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In Situ Block Lifting Strategies for Fragile Waterlogged Archaeological Remains: A Case Study from the Nanhai No. 1 Shipwreck

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Keywords: Block lifting; Nanhai No. 1; Multimaterial framework; Waterlogged archaeological remains; *in situ* conservation

Abstract

Fragile remains from waterlogged and high-humidity environments often present considerable challenges for *in situ* recovery due to long-term degradation, reduced mechanical strength, and the need to preserve archaeological context. Block lifting can effectively recover fragile remains while preserving spatial relationships, though the choice of strategy depends on preservation conditions and field requirements. This study examines the development and application of *in situ* block lifting strategies during the long-term excavation of the Nanhai No. 1 shipwreck. Based on archaeological assessment and recovery requirements, three strategies were developed: direct lifting, single-material lifting, and multimaterial lifting. The multimaterial strategy integrated menthol, polyurethane bandages, plaster, and polyurethane foam, with each material performing specific functions in surface protection, conformable reinforcement, and external structural support. These strategies were applied under monitored high-humidity conditions (RH frequently exceeding 85%) to recover wooden components, fragile organic remains, and complex assemblages. The results demonstrate that condition-based selection of lifting strategies enabled safe recovery while preserving morphology and spatial relationships. The Nanhai No. 1 excavation provides practical insights into integrating archaeological assessment, material selection, and structural support during *in situ* recovery of fragile remains.

1.Introduction

In situ conservation is essential for preserving both the cultural and physical values of cultural heritage remains during field excavation (Pedelì and Pulga 2013). However, severe deterioration, large sizes, or complex spatial relationships may prevent the direct removal of individual objects when the surrounding matrix contains essential information, such as object arrangements, packaging organization, and depositional relationships; disassembly extraction risks losing that evidence.

Block lifting provides an effective solution by preserving fragile remains together with their surrounding matrix until they can be safely transferred to a laboratory for controlled excavation (Cronyn 1990; Sease 1994; Pedelì and Pulga 2013). Unlike disassembly extraction, block lifting maintains relationships among artifacts, sediments, and associated materials, supporting both conservation and archaeological interpretation. This approach has been successfully applied to various fragile remains, including wooden coffins (Wang, 2019), wheels (Liu et al., 2022), bamboo slips (Yang et al., 2008), and waterlogged ivory (Xiao et al., 2022). Recent work on the temporary undisturbed reinforcement and extraction of fragile organic and composite remains from shipwrecks has further demonstrated the importance of carefully designed support systems (Wang et al. 2021).

Successful block lifting relies on the coordinated use of temporary consolidants, protective layers, and supporting structures. Conventional materials such as plaster, wax, timber casings, and volatile binding media (VBMs), including cyclododecane (CDD) (Payton 1992; Sease 1994; Hangleiter et al. 1995; Brückle et al. 1999; Stein et al. 2000; Karsten A et al. 2018; Pedelì and Pulga 2013; Han et al. 2017; Rowe and Rozeik 2008), are used. While these have proven useful, their performance in humid or waterlogged conditions can be limited by moisture sensitivity, curing behavior, sublimation rates, and compatibility with fragile materials (Han et al. 2016, 2018; Rowe and Rozeik 2008). High humidity may compromise stability and handling, and the slow sublimation of CDD can delay subsequent treatment（Hangleiter et al. 1995）. Developing strategies that enable rapid stabilization, safe recovery, context preservation, and compatibility with later conservation remains a key challenge.

Recent conservation practices indicate that no single material can simultaneously meet all requirements for the recovery of complex remains (Han et al. 2016, 2018; Pedelì and Pulga 2013). Flexible materials are advantageous for surface protection and adaptation to irregular structures, whereas rigid materials

provide essential mechanical support during lifting and transport. A combination of materials with complementary properties may therefore provide a more effective approach for challenging excavation environments. However, applying such multimaterial systems under real archaeological conditions, particularly in high-humidity environments, requires further investigation.

The Nanhai No. 1 shipwreck, with its exceptional scale, material diversity, and preservation conditions, provided a unique opportunity to develop such strategies (Xu 2015; Zhang 2019). Long-term marine immersion, combined with exposure to high temperature and humidity (RH > 85%) after excavation, caused severe degradation and significant loss of mechanical strength, particularly in organic and composite remains.

Under these conditions, three major challenges emerged. First, highly degraded organic remains, including bamboo baskets, rope fragments, and wooden containers, had very low mechanical strength and relied on surrounding sediment for support. Unreinforced lifting risked collapse or deformation, and rapid moisture loss after exposure could cause secondary cracking. Second, many composite assemblages preserved important spatial information about cargo organization, packaging, and maritime transport. Disassembly would separate artifacts from their original context and destroy that information. Third, excavation operations in a purpose-built caisson were limited by confined space and temporary structures, which limited *in situ* conservation. Block lifting became not only an excavation method but also a means of transferring fragile archaeological units from the constrained field environment to the controlled laboratory.

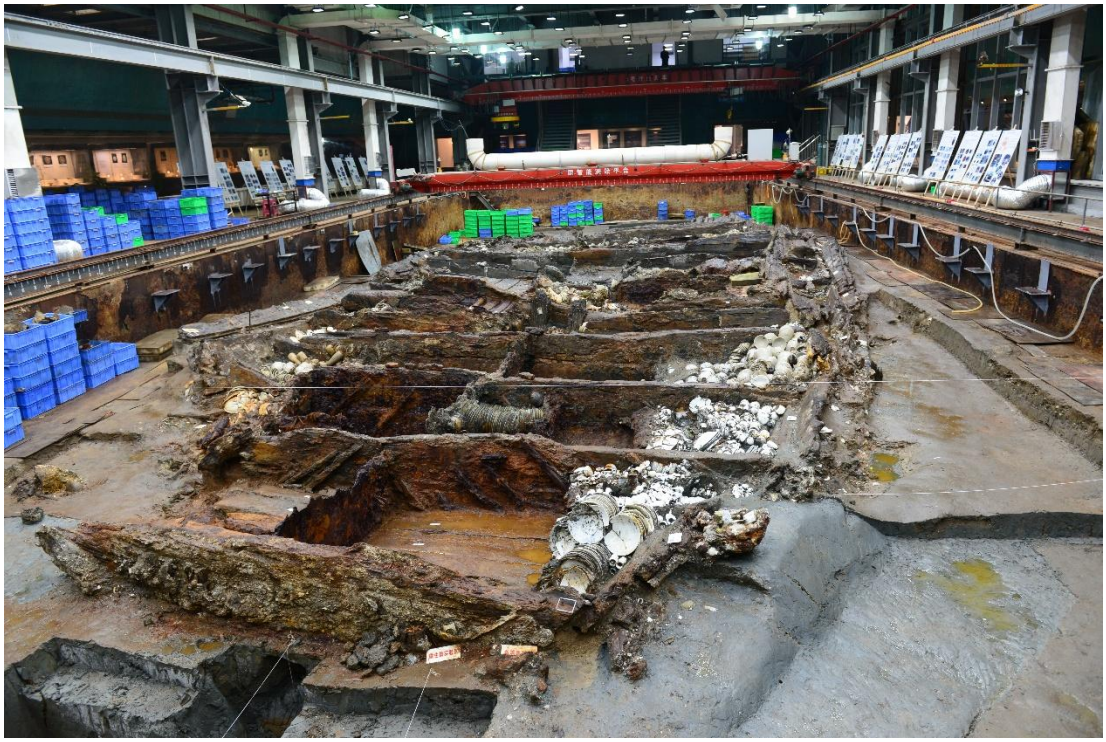
To address these challenges, this study presents condition-based block lifting strategies developed and applied during the Nanhai No. 1 shipwreck excavation. The framework combines menthol, polyurethane bandages, plaster, and expanded polyurethane foam to provide flexible isolation, conformable reinforcement, and rigid load-bearing support. Through monitored field applications across different categories of remains, this study examines material coordination during block lifting. It proposes a transferable framework for block lifting fragile, waterlogged remains in marine and humid environments.

2. Site Background

The Nanhai No. 1 shipwreck is a Southern Song Dynasty (1127–1279 AD) merchant vessel recovered through a total integral salvage approach and relocated to the Guangdong Maritime Silk Road Museum

(National Center for Underwater Cultural Heritage Protection et al. 2017, 2018). The vessel measures approximately 21.91 m in length and 9.87 m in width and contains 13 cargo compartments (Fig.1). During more than a decade of excavation, nearly 180,000 archaeological artifacts were recovered, including ceramics, metal objects, gold and silver artifacts, lacquered woodenware, coins, cinnabar, and biological remains (National Cultural Heritage Administration China 2020).

Fig. 1



The Nanhai No. 1 Conservation and Excavation Site

Artifact recovery was conducted in two main stages: extracting cargo remains from within the hull and recovering scattered remains from the vessel's exterior. Prolonged marine immersion, combined with subsequent exposure to high temperature and humidity, caused severe degradation and significant loss of mechanical strength, particularly among organic and composite remains. Relative humidity during excavation frequently exceeded 85%, creating additional challenges for temporary consolidation, material curing, and safe handling of fragile artifacts.

3. Temporary Consolidation Materials

The feasibility of block lifting depends on the compatibility of temporary consolidants and supporting

materials with both the artifacts and subsequent conservation procedures. Materials should provide adequate stabilization during extraction while minimizing adverse effects on fragile remains. Applications in humid environments also require appropriate setting behavior, moisture tolerance, and compatibility with subsequent treatment processes.

Common temporary lifting materials include rigid supports such as plaster and polyurethane foam (Jones 1980), and volatile consolidants such as cyclododecane and menthol (Hangleiter et al. 1995; Rowe and Rozeik 2008; Han et al. 2016, 2018). However, most remains from the Nanhai No. 1 were waterlogged and required prolonged immersion for desalination. Material selection therefore had to consider not only immediate mechanical stabilization but also compatibility with subsequent laboratory conservation.

Based on these requirements, menthol, polyurethane bandages, plaster, and expanded polyurethane foam were selected for different functional roles within the lifting framework. Menthol provided temporary surface stabilization, polyurethane bandages provided conformable reinforcement, and plaster and polyurethane foam supplied external structural support during lifting and transport.

3.1 Plaster and Plaster Bandages

Plaster has been widely used in archaeological lifting because it provides rigid support once cured. Its high compressive strength helps distribute mechanical loads during handling and transport. However, moisture can influence curing behavior and long-term stability, limiting its application in high-humidity environments. These materials were used mainly where rigid external support was needed, and site conditions were suitable.

3.2. Polyurethane Foam

Polyurethane foam provides lightweight filling and supporting functions due to its low density and volume expansion. However, its application in waterlogged archaeological contexts requires careful evaluation. The material's low density may generate buoyancy effects when used underwater, and its limited conformability may reduce direct contact with irregular archaeological surfaces. Therefore, polyurethane foam was primarily used as an external support material rather than as the primary reinforcement layer.

3.3. Volatile Binding Media (VBMs)

Menthol is used in archaeological conservation as a temporary consolidant due to its volatility and low residue after evaporation (Han et al. 2016, 2018). At Nanhai No.1, menthol was used to reinforce the fragile, porous organic remains that required temporary surface reinforcement. However, due to its limited mechanical strength, it was typically combined with additional supporting structures when greater stability was required.

3.4. Polyurethane Bandages

Polyurethane bandages were developed in the 1970s as a substitute for plaster and have been used in artifact extraction since the 1990s (Jones 1980, Payton 1992). They consist of a fabric coated with polyurethane prepolymer, offering high strength, light weight, and rapid curing. Their key advantage is chemical stability after curing: they produce no buoyancy in liquids and show no softening or deformation(Wytch et al. 1987). These properties make them ideal for waterlogged sites.

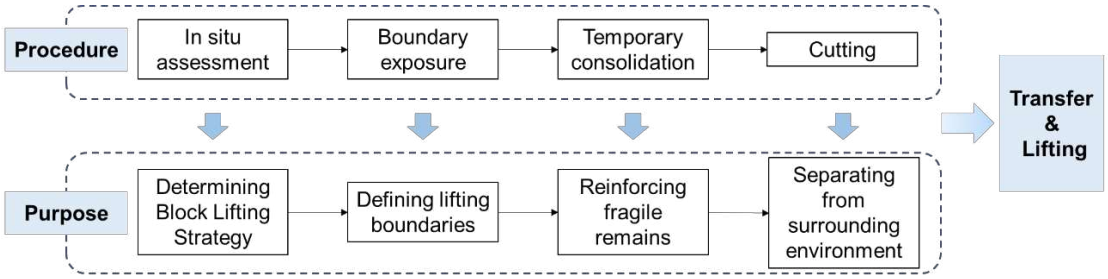
At Nanhai No. 1, polyurethane bandages provided critical support. They formed a conformable shell that stabilized fragile items such as ropes and bamboo objects, reducing damage during extraction and transport. The same shell was later reused as a support cradle in the laboratory, providing both morphological conformity and permeability to air and moisture.

4. In Situ Block Lifting Strategies

4.1 Block lifting procedure

These strategies followed four sequential steps. The process began with *an in situ assessment, which evaluated* structural preservation, sediment matrix stability, and archaeological relationships. Next, boundary exposure was performed by carefully removing the surrounding matrix to define the lifting boundaries while minimizing disturbance. Temporary reinforcement was then applied using single- or multimaterial systems, depending on the preservation condition, structural requirements, and lifting objectives. Finally, separation and transfer were performed by cutting the consolidated base, followed by manual extraction or crane-assisted lifting. (Fig. 2)

Fig. 2



Workflow of block lifting

Based on the archaeological condition assessment, three lifting strategies were developed during the Nanhai No. 1 excavation: direct lifting, single material lifting, and a multimaterial framework.

4.2 Direct Lifting

Direct lifting was applied to remains with relatively stable structural conditions. The procedure involved evaluating structural stability, removing surrounding sediments where necessary, installing supporting structures, and then lifting and transporting the block. This strategy was mainly suitable for large wooden components that retained sufficient mechanical integrity.

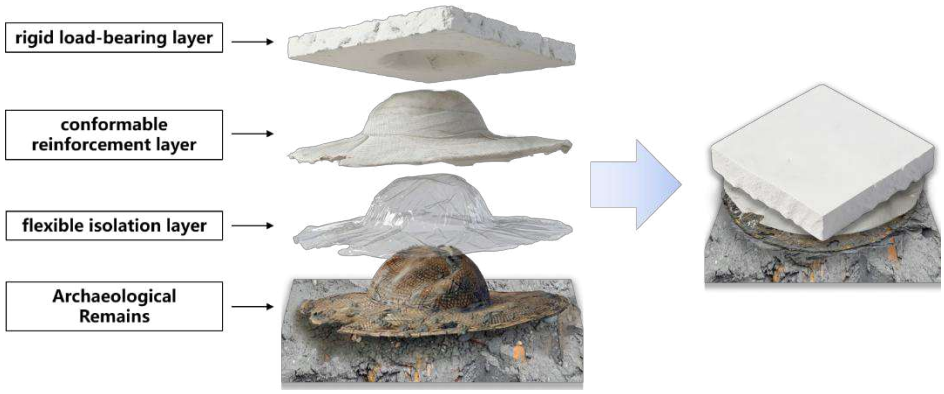
4.3 Single Material Lifting

Single material lifting was applied when the remains required additional reinforcement before being lifted. The choice of material depended on the nature of the remains: polyurethane bandages were used for fragile organic remains, while plaster-based systems were used where rigid support was needed. This strategy provided temporary stabilization while minimizing disturbance.

4.4 Multimaterial Framework Lifting

For highly fragile, irregular, or composite remains, direct lifting or single material lifting often failed to meet the combined requirements of penetration depth, mechanical strength, and extraction safety. A multimaterial framework was therefore developed, consisting of three functional layers arranged from the inner surface outward (Fig. 3).

Fig. 3



Three-layer composite structure of the multimaterial framework

The flexible isolation layer acted as the interface between the remains and external reinforcement, protecting surfaces and minimizing direct mechanical contact during lifting.

The conformable reinforcement layer adapted closely to the remains' morphology, providing external stabilization while preserving the original shape.

The rigid load-bearing layer provided the mechanical stability required for lifting, transport, and subsequent conservation.

Through the coordinated functions of these three layers, different materials were assigned specific roles, integrating flexible protection, conformable reinforcement, and external mechanical support into a single framework.

5. Results and Case Studies

During the Nanhai No. 1 excavation, lifting strategies were selected according to the preservation condition, structural stability, and recovery requirements of the remains, rather than applying a uniform method. Table 1 summarizes the relationship between archaeological condition and lifting strategy.

Table.1

Lifting strategies and their archaeological applications

Strategy	Archaeological condition	Main challenge
Direct Lifting	Stable structural remains	Limited deformation risk
Single Material Lifting	Fragile organic remains	Low mechanical strength
Multimaterial Framework Lifting	Irregular/composite remains	Multiple structural requirements

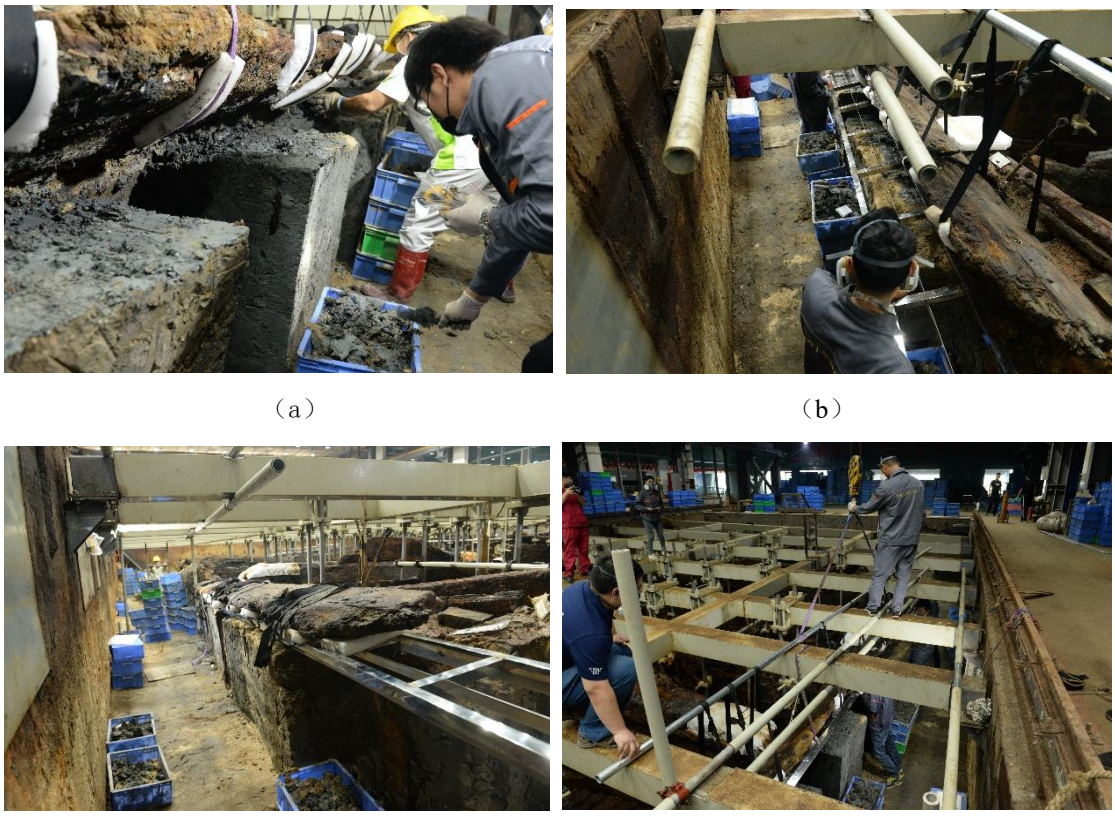
Lifting strategies were therefore selected based on the condition of individual remains rather than material categories alone, allowing different combinations of reinforcement and supporting materials to be applied according to specific preservation conditions and operational requirements.

5.1 Direct lifting of relatively stable wooden ship components

Large wooden components were an important category of remains recovered from the Nanhai No. 1 shipwreck. Although some ship structures retained their overall morphology after long-term underwater burial, prolonged immersion resulted in varying degrees of wood degradation and reduced mechanical strength.

During excavation, wooden components that retained sufficient structural stability after assessment were lifted directly. The relationship between the components and the surrounding sediments was carefully evaluated, and supporting structures were installed based on size, shape, and preservation condition to reduce mechanical stress during removal and transport.

Fig. 4



（a） （b）

（c） （d）



（e） （f）

Direct lifting of the long starboard hull plank:（a）Preliminary cleaning and placement of the flexible cushioning layer（b）Suspension of the hull plank and insertion of the support frame（c）Placement of the hull plank onto the support frame（d）Lifting with an overhead crane（e）Transport with an overhead crane（f）Hull plank after recovery

The lifting procedure involved structural assessment, removal of surrounding sediments where necessary, installation of external supports, and subsequent block extraction. In these cases, direct lifting was successfully performed without additional consolidation when the structural stability of the object sediment system was sufficient.

5.2 Single material lifting for fragile organic remains

Organic remains preserved in waterlogged environments are among the most vulnerable materials encountered during excavation. Bamboo objects and rope fragments from the Nanhai No. 1 had undergone long-term degradation and exhibited extremely limited mechanical strength.

In many cases, the surrounding sediment preserved their original morphology. Removing the sediment without reinforcement could result in collapse, fragmentation, or significant deformation. Polyurethane (PU) bandages were therefore applied as a temporary reinforcement system for these fragile remains.

Fig. 5



Single material lifting of rope remains with PU:（a）Removal of surrounding sediment（b）Surface reinforcement with PU to form a support shell（c）Lifting supported by PU （d）PU used as a support cradle for immersion

The application involved protecting the artifact surfaces, applying PU bandages around the remains, and allowing the material to cure into a lightweight supporting structure. Because the bandages were flexible before curing, they could conform closely to irregular surfaces and provide external reinforcement while preserving the original morphology.

After curing, the reinforced structures provided sufficient support for lifting and transfer. During subsequent laboratory conservation, some PU structures were retained to facilitate handling and immersion treatment, thereby reducing the need for repeated manipulation of fragile remains.

5.3 Multimaterial Framework for complex archaeological assemblages

Some remains recovered from the Nanhai No. 1 exhibited complex preservation conditions, including irregular morphology, multiple material components, and uncertain internal structures. Large ceramic containers and associated assemblages were typical examples.

Although ceramic materials generally possess higher mechanical strength than degraded organic remains,

large vessels from shipwreck deposits may contain internal sediments or associated objects, or may have weakened structures due to long-term burial. For these remains, direct lifting or single material lifting could not provide sufficient protection or structural stability during extraction and transport.

The multimaterial framework was therefore applied to these complex remains (Fig. 3). Surface protection was first applied to isolate fragile surfaces from reinforcement materials. Conformable reinforcement was then used to maintain morphology and stability, followed by a rigid load-bearing layer for lifting and transport.

Fig. 6



Multimaterial framework for block lifting of a stack of ceramic jars: (a) plastic wrap covering to isolate fragile surfaces and PU conformable reinforcement to maintain morphology and stability; (b) plaster used to construct a rigid load-bearing layer; (c) turning over and supporting with a partition board for lifting and transport; (d) condition after lifting.

The multimaterial framework enabled the recovery of complex remains while preserving their original morphology and spatial relationships with surrounding sediment.

6. Discussion

6.1 Material selection and compatibility with subsequent conservation

The recovery of fragile waterlogged remains requires temporary materials that reconcile lifting performance with the demands of subsequent conservation, particularly prolonged aqueous desalination and long-term storage. Conventional block lifting approaches often treat field extraction as an isolated event, relying on materials such as plaster or waxes that must be removed immediately after recovery or dissolve during immersion (Pedelì and Pulga 2013). At Nanhai No. 1, material selection was based instead on each material's functional role throughout the entire conservation lifecycle.

Cured polyurethane bandages provided conformable external reinforcement during field extraction and subsequently served as chemically inert, non-buoyant support cradles during laboratory immersion. Retaining these structures eliminated unnecessary handling and reduced the risk of secondary damage. Menthol, used as a temporary surface consolidant, sublimates without leaving residues that could interfere with later treatment. Plaster and polyurethane foam, employed as external load-bearing elements, could be removed after transfer without compromising the integrity of the remains.

This experience demonstrates that temporary consolidants and supporting materials should be evaluated not only for short-term field stabilization, but also for their compatibility across a continuous, multi-stage conservation workflow. Materials that can transition from field reinforcement to laboratory support offer particular practical advantages in treating large or highly fragile waterlogged assemblages.

6.2 A functional layered framework for block lifting

To address the conflict between fragile surfaces and the forces involved in heavy lifting, a function-partitioned composite framework was developed. Rather than relying on a single material to fulfill all stabilization requirements, distinct functions were assigned to three sequential layers: an inner flexible isolation layer (menthol applied on facing tissue), providing non-stress surface protection and preventing direct contact with reinforcement materials; an intermediate conformable reinforcement layer (polyurethane bandages), for absorbing lateral shear, adapting to complex geometries, and maintaining morphological integrity; an outer rigid load-bearing layer (plaster and polyurethane foam), responsible

for structural load transfer and vibration damping during crane-assisted transport.

The significance of this framework lies in mechanical decoupling. By separating surface protection, morphological stabilization, and load-bearing functions, complementary material properties can be coordinated to achieve soft surface protection and rigid structural support simultaneously. Field applications to complex ceramic assemblages and irregular organic remains confirmed that this layered approach reduced the risk of surface damage and structural collapse during extraction and transport, while still allowing supporting structures to be partially retained or removed as required in the laboratory.

6.3 Condition-based selection and practical transferability

In situ conservation decisions are inevitably shaped by the operational environment, spatial limitations, and resource accessibility. Inside the highly restricted, high-humidity steel caisson of the Nanhai No. 1, conventional timber framing proved impractical due to weight, space constraints, and slow installation. A condition-based approach was therefore implemented, with strategies selected according to the degradation state, structural stability, and contextual importance of each assemblage. These included direct lifting, single-material reinforcement, and lifting of multimaterial frameworks.

Standardized, commercially available materials, such as medical-grade polyurethane bandages and expanded polyurethane foam, were adopted as lightweight, fast-curing alternatives to traditional timber. This pragmatic selection enabled rapid response under high-humidity conditions while maintaining adequate mechanical performance.

The strategies developed at the Nanhai No. 1 are not intended as rigid protocols but as a transferable decision framework. Sites with comparable challenges, including high humidity, fragile organic remains, and the need to preserve spatial relationships, may adapt the same principles of functional layering and condition-based selection, adjusting specific materials according to local availability and subsequent treatment requirements. The experience demonstrates that integrating material compatibility, function partitioning, and responsive field decision-making can significantly improve the safe recovery of fragile waterlogged remains (Karsten A et al. 2018; Pedelì and Pulga 2013).

7. Conclusion

The Nanhai No. 1 excavation demonstrates that recovering fragile, waterlogged remains in humid conditions requires condition-specific lifting strategies rather than a single standardized approach. This study developed and applied three strategies: direct lifting, single material lifting, and multimaterial framework lifting, tailored to preservation conditions and recovery requirements.

The multimaterial framework integrated menthol, polyurethane bandages, plaster, and polyurethane foam through a three-layer support system, enabling the recovery of complex remains while preserving morphology and archaeological context. Reusing polyurethane reinforcement structures as immersion support cradles during laboratory conservation reduced unnecessary handling and maintained continuous support for fragile remains.

This experience highlights that block lifting should be considered an integrated conservation process that combines material selection, structural support, context preservation, and future treatment requirements. The proposed strategies provide a practical and transferable reference for recovering fragile, waterlogged remains in high-humidity environments, contributing to both field methodology and the heritage management of large shipwreck sites.

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Contributions

Jing D. wrote the main manuscript text and prepared all figures. Dawa S. guided the conceptual framework and advised on manuscript revisions. Jing D., Dawa S., Huihui Y., Tianyou Y., and Zheng J. conducted the case studies. Naisheng Li (Corresponding author) reviewed and edited the manuscript. All authors reviewed and approved the final manuscript.

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Ethics declarations

Conflict of interest

The authors declare no competing interests.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used Grok to improve language and readability. After using this AI tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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