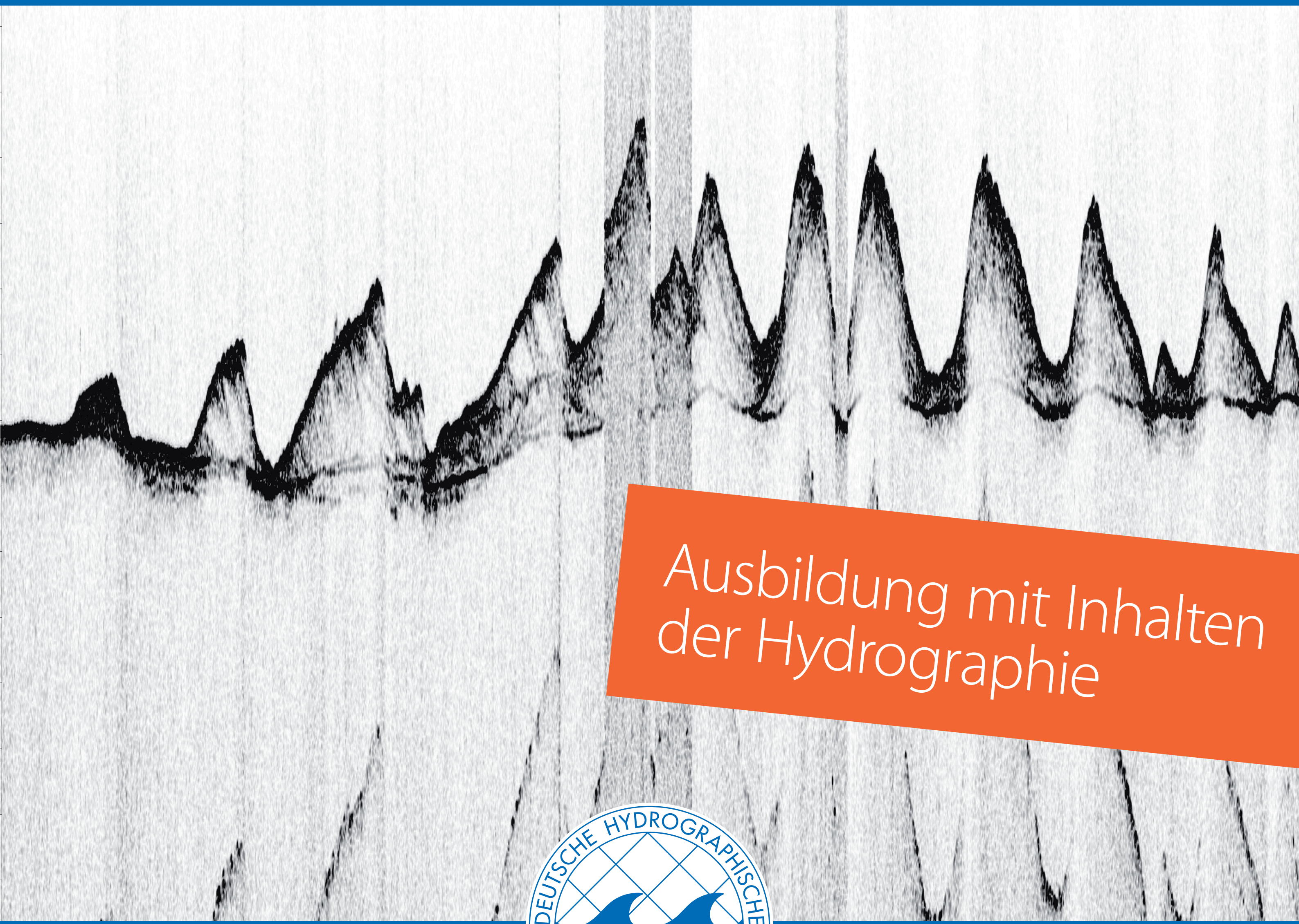

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The influence of the Elbtunnels on the Elbe riverbed

Investigating scour effects around the Old and New Elbtunnels and exploring potential contributing factors

An article by ERIC IDUN

Hydrographic surveying plays a critical role in ensuring maritime safety and navigation by providing essential data on underwater topography and seabed conditions. This study examines the scouring effects around the Old and New Elbtunnels in Hamburg, Germany, using high-resolution bathymetric mapping, sub-bottom profiling, water velocity measurements and riverbed sediment analysis. The results reveal significant scour around the Old Elbtunnel, with erosion depths reaching 1.5 metres. In contrast, no evidence of scouring was found near the New Elbtunnel. Sediment analysis showed that areas with sand and silt, particularly downstream of the Old Elbtunnel, were more prone to erosion. The findings highlight the combined impact of tunnel protrusion above the riverbed, sediment type and hydrodynamic conditions on scour development. The study emphasises the importance of long-term monitoring to assess and manage these effects for maritime operations.

scouring effects | scouring | Old Elbtunnel | New Elbtunnel | sediment analysis | monitoring
Kolkeffekte | Auskolkung | Alter Elbtunnel | Neuer Elbtunnel | Sedimentanalyse | Überwachung

Die hydrographische Vermessung spielt eine entscheidende Rolle bei der Gewährleistung der Sicherheit und Navigation auf See, da sie wichtige Daten über die Unterwassertopografie und die Meeresbodengegebenheiten liefert. In dieser Studie werden die Kolkeffekte um den Alten und Neuen Elbtunnel in Hamburg mit Hilfe von hochauflösenden bathymetrischen Vermessungsdaten, Sedimentlotungen, Wassergeschwindigkeitsmessungen und Flusssedimentanalysen untersucht. Die Ergebnisse zeigen erhebliche Auskolkungen im Bereich des Alten Elbtunnels mit Erosionstiefen von bis zu 1,5 Metern. Im Gegensatz dazu wurden in der Nähe des Neuen Elbtunnels keine Hinweise auf Auskolkungen gefunden. Die Sedimentanalyse zeigte, dass Bereiche mit Sand und Schlick, insbesondere flussabwärts des Alten Elbtunnels, anfälliger für Erosion waren. Die Ergebnisse verdeutlichen den kombinierten Einfluss des Tunnelvorsprungs über dem Flussbett, des Sedimenttyps und der hydrodynamischen Bedingungen auf die Kolkentwicklung. Die Studie unterstreicht die Bedeutung einer langfristigen Überwachung, um die Auswirkungen für den Schiffsbetrieb zu bewerten und zu steuern.

1 Background and objective

Numerous factors contribute to the alteration of the seafloor by artificial structures, with scouring being the most prevalent. This phenomenon can negatively impact both the seafloor and the structure itself. For instance, more than 150 state-owned bridges in Georgia, US, suffered scour damages during the 1994 Alberto storm flooding and necessitated replacement (Arneson et al. 2012).

Scouring is characterised by the rapid removal of loose granular soils from the riverbed by the flowing water body. This phenomenon becomes more pronounced, especially when the structure is elevated above the seafloor as shown in Fig. 1. The water velocity over the structure induces cohesion, leading to erosion.

The investigation presented in this article involves measuring bathymetry of the river Elbe to identify potential scour effects around the Elbtunnels in Hamburg, Germany. Backscatter

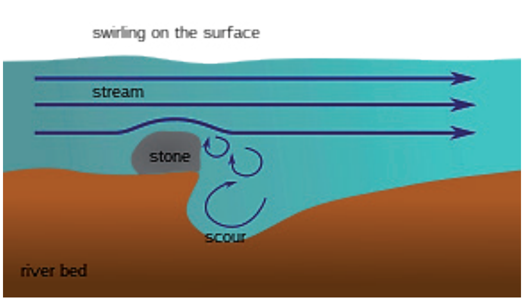

Fig. 1: Scouring formation mechanism (Amangabara 2023)

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analysis is conducted to determine the type of sediments in the area and assess their susceptibility to erosion based on the water velocity. Sub-bottom profiling is employed to examine the depth of the tunnel and ascertain whether scour effects are present. The study focuses on examining the impacts of scouring around the Elbtunnels and exploring potential contributing factors. It seeks to address the questions: How does the presence of the tunnel affect the physical characteristics and topography of the riverbed? And: Which indicators and characteristics of the riverbed potentially influence the scouring effects around the tunnel?

2 Data acquisition

The survey was conducted using two vessels, *DVocean* owned by HCU and *Ludwig Prandtl,* a research vessel from Helmholtz-Zentrum Hereon. Each vessel is equipped with specific instruments for targeted data collection. The *DVocean* vessel carried out bathymetric and sub-bottom profiling surveys over the Old and New Elbtunnels on November 3, 2023, using a Kongsberg EM2040P MKII multibeam echo sounder, an AML-3 LGR sound velocity profiler and an Innomar compact sub-bottom profiler. The survey covered an area of 44,134 m², with eight profile lines and one crossline. The multibeam echo sounder operated at a frequency of 300 kHz and 110° swath angle. A 40 % line overlap ensured full coverage, while Qinsy 9.6 software managed navigation and data acquisition. Simultaneously, sub-bottom profiling was conducted using an Innomar SES-2000 compact, with secondary low frequencies between 6 and 12 kHz.

On December 15, 2023, the *Ludwig Prandtl* vessel collected water velocity data from Wedel to Oortkaten, strategically crossing the Elbtunnels at low tide. It was equipped with a 600-kHz Teledyne RDI Workhorse ADCP, operating throughout the survey period and monitored using WinRiver 2.16.

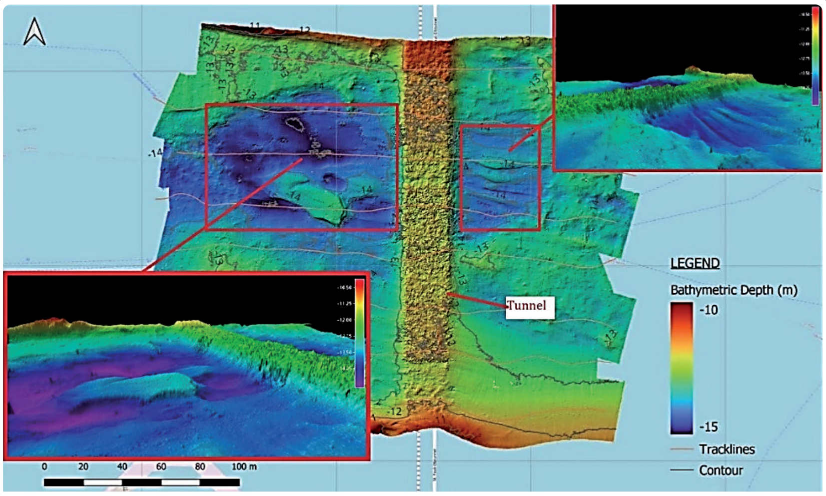

Fig. 2: Bathymetric data showing scour location around the Old Elbtunnel

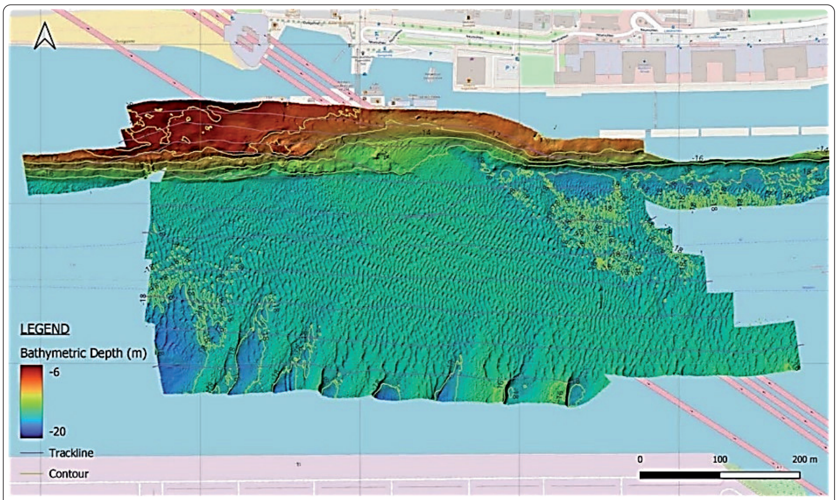

Fig. 3: Bathymetric data of the New Elbtunnel

3 Data processing

Multibeam echo sounder (MBES) data was processed using QPS Qimera 2.5.1. A dynamic surface with a 0.50-m cell size was generated following the coordinate system setup. A patch test was conducted to calibrate the orientation of the MBES. The sound velocity profiles (SVP) were imported, and the bathymetric data was corrected accordingly. Motion sensor and GNSS data were validated, and swath editing removed noise artefacts. The CUBE method with a 0.25-m cell size was used to further refine the dataset. After all, the total propagated uncertainty (TPU) values ranged from 0.10 to 0.27 m (THU) and 0.08 to 0.09 m (TVU) and the dataset therewith meets IHO S-44 Special Order standards. Backscatter data were exported in GSF format and processed in QPS FMGT 7.10.2, applying beam pattern and AVG corrections to produce a 0.50-m pixel mosaic. ADCP data were processed in WinRiver II (v2.16), with adjustments for transducer offset and depth. Data validation showed no errors in GNSS or motion sensors. Sub-bottom profiler data were processed in ISE 2.9.5, including heave compensation, positional verification and manual correction of signal spikes following automated seabed detection.

4 Results

A digital terrain model (DTM) with a 0.25-m cell size was generated from the processed MBES bathymetric data. Quality assessment included a statistical comparison of the crossline to the regularly surveyed data (cross check), in accordance with IHO S-44 Special Order standards. The analysis showed a mean difference of 0.003558 m and computed uncertainty of 0.20 m, which was below the allowable limit of 0.27 m. The survey encompassed approximately 49,000 m² around the Old Elbtunnel (depth below NHN: –10 to –15 m) and 274,000 m² around the New Elbtunnel (depth below NHN: –6 to –21 m), both exhibiting east-to-west sloping topography.

Backscatter data processing, including nadir intensity correction, enhanced the mosaic clarity. High signal absorption areas appeared dark, while high backscatter zones were bright, improving substrate differentiation.

ADCP results were visualised as time–depth contour plots, depicting current velocity profiles with colour gradients (purple to red) indicating flow strength. These plots allowed for temporal and vertical profiling of current strength and direction.

Sub-bottom profiler (SBP) data provided structural insights into the tunnels' positions relative to the riverbed. In the case of the Old Elbtunnel, the echo plot revealed the tunnel elevated above the river floor. For the New Elbtunnel, only the river floor was visible, with no distinct subsurface features identified.

5 Discussion

5.1 Scour analysis

The bathymetry provided critical insights into the river floor conditions around both the Old and New Elbtunnels. Evidence of scour activity was observed around the Old Elbtunnel (see Fig. 2), particularly in two distinct areas: A relatively minor 2,500 m² region upstream the tunnel in the east-to-west flow direction and a more prominent 3,500 m² area downstream, where erosion depths reached approximately 1.5 m compared to the surrounding riverbed. The tunnel itself protrudes about 2 m above the riverbed, a factor likely contributing to the observed localised scour.

In contrast, the New Elbtunnel showed no visible signs of scour (see Fig. 3), with a flat, ripple-patterned topography, consistent with its buried position beneath the riverbed.

5.2 Tunnel depth

The analysis of SBP echograms provided a comprehensive examination of subsurface conditions, contributing to a better understanding of tunnel visibility and potential scour characteristics.

The Old Elbtunnel echogram revealed the tunnel structure and supported the evidence of scour (see Fig. 4).

However, the echogram for the New Elbtunnel did not show any scour effects, and the tunnel did not extend beyond the riverbed. The absence of scour is evident in the echogram (see Fig. 5). The figure shows light reflections approximately 2 m below the riverbed, indicating the possibility of underlying structures. Dark reflections observed in the figure could be attributed to the high reflectivity of the tunnel's concrete, hindering penetration and resulting in limited visibility of deeper layers.

5.3 Sediment classification

Backscatter processing focused exclusively on the Old Elbtunnel site due to indications of potential scour effects. The resulting mosaic reveals distinct features, strong reflections concentrated over the tunnel and lower reflections in the scour areas A and B, as illustrated in Fig. 6. Additionally,

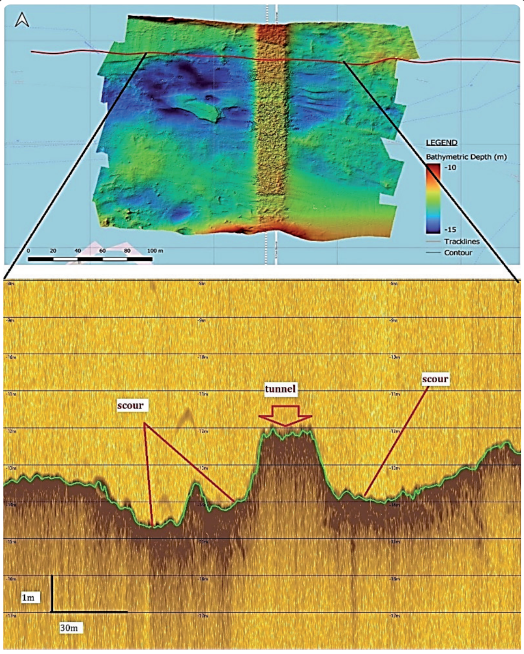

Fig. 4: SBP echogram over the Old Elbtunnel with location in the bathymetric data

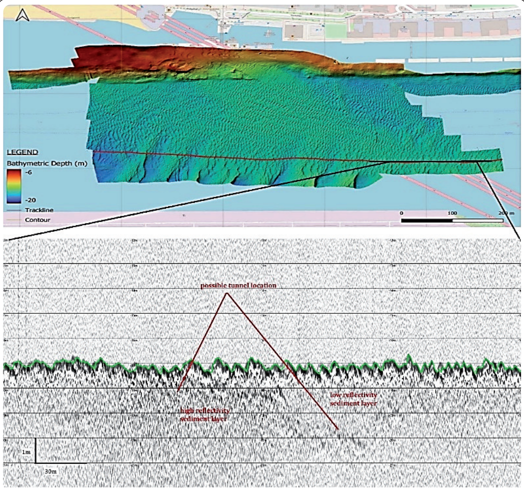

Fig. 5: SBP echogram over the New Elbtunnel with location in the bathymetric data

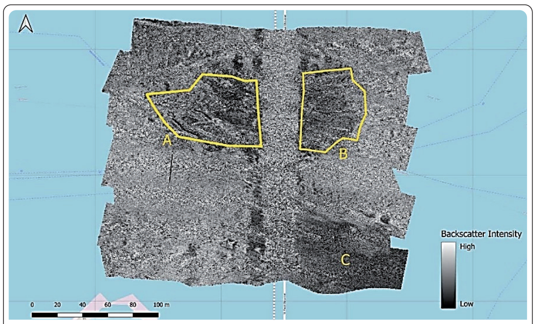

Fig. 6: Backscatter mosaic of the Old Elbtunnel

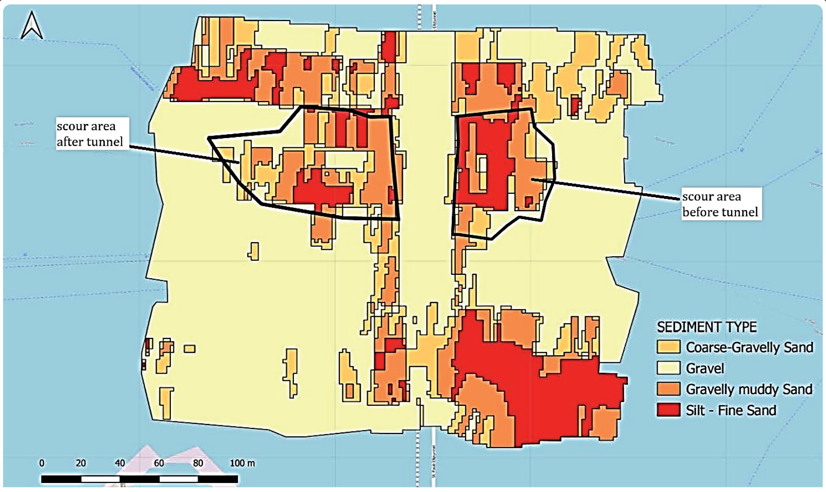

Fig. 7: ARA sediment classification

there are regions of reduced reflections on the south-eastern side of the survey area (Area C), potentially indicative of similar sediment types to A and B.

The entire survey area underwent classification into four categories: Coarse-gravelly sand, gravel, gravelly muddy sand, and silt-fine sand, based on the generated angular response analysis (ARA). Predominantly, the area comprises gravel, with fewer sections consisting of sand and silt. The scour areas exhibit a predominant composition of sand, as depicted in Fig. 7. The classification aligns with the understanding that loose granular sediments, such as sand and silt, are more prone to erosion by water (Earle 2015). This provides a possible explanation for the prevalence of these sediment types in the scour areas, indicating their vulnerability to scouring processes.

Fig. 7 highlights the presence of areas with sediment compositions similar to those observed in the scour areas, yet without noticeable scouring effects. This can be attributed to several factors contributing to the scouring in specific regions.

Firstly, the scour areas may coincide with the natural path of the river, subjecting them to the continuous erosive forces of water flow during both high and low tides. The repetitive action over time leads to the removal of sediments, resulting in the observed scour effects. Secondly, it is possible that the water velocity in the direction of these scour areas is high enough to intensify the erosive impact, and contribute to the scouring effects in these specific locations, even if other areas share similar sediment compositions.

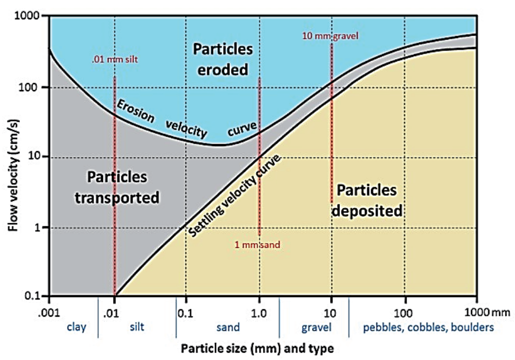

Fig. 8: The Hjulström-Sundborg diagram showing particle size and different velocities it can be eroded (Earle 2015)

5.4 Water velocity

ADCP measurements were conducted to measure water velocity, with the aim of determining if water velocity plays a role in the observed scour effects around the tunnel. The erosion of sediments on the riverbed is linked to water velocity, as higher water velocities increase the likelihood of sediment erosion (Earle 2015). Utilising the Hjulström-Sundborg diagram depicted in Fig. 8, it becomes clear that silt sediments can be eroded at a minimum velocity of 30 cm/s, while sand sediments can undergo erosion at a minimum velocity of 20 cm/s.

In Fig. 9, the ADCP velocity contour plot illustrates the distribution of water velocities over the scour area. The highlighted region in red indicates the velocity specifically within the scour area just after the tunnel. It can be observed that the average velocity within this area ranges from 30 cm/s to 70 cm/s. This observation is consistent with the indications of the Hjulström-Sundborg diagram, suggesting a significant likelihood of sediment erosion, particularly for silt and sand sediments. Given that the scour areas predominantly consist of these sediment types, the water velocities observed in this specific region offer a possible explanation for the observed scour effects.

6 Conclusion

The bathymetric survey met the IHO special order requirements, resulting in the creation of a high-resolution DTM of the survey areas around the Old and New Elbtunnels in Hamburg. The survey revealed scour effects around the Old Elbtunnel, with affected areas measuring 6,000 m^2 and an average depth of 1.5 m, whereas no scour effects were detected around the New Elbtunnel. SBP measurements were conducted to investigate any correlation between the tunnel's protrusion and the observed scouring effects. The findings indicated that the New Elbtunnel was buried at least 2 m beneath the seafloor, which is likely due to its construction using a tunnel boring machine, whereas the Old Elbtunnel protruded above the river floor, exhibiting noticeable scour. Further seabed classification analysis was carried out to determine the sediment types, which may also contribute to scouring effects. This analysis revealed predominantly gravel sediments across the survey area, with sand and silt sediments predominant in the scour areas. ADCP measurements disclosed

References

Amangabara, Gordon Tami (2023): Gully Erosion Sites in Southeast Nigeria: Prospects for Geotourism. In: Adetoye Faniran; Lawrence kosoko Jeje; Olutoyin A. Fashae; Adeyemi O. Olusola (Eds.): World Geomorphological Landscapes – Landscapes and Landforms of Nigeria. Springer Nature, DOI: 10.1007/978-3-031-17972-3_16

Arneson, L.; L. Zevenbergen; P. Lagasse; P. Clopper (2012): Evaluating Scour at Bridges. U.S. Department of Transportation, www.fhwa.dot.gov/engineering/hydraulics/pubs/hif12003.pdf

Earle, Steve (2015): Physical Geology. BCcampus, https://opentextbc.ca/physicalgeology2ed/

the water velocity at scour areas, and utilising the Hjulström-Sundborg diagram, it was determined that sand and silt could be easily eroded at a minimum velocity of 20 cm/s.

The study suggests that the scouring effects observed around the tunnel are primarily attributed to the rapid removal of sand and silt sediments. This phenomenon is predominantly influenced by the tunnel's protrusion above the riverbed. Changes in river flow velocity intensify the scouring process, leading to the erosion of sediments around the old tunnel.

Scouring poses a significant threat to the stability of structures, gradually weakening the foundation of the Elbtunnel over time and potentially leading to infrastructural collapse and careful monitoring of the infrastructure is advised.

By assessing changes in seabed topography or scour effects around the tunnel, researchers can monitor and further investigate to prevent any infrastructural failure. The study advocates for long-term monitoring, integrated with other studies, to assess the evolution of scour effects around the tunnel. //

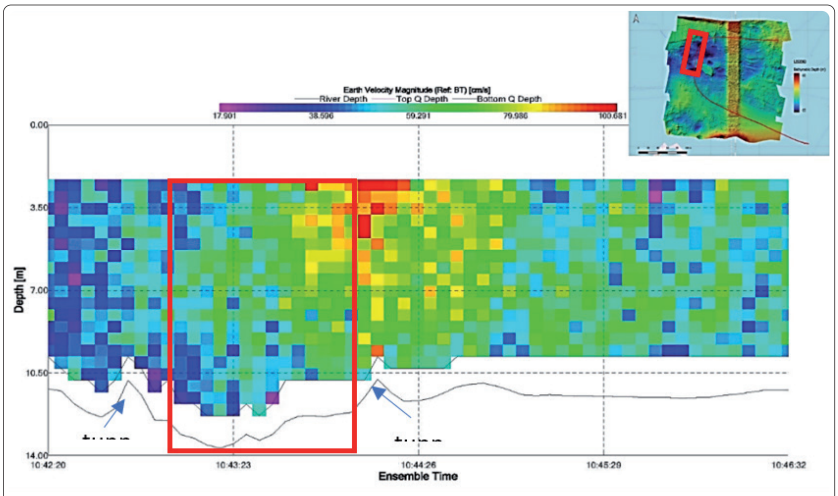

Fig. 9: ADCP velocity contour plot over scour area