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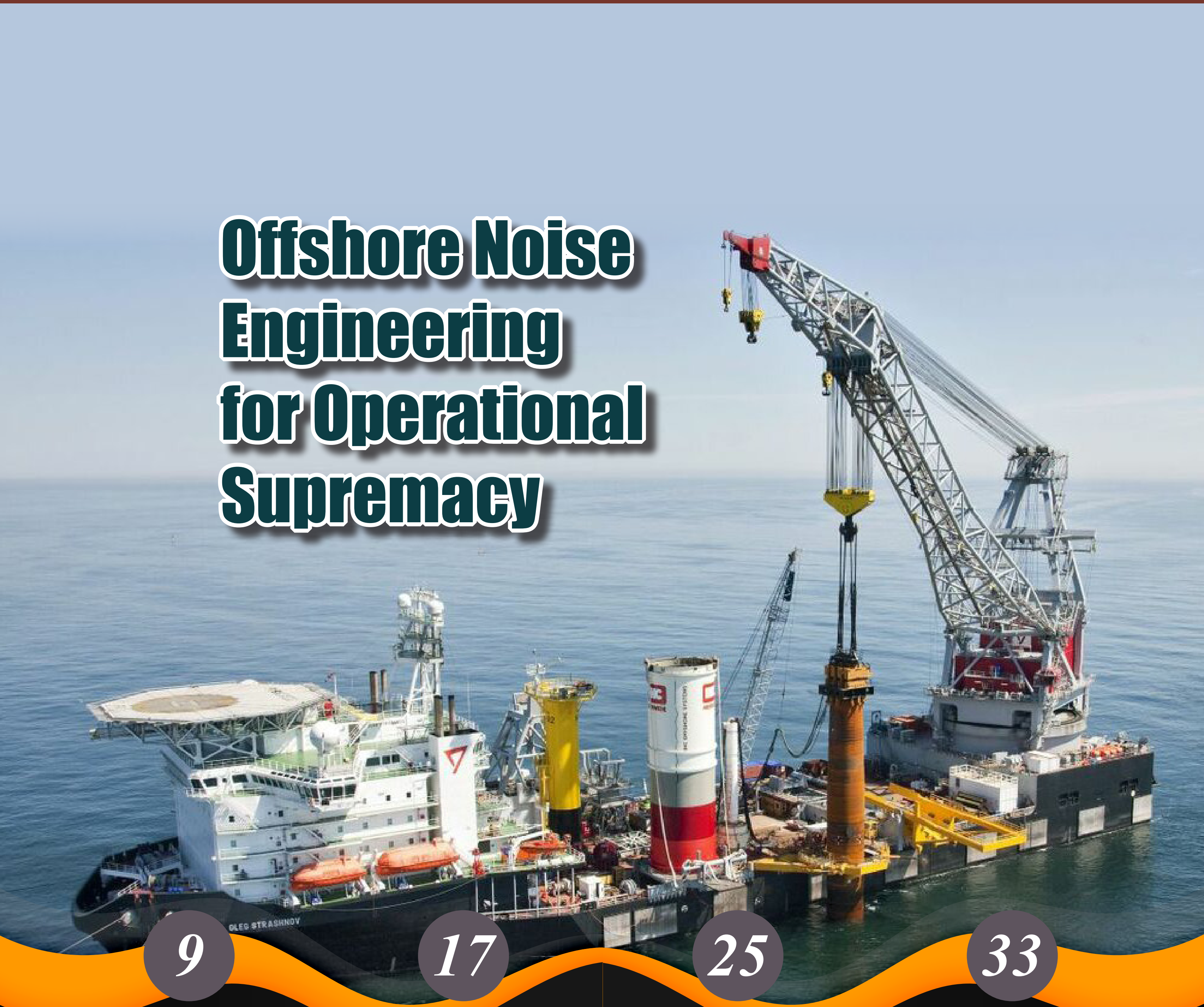

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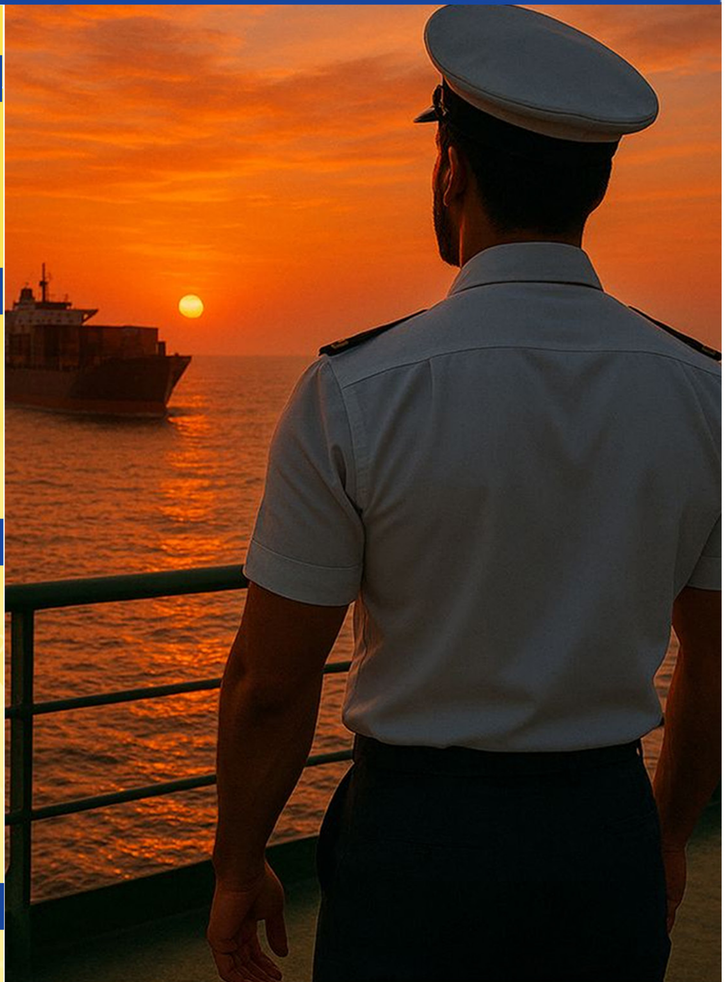

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EDITORIAL

The best way to predict the future is to create it.
- Peter Drucker

"As the Year Ends, the Tide Turns Toward a New Maritime Future"

As 2025 comes to a close, the maritime world finds itself at a defining inflection point. What once appeared as a distant decarbonisation ambition has become an operational reality influencing design decisions, commercial planning, seafarer training and day-to-day engine-room practices. Sustainability is no longer a peripheral discussion — it has become part of the industry's working vocabulary.

This shift gained global clarity at **COP30 in Belém, Brazil**, where shipping was meaningfully included in climate negotiations for the first time. The resulting *Belém Declaration* placed maritime transport within three mandates: pursuing a just energy transition, developing green trade corridors and establishing a global finance facility to help developing nations build zero-emission maritime infrastructure. Shipping is now positioned as a core partner in the world's climate strategy.

Regulation reinforced this momentum. IMO's MEPC 83 and subsequent 2025 sessions moved decisively from ambition to implementation. The Organisation advanced frameworks for a global marine fuel standard and endorsed a market-based carbon pricing mechanism intended to take effect before the decade's end. Meanwhile, regional regulators continued setting the pace. The EU ETS expanded to 70% maritime inclusion and FuelEU Maritime completed its first compliance cycle, compelling owners to track greenhouse-gas intensity with a precision once reserved for bunker planning. Carbon has become both a compliance metric and a commercial cost centre.

For Indian shipowners and managers, 2025 brought both pressure and perspective. Freight markets softened as disruptions in the Red Sea stabilised, while an influx of newbuild deliveries increased capacity and tightened margins. Compliance burdens grew, but adversity renewed innovation. Engineers and superintendents responded with slow-steaming optimisation, flow-improving hull treatments, condition-based maintenance and predictive diagnostics — strengthening the long-held truth that operational excellence is the best defence against market uncertainty.

Looking toward 2026, two powerful undercurrents will shape the industry.

1. The Rise of Digital Vigilance. Artificial intelligence has reshaped the operational landscape, connecting ship and shore more tightly than ever before. Real-time performance monitoring, automated cargo-risk screening, fault prediction, energy-efficiency dashboards and AI-assisted routing are becoming standard. Tomorrow's Chief Engineer must interpret data as fluently as drawings, merging analytical skills with seagoing judgment. Digital awareness is now a core competency central to safety, compliance and fuel optimisation.

2. The Era of Fuel Pluralism. The global fleet is entering a multi-fuel age. LNG retains a lead through its infrastructure maturity. Methanol continues to accelerate via green-corridor commitments reiterated at COP30. Ammonia is advancing through pilot projects and IGF Code developments. Hydrogen, though early-stage, remains politically attractive. Each fuel introduces its own design, handling and safety complexities, demanding new competencies in bunkering, emergency response and risk evaluation. Here, India has strategic strength — through its maritime academies, classification societies and increasingly capable shipyards preparing for alternative-fuel-ready vessels.

Domestically, India's maritime momentum is unmistakable. The ₹70,000-crore Maritime Development Fund, upcoming Sagarmala 2.0 upgrades and the Great Nicobar Deep-Sea Port demonstrate national intent to build capacity and strengthen strategic influence. Yet true leadership will be defined not just by increased gross tonnage, but by green tonnage — sustainable design, sound digital governance and a highly trained workforce aligned with evolving global expectations.

In retrospect, 2025 was not a year of comfort but of convergence. Regulatory, technological and commercial currents finally aligned to place the sector firmly on a low-carbon heading. The uncertainty that clouded the early years of the decade has begun to clear; the channel ahead is more visible, if still demanding.

As we enter 2026, COP30's message resonates across vessels, offices and classrooms: the climate story has become inseparable from the shipping story. For India's marine engineers, surveyors, policymakers and educators, the task is to translate global ambition into practical local action — in simulators, workshops, SMS procedures and audit cycles.

May the year ahead inspire greater confidence, competence, and courage as we steer not behind the tide of change, but ahead of it — toward a cleaner, smarter, and more resilient maritime future.

Here is the December 2025 issue for your reading pleasure and intellectual rumination.

Mani Ganapathi Ramachandran
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Administration Office
IMEI House
Plot No. 94, Sector - 19, Nerul,
Navi Mumbai 400 706.
Tel. : +91 22 2770 16 64
Fax : +91 22 2771 16 63
E-mail : editormer@imare.in
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Errata: In MER November 2025, Vol. 19, Issue XII, Dr. Rajoo Balaji's name was incorrectly mentioned under "Printed, Published and Edited by." The correct name should be Mr. Mani Ganapathi Ramachandran. We regret the error.

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3D Acoustic Modelling of Noise from Offshore Pile-Driving Operations

Prabhu Duplex

Abstract: Offshore pile driving for bridges, wind farms and coastal infrastructure is one of the most intense anthropogenic impulsive noise sources in the marine environment. Its dominant frequency content overlaps the hearing ranges of many marine mammals and fish, and in ecologically sensitive straits the risk of disturbance or injury is non-trivial. Predicting received levels at distance therefore requires an underwater acoustic propagation model capable of handling range-dependent shallow-water environments and both water-column and seabed interactions.

This paper presents the essential theory and a feasibility study using the 3D beam/ray model **BELLHOP3D** to simulate transmission loss (TL) for a representative piling frequency (250 Hz). It summarises the role of environmental inputs—bathymetry, sound speed profile (SSP), seabed geoacoustics and sea surface—together with source representation issues specific to pile driving. A synthetic bathymetry with upslope, downslope and a deep gorge was constructed to test whether Bellhop reproduces physically sensible TL patterns.

The results, shown in a series of polar and range–depth plots **(Figures 6–11)**, indicate that Bellhop3D can provide realistic first-order predictions for high-frequency components of piling noise, and can later be fine-tuned with site data. All figures referenced in the original article **(Figures 1–11, plus Figures 3–5)** are noted here as supporting illustrations of frequency overlap, propagation model inventory, model architecture and simulation outputs.

Keywords: Offshore pile driving; underwater acoustics; transmission loss; BELLHOP3D; shallow water; bathymetry; marine mammals; Gaussian beam; ray tracing.

1. Introduction

Pile driving is routinely used for the installation of offshore wind monopiles, bridge piers, jetties and subsea structures. The impact or vibratory hammering of large piles produces very high underwater sound pressure levels which propagate through both water and sediment. Because the piling spectrum lies in the same band as the audibility zones of many marine species, unmitigated operations can lead to behavioural disturbance, masking, temporary threshold shift or, at very close range, physical injury. This concern is amplified in narrow marine passages that act as biological corridors. The original article highlighted such a case by noting that bridge construction in a strait "with one of the highest concentrations of biodiversity in the world" could disrupt migration routes of birds and marine mammals.

The first step in any impact assessment is to know the **source spectrum**; the second is to predict **receiver levels** at various ranges and depths. The latter requires an acoustic propagation model that can handle high frequencies and range-dependent environments. The present condensation focuses on that second step and, specifically, on the use of the 3D variant of the Bellhop model.

Two early figures guide the problem framing: **Figure 1** presents an overview of the overlap between anthropogenic sound (including pile driving) and the hearing bands of marine animals.

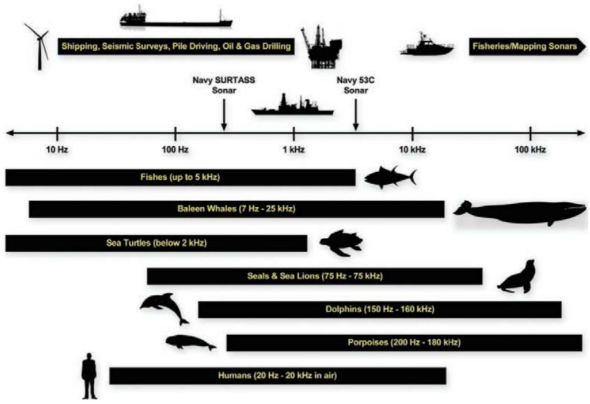

Figure 1: Overview of the overlap in frequency between human activities and the audibility zones of marine animals

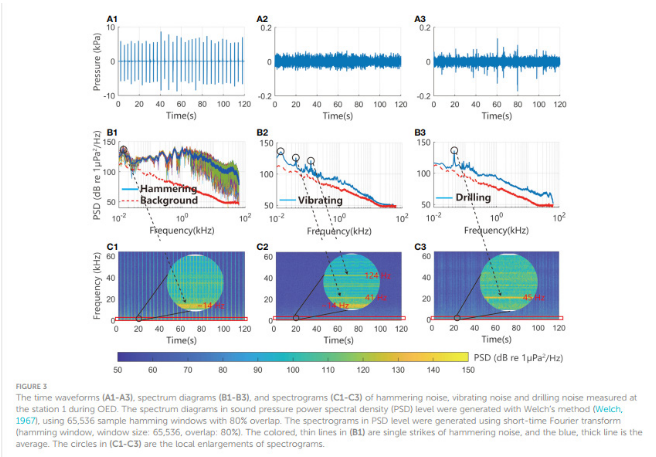

Figure 2: Piling noise spectrum

Figure 2 shows a typical piling noise spectrum, illustrating why frequencies around a few hundred hertz were chosen for the test simulations.

2. Fundamentals of Underwater Acoustics

Underwater sound propagation is strongly environment-dependent. Acoustic oceanography links water-column structure, boundaries and sediments to the paths sound can take. A central quantity in prediction is **transmission loss (TL)**, defined through the sonar equation as:

TL = SL – RL

where **SL** is source level and **RL** is received level, both in dB re 1 μPa. TL aggregates geometric spreading, absorption, surface/bottom interaction and leakage into the seabed.

Several environmental factors govern TL:

1. **Source representation.** For computation, many models assume a monopole point source. Pile driving, however, is an extended source that penetrates the seabed and can radiate via both water and sediment paths. At distances of a few hundred metres, a point-source approximation is often acceptable, but users must recognise this simplification.
2. **Bathymetry.** In shallow seas, not only the depth but also the *shape* of the seabed matters. Slopes, shelves, channels and gorges can focus or defocus energy. The simulations therefore used a deliberately non-uniform bathymetry so that the model's 3D capabilities could be exercised. This motivation is explicitly linked to **Figure 5**, which shows the assumed SSP (left) and the constructed bathymetry (right).
3. **Seabed properties.** The acoustic impedance contrast at the water–sediment boundary determines how much sound is reflected, transmitted and possibly

> *Pile driving creates intense impulsive underwater noise overlapping marine species' hearing ranges, requiring accurate modelling to assess ecological disturbance and regulatory compliance*

Table 2: Inventory of some commonly used, freely available, ocean acoustic propagation modelling implementations, outlining the model suitability, with model source reference also provided.

Method	Model Name	Shallow water		Deep water		Range dependent	Availability	Originator
		LF	HF	LF	HF			
Ray	BELLHOP	NO	YES¤	YES‡¤	YES¤	YES¤	http://oalib.hlsresearch.com/Rays/index.html	*M. Porter* Heat, Light, and Sound Research, Inc. La Jolla, CA, USA
Normal mode	Kraken	YES	YES‡	YES‡	NO	YES	http://oalib.hlsresearch.com/Modes/index.html	*M. Porter* SACLANT Undersea Research Centre, Italy
Wave number integration	SCOOTER	YES	YES	YES	YES‡	NO	http://oalib.hlsresearch.com/FFP/index.html	*M. Porter* Heat, Light, and Sound Research, Inc. La Jolla, CA, USA
	OASES	YES	YES	YES	YES‡	YES†	http://lamss.mit.edu/lamss/pmwiki/pmwiki.php?n=Site.Oases	*H. Schmidt* Massachusetts Institute of Technology, MA, USA
Parabolic equation	RAM	YES	NO	YES	YES‡	YES	http://oalib.hlsresearch.com/PE/index.html	*M. Collins* Naval Research Laboratory, Washington, USA
	IFD	YES	NO	YES	YES‡	YES	Ocean Acoustic Propagation by finite difference methods, Pergamon Press, Oxford, 1988	*D. Lee and S. T. McDaniel* Naval undersea warfare centre CA, USA
	MMPE	YES	NO	YES	YES‡	YES	http://oalib.hlsresearch.com/PE/index.html	*F. Tapper and K. Smith* U.S. Naval Postgraduate School, and Rosenstiel School of Marine and Atmospheric Sciences, USA
	P-CAN	YES	NO	YES	YES‡	YES	http://oalib.hlsresearch.com/PE/index.html	*G. Brooke* Defence Research Establishment Atlantic, Canada

‡ Suitable with limitations. † A range dependent version OASES exists, however, it is not freely available.
¤ Requires a suitable, simplified, sound speed profile at any frequency.

Figure 3: Inventory of commonly used freely available ocean acoustic models and details

re-radiated. A stratified seabed can bend sound and produce multiple arrivals back into the water column.

4. **Sound speed profile (SSP).** In deep water, SSP gradients can dominate propagation; in shallow water, SSP interacts with bathymetry and bottom to shape the field. For the test, a plausible SSP was assumed and interpolated.
5. **Sea surface and wind.** A rough or bubbly surface adds loss and scattering. In many engineering models this is parameterised by wind speed at 10 m.

Because all of these parameters can vary in time and space, the accuracy of any propagation prediction is ultimately limited by the accuracy of the environmental inputs.

3. Propagation Modelling Approaches

Underwater propagation codes solve, approximately or numerically, the Helmholtz equation. The original article grouped common approaches and illustrated them in **Figure 3: Inventory of commonly used freely available ocean acoustic models and details.**

These included:

- **Ray tracing / beam tracing** – efficient at higher frequencies, intuitive, good for range-dependent environments.
- **Normal modes** – suited to low frequencies and layered media, more 2D in character.
- **Parabolic equation (PE)** – robust over long ranges and for complicated environments, but more computationally intensive.
- **Wavenumber integration, energy-flux and finite-element/difference** models – each with strengths in certain bands or geometries.

For offshore piling, which produces significant energy in the mid–high band and is often assessed over hundreds of metres to a few kilometres, ray or beam tracing is attractive because it is fast and can be made 3D. Ray theory expresses the pressure as a slowly varying amplitude times a rapidly varying phase; this yields the **eikonal equation** for ray paths and the **transport equation** for amplitude. It is a high-frequency approximation, so at very low frequencies or in strong elastic bottoms another method might be preferable.

4. BELLHOP3D: Structure and Capabilities

Bellhop is a well-known Fortran-based Gaussian beam / ray model; **BELLHOP3D** extends it to full 3D so that horizontal refraction can be modelled. This matters when the bathymetry changes with bearing or when oceanographic features have strong lateral gradients.

> *3D acoustic modelling with BELLHOP3D captures bathymetry, sound-speed and seabed effects—essential for realistic transmission-loss predictions in shallow coastal waters*

The program structure, shown in the original **Figure 4: Bellhop structure**, is modular. A main **environmental file** specifies SSP, surface and bottom types, and the basic run (rays, TL, arrivals, eigenrays). Optional files define:

- range-dependent **bathymetry**;
- range- or 3D-dependent **SSP**;
- **top and bottom reflection coefficients** for more realistic boundary behaviour;
- **source beam patterns** when the source is not omnidirectional.

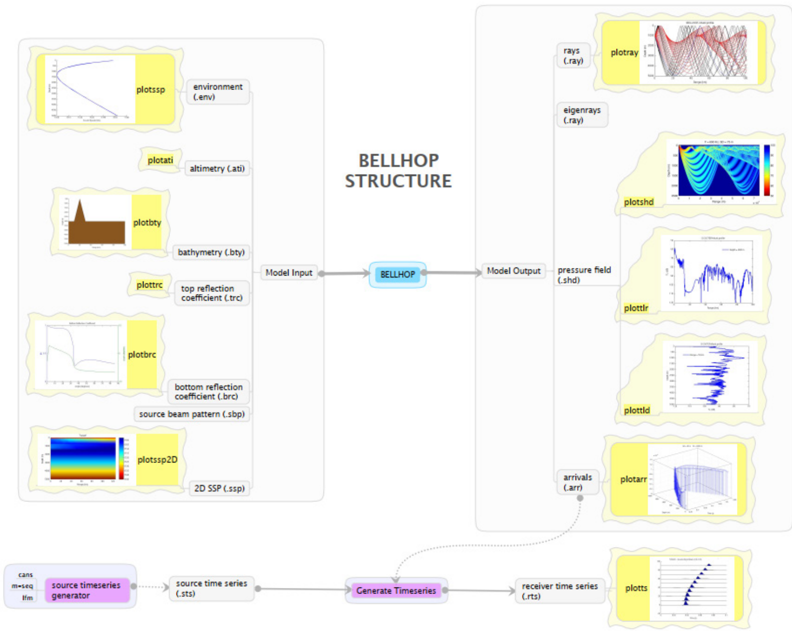

Figure 4: Bellhop structure

Outputs depend on options: a **ray file** for visualising propagation paths; a **shade/TL file** for plotting transmission loss as range–depth slices; and an **arrivals file** listing amplitude–delay pairs so that a received time series can be reconstructed. MATLAB scripts are typically used to plot these.

This architecture makes Bellhop3D well suited to feasibility work: one can start with a simple, uniform environment and progressively add realism.

5. Simulation Setup

The condensed case study aimed to check whether Bellhop3D, with reasonable parameter choices, produces physically consistent TL fields for a piling-like source.

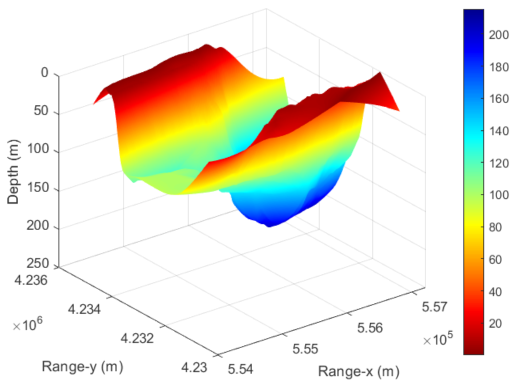

Figure 5: SSP (L), Bathymetry (R)

Geometry and grids. A 100 × 100 Cartesian grid was built to represent shallow water with an upslope, downslope and a deep gorge, as shown in **Figure 5 (right)**. Coordinates were given in metres. The SSP used is shown in **Figure 5 (left)**. Interpolation (MATLAB v4) was used to obtain a smooth 3D bathymetric surface acceptable to Bellhop.

Seabed. An acoustic–elastic half-space representing a "gravely smooth bottom" (after reference [14]) was assumed. Density, P-wave velocity and absorption coefficient were provided; attenuation was defined in (dB/m)·kHz. The article notes that, for a truly shallow, layered area, it would be better to add S-wave velocity and layer-dependent reflection coefficients (e.g. from BOUNCE), but this was left for future simulations. That statement is important because it marks the current results as *feasibility-level*, not final site predictions.

Source and receivers.

- Source depth: 10 m, placed near the centre of the bathymetric grid.
- Frequency: 250 Hz, justified by Bellhop examples and by the piling spectrum shown earlier in **Figure 2**.
- Receiver ranges: initially to 300 m with 500 points; for ray-tracing visuals, extended to 1,000 m to improve interpretability.
- Receiver depths: up to the seafloor, with as many as 1,000 depths to resolve vertical TL structure.

Beams and angles. For the full 3D TL run, vertical launch angles were set from –20° to +20° with 100 beams, and horizontal angles covered 0–360° with 180 beams. This gave good directional coverage but still completed quickly (on the order of a minute in the original test environment). For the 1 km ray-tracing run the number of beams was reduced (30 vertical, 5 horizontal) to shorten computation, because the goal was to see *logic* rather than to produce very smooth fields.

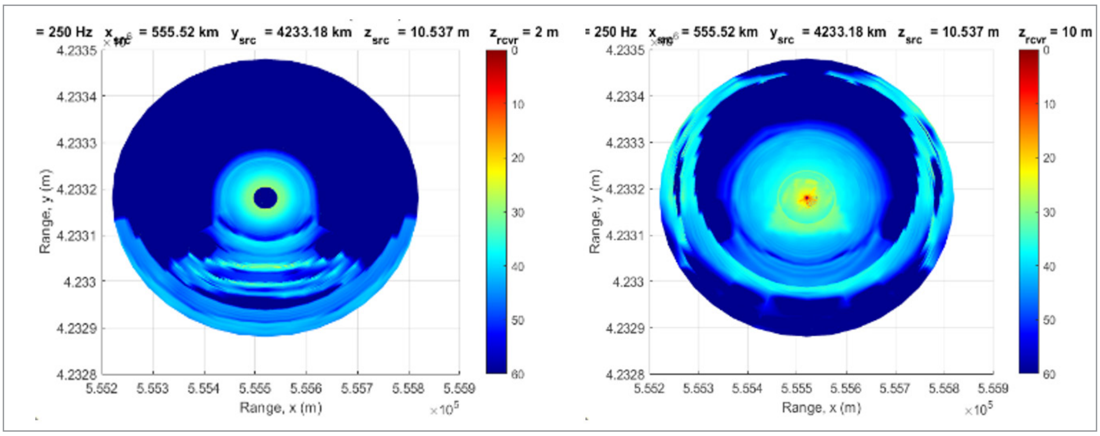

Figure 6: Source depth: 10.0 m: Transmission loss at 2m depth (L), 10 m depth (R)

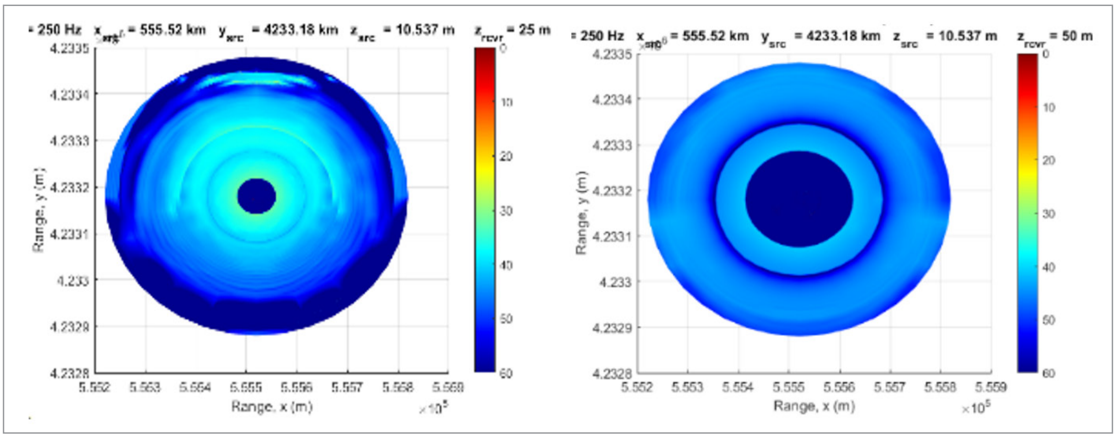

Figure 7: Source depth: 10.0 m: Transmission loss at 25m depth (L), Transmission loss at 50m depth (R)

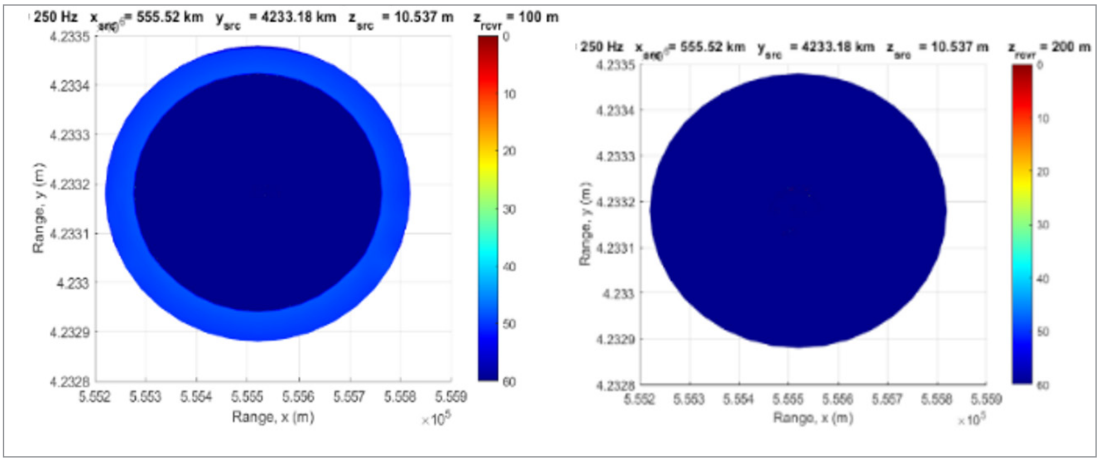

Figure 8: Source depth: 10.0 m: Transmission loss at 100m depth (L), Transmission loss at 200 m depth (R)

Numerical options. Geometric hat beams with the "minimum width" option were used, following Bellhop3D tutorial examples. The article notes that some beam parameters (e.g. *epmult*, *Rloop*, *NImage*, *IBWin*) are insufficiently explained in the user guide and were therefore kept aligned with the example "Taiwan seas" 3D case.

6. Results and Discussion

The model outputs were presented in a series of figures that collectively build confidence in the setup:

- **Figures 6–8**: Polar-style transmission-loss views at different receiver depths (2 m, 10 m, 25 m, 50 m, 100 m, 200 m) for a source at 10 m. These plots showed that TL is lowest (i.e. sound levels are highest) close to the source depth and increases with depth. This is consistent with expectations in shallow, range-dependent water where deeper paths interact more with the bottom.

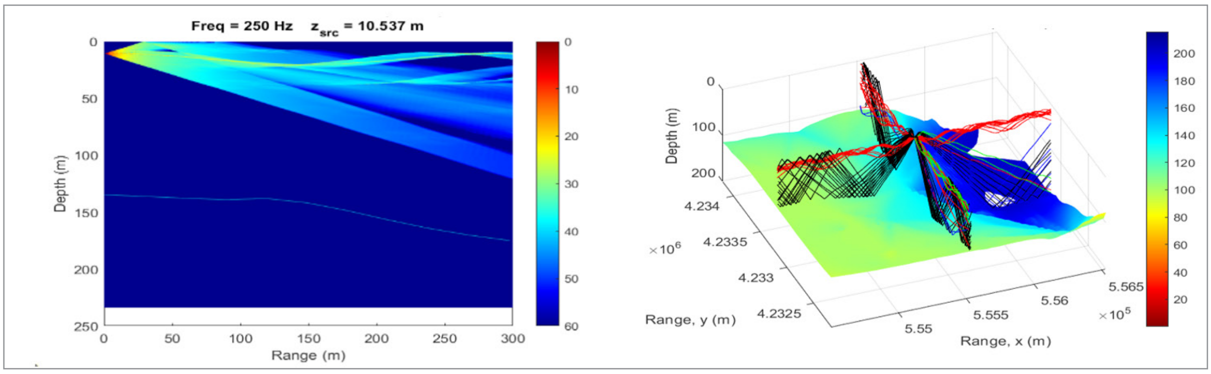

Figure 9: Transmission loss for 300 m (bathymetry marked) (L), Ray trace for 1000 m range (R)

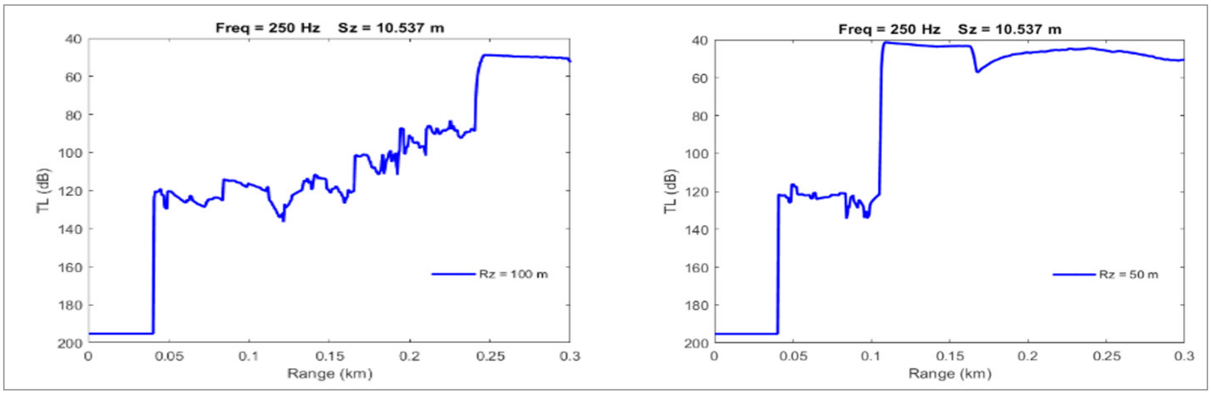

Figure 10: Range vs Transmission Loss (TL): Receiver at 100 m depth (L), Receiver at 50m depth

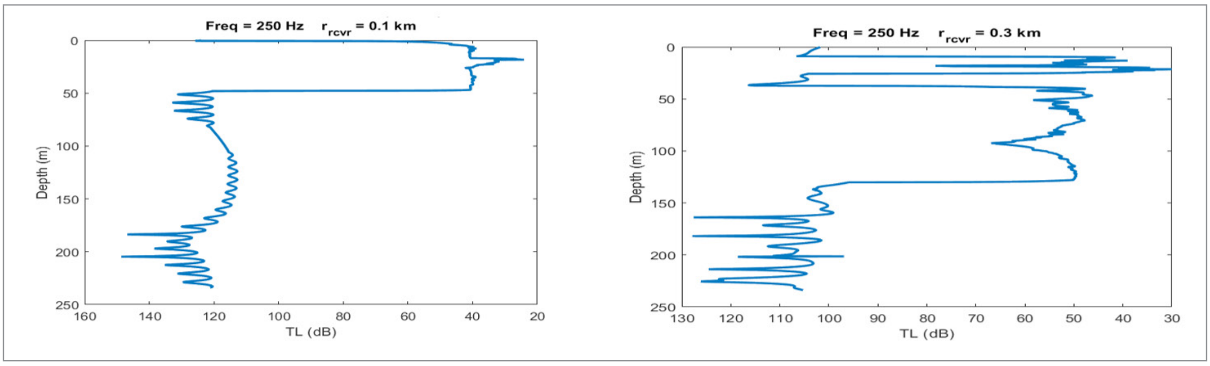

Figure 11: Transmission Loss (TL) vs Depth: Source at 10.0m depth, receiver at 100 m from source (L), 300 m from source (R),

- **Figure 9 (left)**: TL for 300 m with the underlying bathymetry marked. This demonstrates that even over a few hundred metres the non-flat bottom affects the TL field – a key argument for using a 3D, range-dependent model instead of a simple range-independent 2D code.
- **Figure 9 (right)**: Ray trace to 1,000 m. Rays were seen to reflect "correctly" from the seabed according to the imposed slopes, without unphysical behaviour, indicating correct environmental-file formatting.
- **Figure 10**: Range vs. TL at specific receiver depths (notably 50 m and 100 m). It was observed that beyond about 0.1 km, TL at 100 m is higher than at 50 m, illustrating that deeper receivers experience more loss in this environment.
- **Figure 11**: TL vs. depth for receivers at 100 m and 300 m range from the source. These showed that at greater range, TL in deeper water is markedly higher – again a sensible outcome for a shallow, sloping environment.

Overall, the findings can be summarised as follows:

1. **Physical plausibility.** The spatial TL patterns followed acoustic intuition: minimum loss near the source depth, increased loss with depth and range, and visible impact of bottom topography.
2. **Suitability for high frequencies.** Because the run frequency (250 Hz) lies in the band where ray/beam methods are efficient, Bellhop3D executed quickly even with 3D bathymetry.

Validated models enable proactive noise-mitigation planning, guiding exclusion zones and construction timing to protect marine biodiversity during offshore infrastructure projects

3. **Basis for refinement.** The study confirms that Bellhop3D can serve as the "first layer" of modelling. Site-specific refinements – measured bathymetry, layered sediments, real pile source signatures, surface roughness from measured winds, and perhaps coupling with low-frequency solvers – can be added later.

4. **Environmental sensitivity.** The authors correctly pointed out that in real projects, uncertainties in bathymetry or sediment properties can cause noticeable differences in TL, so environmental data quality is as important as solver choice.

7. Conclusions

This paper has shown that a free, well-established 3D beam-tracing model such as **BELLHOP3D** can be used to evaluate the feasibility of modelling underwater noise from offshore pile-driving operations in shallow, range-dependent waters. From simulations, one can gain an initial confidence in the Bellhop 3D software and can be fine-tuned for a specific environment in the future real scenarios. Using a realistically varying bathymetry, plausible seabed parameters and a representative piling frequency, the model produced TL and ray patterns (Figures 6–11) were acoustically consistent.

This gives initial confidence that, once real site data are available, Bellhop3D can support:

- prediction of received levels at ranges of regulatory interest.
- comparison of alternative construction scenarios.
- input to marine-mammal impact assessments and mitigation planning.

The study also acknowledged present limitations: better representation of layered seabed's, explicit inclusion of S-wave properties, and improved documentation of some beam parameters would further enhance result fidelity. For very low-frequency components of piling noise, or for long-range propagation, additional research or hybrid modelling (e.g. PE for LF and Bellhop for HF) would be beneficial.

Professionally, the work aligns with current practice in environmental acoustics: begin with a transparent, fast model to understand propagation physics, then iterate toward higher realism as data and project maturity increase.

Acknowledgement

This work was performed at the University of Pisa under the project "Study of Road Noise with Innovative Methods" in close collaboration with Agenzia regionale per la protezione ambientale della Toscana – Direzione (ARPAT). I thank Prof. Gaetano Licitra, Prof. Francesco Fidecaro and researcher Eduardo Rossi for their valuable support in the context of this work.

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About the Author

Prabu Duplex had sailed as a marine engineer between 2005- 2013. His recent assignment was with the University of Pisa as a research associate. In this period, he collaborated with the department of physics and environmental protection agency (ARPAT) for the above-mentioned research project. He also has a Professional Doctorate in Engineering (PDEng) degree in maintenance, and a Master's degree in Naval Architecture. Presently, he is looking for a career in design or research activities in naval, wind, offshore or predictive maintenance domains.

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Pitfalls in Shipbuilding Contracts – Part 1:

Foundations and Frameworks of Shipbuilding Contracts

Narayana Prakash

Introduction

Shipbuilding contracts are among the most complex commercial documents in global industry. They unite heavy capital investment, technical intricacy, and cross-border legal risk into a single framework that must remain valid over several years of construction. Each clause becomes a bridge between the aspirations of owners, the capabilities of shipyards, and the expectations of financiers. A single gap in drafting can trigger multimillion-dollar disputes that ripple across engineering, cash flow, and delivery schedules.

This first article in the three-part series **"Pitfalls in Shipbuilding Contracts"** explores how contract architecture, risk allocation, and early-stage documentation define success or failure long before a vessel takes shape. By dissecting common contractual models and pre-signing missteps, it offers a practical guide for both lawyers and shipyard professionals seeking to prevent disputes rather than litigate them.

1 The Nature and Purpose of Shipbuilding Contracts

A shipbuilding contract performs three interlocking functions:

1. **Commercial Instrument** – It defines price, payment milestones, and ownership transfer.
2. **Technical Charter** – It incorporates the vessel's specification and performance guarantees.
3. **Risk-Allocation Matrix** – It distributes liability among builder, buyer, and guarantor.

Unlike a simple sale of goods, the subject matter—a vessel under construction—evolves over years. Market conditions, steel prices, or emission standards can all change mid-build. A sound contract therefore serves less as a static promise and more as a *governance framework* enabling adaptation without chaos.

Yet, despite decades of experience, disputes remain endemic. The same patterns reappear: unclear refund guarantees, inconsistent specifications, missing long-stop dates, and ambiguous force-majeure language. Most of these originate not from unforeseeable risk but from *avoidable drafting weaknesses.*

2 Common Contract Models: How Risk Moves Across the Table

Shipyards and owners negotiate within a limited set of global templates, each reflecting a different appetite for risk and control. Understanding these archetypes is essential before signing.

2.1 Lump-Sum / Fixed-Price Contracts

The worldwide default for merchant vessels.

- **Builder's View:** predictable income, but every overrun is their loss.
- **Owner's Concern:** any design change triggers cost claims.
- **Operational Implication:** yard discipline in scheduling and procurement is critical.

These contracts reward precision; a vague specification can wipe out profit margins through variation claims.

2.2 Cost-Plus / Reimbursable Contracts

Favoured for prototype, naval, or offshore vessels.

- **Risk:** shifts largely to the owner, who pays actual cost + fee.

- **Benefit:** flexibility for evolving designs.
- **Caution:** demands meticulous cost documentation; otherwise invoice disputes multiply.

2.3 Design-and-Build Contracts

Here, the shipyard assumes design responsibility. Innovation is possible—but so is exposure. Failure of performance becomes the yard's liability even if the owner approved the concept. Integrating design and production teams early mitigates this risk.

2.4 Turnkey / EPC (Engineering, Procurement & Construction) Contracts

Popular in offshore and LNG sectors where owners desire a *ready-to-operate* unit. These give the builder total control but also total accountability. Disputes often arise over **acceptance criteria** and **final performance tests.**

2.5 Time-and-Material and Hybrid Contracts

Useful when scope is uncertain or modular. However, they demand rigorous daily reporting of labour and materials to justify cost. Weak documentation invites audits and claims of inefficiency.

2.6 Standard-Form Contracts

Global commerce has gravitated toward a few model forms:

- **SAJ Form** (Shipbuilders' Association of Japan) – builder-friendly; cornerstone for Asian shipyards.
- **BIMCO NEWBUILDCON** – introduced 2007, offers a more balanced template with clearer clauses on delay, force majeure, and specification.
- **Chinese and Korean yard forms** – adaptations of SAJ with national legal nuances.

While these templates streamline negotiation, they are *not* turnkey documents. Each requires bespoke adaptation to the project's commercial and technical realities.

3 Risk Allocation – The Hidden Geometry of Contracts

Every clause in a shipbuilding agreement moves risk along three axes: **time, money and quality.**

- **Time risk** manifests as delivery delays and associated liquidated damages (LDs).
- **Money risk** appears through refund guarantees, payment schedules, and cost overruns.
- **Quality risk** arises from specifications, warranties, and performance tests.

A balanced contract distributes these so that neither party faces insolvency if one parameter slips. Yet imbalance is common. Owners often demand tight delivery with capped LDs, while builders accept unrealistic milestones to secure orders. The result: *inevitable breach disguised as ambition.*

> *"A single gap in drafting can trigger multimillion-dollar disputes that ripple across engineering, cash flow and delivery schedules"*

Key principle: *Risk cannot be eliminated—only priced and allocated.* Transparency in this allocation reduces litigation and enhances project realism.

4 Pre-Signing Checklist: The Ten Clauses That Decide the Voyage

Before the first steel plate is cut, every prudent buyer or builder should verify ten foundational issues. Most disputes originate from one of these.

4.1 Hierarchy of Documents

Specify which document prevails in case of conflict: the main contract, the specification, or drawings.

- **Typical Pitfall:** specifications impose obligations inconsistent with contract text.
- **Remedy:** hierarchy clause—*Contract > Specification > Drawings.*

4.2 Performance Guarantees

Define whether parameters like speed, fuel consumption, or deadweight are *binding guarantees* or *design targets.* Vague phrasing turns performance trials into courtroom arguments.

4.3 Delivery Date and Extensions

List exhaustively what events justify extensions—force majeure, regulatory change, or owner-caused delay. Ambiguity here converts natural delays into contentious LD claims.

4.4 Regulatory Compliance

Clarify which rules apply—those at contract signing or at delivery. If left open, mid-project IMO or class rule changes can shift unplanned cost to the builder.

4.5 Payment Terms and Milestones

Link each instalment to a verifiable event—keel laying, launching, delivery. Avoid vague triggers like "substantial completion," which breed disputes and cash-flow imbalance.

4.6 Refund Guarantee

This is the buyer's lifeboat. Ensure a **bank-backed, unconditional, on-demand** guarantee compliant with ICC URDG 758. Conditional or local-bank guarantees have failed repeatedly in court.

4.7 Liquidated Damages (LDs)

LDs must be *reasonable, precise, and capped.* If drafted loosely, builders argue "penalty," owners lose enforceability. If omitted, the only remedy is uncertain common-law damages.

4.8 Variation and Change-Order Procedure

Without a defined process, informal changes at site level become legal chaos. State how variation requests are priced, approved, and incorporated into schedule.

4.9 Warranties and Defect Liability

Set clear duration (usually 12–24 months) and scope—materials & workmanship only unless extended.

> *Every clause in a shipbuilding agreement moves risk along three axes: time, money and quality*

Prevent *specification creep* that silently expands warranty obligations.

4.10 Governing Law and Dispute Resolution

Choose a law with maritime precedent—commonly English law—and an arbitral seat such as **London (LMAA)** or **Singapore (SIAC).** Avoid obscure local forums that add bias and procedural delay.

5 The Anatomy of Technical Specifications

The specification is often drafted by engineers in parallel with the contract negotiated by lawyers. Unless these streams converge, contradictions are inevitable.

5.1 When Engineering Becomes Law

Phrases like *"built to good marine practice"* or *"reputable maker"* sound harmless but are *legally binding*. Each undefined adjective creates interpretive latitude. Arbitration records are full of disputes where "about 15 knots" became a guarantee instead of a design intent.

5.2 Cost Migration Through Rule Changes

Many specs require compliance with "latest IMO / SOLAS rules." When standards evolve mid-project, the cost of compliance migrates silently to the builder. Freezing rule applicability at contract date—or sharing cost by formula—avoids this trap.

5.3 The Maker's List Dilemma

Listing approved suppliers without defining substitution rights invites conflict. A balanced clause might read: *"Substitution with equivalent maker shall not be unreasonably withheld."*

5.4 Plan Approval Loopholes

Specs deferring details to "to be agreed at plan approval" postpone disputes rather than prevent them. Critical parameters—propulsion type, hull coatings, class notations—must be frozen at contract stage.

5.5 Spec Creep and Informal Change

Every "minor" owner request can shift scope. Without documented change orders, shipyards face uncompensated cost. Discipline in document control is a shipyard's best defence.

6 International Contract Forms: Convergence and Divergence

6.1 SAJ Form

- Strength: proven template; predictable arbitration precedent.
- Weakness: builder-friendly; weak refund-guarantee and hierarchy provisions.
- Lesson: modern projects should amend these gaps explicitly.

6.2 BIMCO NEWBUILDCON

- Designed for balance; incorporates lessons from decades of SAJ disputes.
- Includes clearer force-majeure, variation, and termination language.
- Increasingly the global benchmark for complex builds.

6.3 Local Adaptations

Chinese and Korean forms often appear familiar but embed domestic-law peculiarities. International buyers must insist on English translations vetted by counsel, ensuring that arbitration clauses remain enforceable abroad.

7 How Disputes Germinate: The Early-Stage Triggers

Even before steel cutting, risk seeds are sown.

1. **Inconsistent Drafts** – Contract and specification evolve separately; nobody performs cross-check.
2. **Unrealistic Timelines** – Commercial departments promise delivery impossible for engineering to sustain.
3. **Financial Assumptions** – Exchange-rate or inflation clauses ignored.
4. **Ambiguous Communication** – Site team interprets drafts differently from head office.
5. **Documentation Gaps** – Email approvals replace formal amendments.

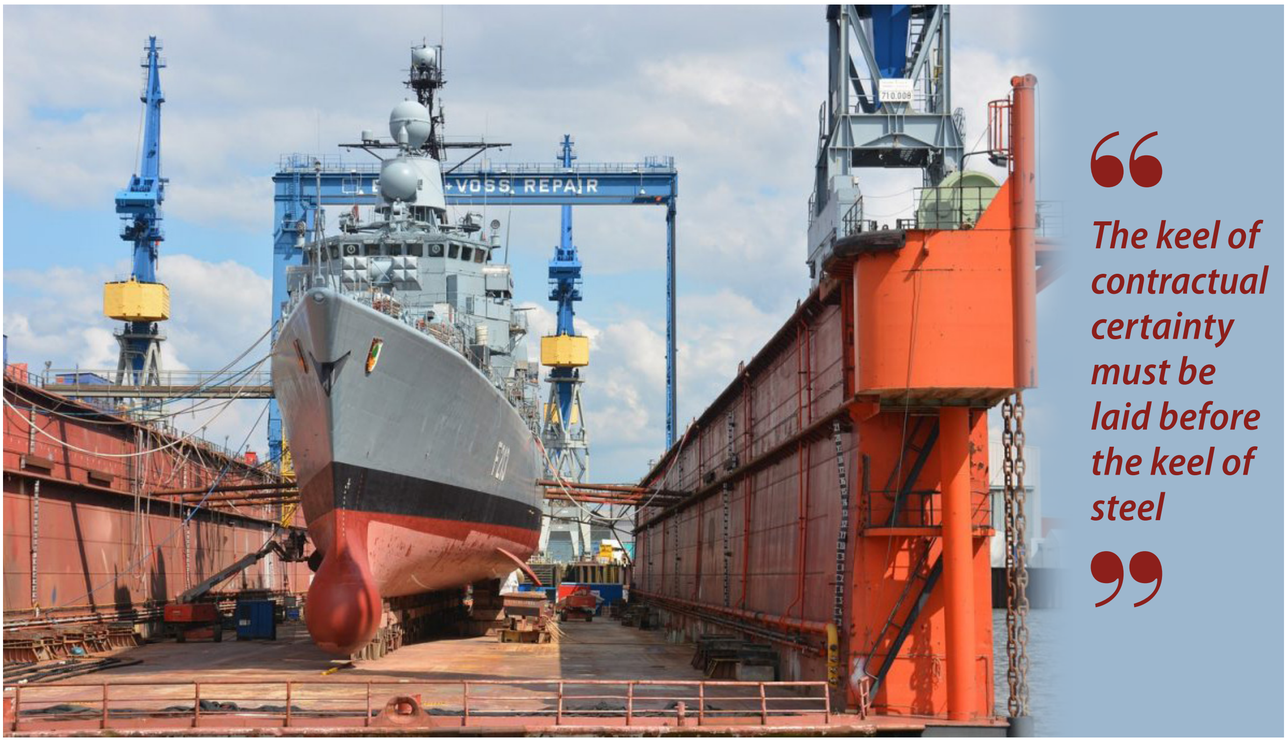
By the time arbitration begins, years later, paper trails are fractured and memories selective. Prevention is exponentially cheaper than cure.

8 Risk Management Principles for Drafting

A mature shipbuilding contract transforms lessons from past disputes into preventative architecture.

Risk Area	Preventive Principle	Operational Control
Refund guarantee	Independent on-demand bank guarantee	Verify authenticity with issuing bank
Delivery delay	Realistic schedule + LD cap	Progress monitoring dashboards
Spec-contract conflict	Explicit hierarchy clause	Joint legal-engineering review
Regulatory change	Rule-freeze + cost-sharing clause	Early notification system

“In arbitration, documentation equals truth”



Risk Area	Preventive Principle	Operational Control
Variation control	Formal change-order workflow	Site-team escalation protocol
Warranty	Defined duration + scope	Post-delivery defect log templates

These six pillars convert contracts from legal minefields into management tools.

9 Integration of Design, Production, and Legal Review

Modern shipyards increasingly adopt **"Design–Legal Integration Workshops"** before contract signing. Such sessions bring naval architects, contract managers, and financiers together to test each clause against real-world feasibility:

- Can the promised delivery date withstand steel-procurement lead times?
- Are emissions-compliance costs adequately priced?
- Do test protocols match class-society practice?

This cross-functional validation transforms risk allocation into an informed consensus rather than a theoretical exercise.

10 The Strategic Role of Documentation

In arbitration, documentation equals truth. Meticulous record-keeping—meeting minutes, plan-approval logs, variation orders—decides outcomes. Every contract should require electronic document control with timestamped audit trails. From a project-management perspective, such discipline also accelerates decision-making and prevents informal commitments.

11 Arbitration Trends and Global Lessons

Reviewing anonymised awards over the past decade reveals recurring themes:

- **Force Majeure Abuse:** builders invoke broad FM clauses for routine supply delays. Tribunals now construe FM narrowly.
- **Refund-Guarantee Litigation:** English courts uphold their independence (e.g., *Chinese Shipyard v Investment Company [2021] EWCA Civ 1147*).
- **Design vs Performance:** tribunals distinguish "designed for" from "shall achieve." The latter triggers warranty liability.
- **Hierarchy of Documents:** in absence of clause, contract body prevails (LMAA practice).

The moral is consistent: clarity prevents creativity in litigation.

12 From Drafting Table to Dockyard: Aligning Intent and Execution

Contracts drafted in boardrooms often fail under the stress of real world constraints—supply-chain delays, classification revisions, or labour unrest. Bridging this divide requires:

- Early inclusion of site engineers during contract negotiation.

- Periodic contractual briefings for production teams.
- Feedback loops converting site experience into future clause improvements.

When engineers understand the legal commitments they implement, disputes decline sharply.

Conclusion – Building Clarity Before the Keel Is Laid

A shipbuilding contract is both a promise and a prediction. Its success depends less on eloquent wording than on disciplined foresight. The first line of defence against arbitration is not the lawyer's argument but the engineer's understanding of what was promised, how it will be measured, and when it can be delivered. The pitfalls germinate at the earliest stages—when risk allocation, specification hierarchy, and refund security are treated as afterthoughts.

To build vessels without building disputes, parties must:

1. Define every term with measurable clarity.
2. Freeze regulatory scope or assign costs transparently.
3. Treat refund guarantees as sacred instruments, not negotiable favours.
4. Train site teams in contractual awareness from day one.

In shipbuilding, prevention is not merely better than cure—it is the only affordable option. The keel of contractual certainty must be laid before the keel of steel.

Abbreviations

- BIMCO – Baltic and International Maritime Council: an international shipping association that publishes standard contract forms, including NEWBUILDCON.
- EWCA Civ – England and Wales Court of Appeal (Civil Division): used in neutral citations; e.g., [2002] EWCA Civ 1147, where "1147" is the sequential judgment number for that year. (Civ denotes the Civil Division, as opposed to Crim for the Criminal Division).
- FM – Force Majeure: a contractual clause excusing parties from liability for non-performance due to extraordinary events beyond their control (e.g., natural disasters, war, pandemics).
- HKIAC – Hong Kong International Arbitration Centre: an arbitration institution for resolving commercial and maritime disputes in the Asia-Pacific region.
- IMO – International Maritime Organization: a UN specialized agency responsible for regulating international shipping.
- LD – Liquidated Damages: a pre-agreed sum payable for failure to perform contractual obligations, typically delayed delivery of a vessel.
- LDs – Liquidated Damages (plural): commonly used shorthand for multiple claims or cumulative sums under LD clauses.
- LMAA – London Maritime Arbitrators Association: a London-based body providing arbitration services for maritime disputes, including shipbuilding and charterparty contracts.
- MARPOL – International Convention for the Prevention of Pollution from Ships: an IMO convention addressing ship-sourced pollution, including oil, chemicals, sewage, and garbage.
- NEWBUILDCON – Newbuilding Contract: a BIMCO standard form used for shipbuilding contracts, covering delivery, payment, warranties, and dispute resolution.
- SAJ Form – Shipbuilders' Association of Japan Standard Form Shipbuilding Contract: a widely used standard form contract in Asia, especially for Japanese and Korean shipyards.
- SIAC – Singapore International Arbitration Centre: a Singapore-based arbitration institution for international commercial disputes, widely used in shipbuilding contracts.
- SOLAS – International Convention for the Safety of Life at Sea: an IMO convention establishing minimum standards for ship construction, equipment, and operation to ensure safety at sea.
- URDG 758 – Uniform Rules for Demand Guarantees, ICC Publication No. 758 (2010): internationally recognized rules governing demand guarantees and counter-guarantees, often applied to refund guarantees in shipbuilding contracts.

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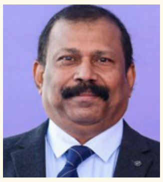
About the Author



Narayana Prakash is a shipbuilding consultant who advises a wide range of shipowners, with a particular emphasis on micro-level details to optimise shipbuilding contracts. With over 17 years of professional experience in shipbuilding, contract review, and arbitration proceedings, he has cultivated extensive expertise and a comprehensive understanding of shipbuilding contracts from both operational and legal perspectives.

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Progress in Tsunami Early Warning Technologies: Part A

Sundar Ranganathan
M Arul Muthiah
N.Vedachalam
R.Balaji

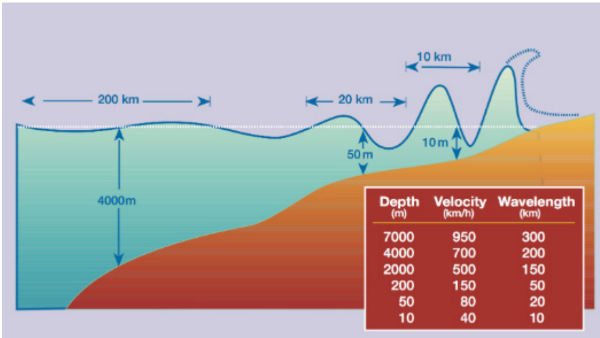

Figure 1. Propagation pattern of a tsunami wave

Abstract: Tsunami is an ever-present to the coastal countries located along the Pacific, Atlantic, Indian Ocean, as well as Caribbean and Mediterranean seas. The Indian Tsunami Early Warning System (ITEWS), since its inception in 2007, is undergoing significant technological improvements. The ITEWS is now serving as a Tsunami Service Provider for whole of the Indian Ocean Region, along with Indonesia and Australia. On-demand reliability is the key requirement for offshore-moored tsunami monitoring buoys that continuously measure and transmit water level changes to the Tsunami Early Warning Centers during tsunamigenic earthquakes. This article is published in two parts. This part describes the principles and technologies involved in tsunami early warning, right from localisation of tsunamigenic earthquakes based on seismic signals; monitor, measure and transmit the water level changes in the deep-oceans; modeling tsunami propagation and the shore-line impacts.

Introduction

Any geological disturbance on the ocean-floor causes displacement of large amounts of water, which triggers a tsunami. Under-sea earthquakes (EQ), landslides, volcanic eruptions and explosions are some known causes of tsunami. Unlike wind-driven waves, tsunamis are characterised by large wavelengths (ranging from 10s-100s of km) and long periods (min to h). Tsunami surface wave travel at a speed of ~700 km/h in deep-oceans and ~100km/h nearer to the coast **(Figure 1),** and its enormous energy cause widespread damage to life and property.

Among the two recent tsunamis, including the 2004 Sumatra-Andaman (Mw 9.2 EQ) and the 2011 Tohoku (Mw 9.0 EQ), the mega-thrust EQs seismologically recorded were the 1952 Mw 9.0 Kamchatka, the 1964 Mw 9.2 Alaska and the 1960 Mw 9.5 Chile events, all these EQs generated trans-oceanic tsunamis in the Pacific & Indian Ocean. In response to these tsunamis, the Pacific Tsunami Warning Center (PTWC) and Pacific-coast located Russian warning centers were established in 1950s. However, it is the 2004 devastating tsunami that led to the intuition of regional Tsunami Early Warning Systems (TEWS) in the

In response to these tsunamis, the Pacific Tsunami Warning Center (PTWC) and Pacific-coast located Russian warning centers were established in 1950s

Indian Ocean, Mediterranean and Caribbean as mandated by the international community under the guidance of Intergovernmental Oceanographic Commission (IOC) of the UNESCO.

As a result, the Intergovernmental Coordination Group for the Indian Ocean Tsunami Warning & Mitigation System (ICG/IOTWMS), the Intergovernmental Coordination Group for the Tsunami Early Warning and Mitigation System in the North-eastern Atlantic, the Mediterranean and Connected Seas (ICG/NEAMTWS), and the Intergovernmental Coordination Group for the Tsunami and Other Coastal Hazards Warning System for the Caribbean and Adjacent Regions (ICG/ CARIBE-EWS) were established. The major objectives of these TEWS are to detect, locate, and determine the magnitude of potentially tsunamigenic earthquakes occurring in the global oceans.

With a potential growth in these observation networks, the warning centers are capable of providing timely advisories (Warning/Alert/Watch) to the vulnerable community, utilising the latest communication methods, following a Standard Operating Procedure (SOP) with back-end support of a pre-run scenario database and in-house built decision support system.

Tsunami Early Warning- Time is the essence

For an effective TEWS, time is of essence, the time constraint is:

$$T1 + T2 + T3 \leq T4$$

where T1 is the tsunami detection time, T2 is the assessment time, T3 is the evacuation time, and T4 is the tsunami travel time. Detection time can be reduced by optimising the locations of seismic stations, offshore tsunami buoys and tide gauges, implementing global real-time data telemetry for the monitoring and by improving data processing and model algorithms. Shortening the assessment time requires improvements in the ability to measure the true size and seismic energy of very large EQ, so as to understand factors contributing to tsunami generation and to make warning decisions using limited historical data samples. The evacuation time T3 of a community is affected by its emergency planning, public awareness, communication network, and other socio-economic, environmental and circumstantial factors. The stages involved in a tsunami early warning process are depicted in **Figure 2.**

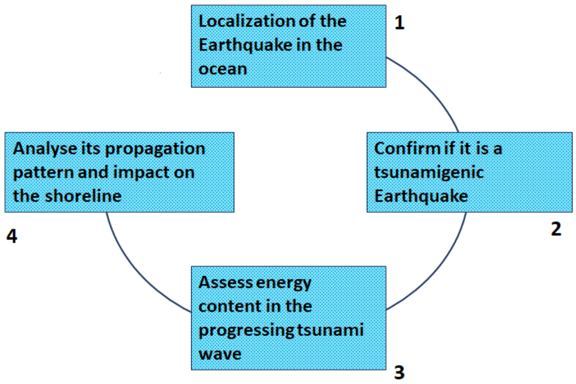

Figure2. Stages involved in a tsunami early warning process

Localisation of the EQ in the Ocean

The primary requirement in a TEWS **(Figure 2)** is to identify the EQ information including the location, magnitude and focal depth, so as to determine the EQ's capability to generate a likely tsunami, if the epicenter of the EQ is in the ocean. About 90% of all EQ results from tectonic events, primarily movements on faults. The remaining 10% are related to volcanism or collapse of subterranean cavities. The EQ epicenters are not uniformly distributed over the Earth's surface but occur predominantly along rather narrow zones of inter-plate seismic activity. Almost all of EQ occur at two tight seismic belts at Earth's surface, including the Circum-Pacific belt (Ring of Fire) with 80% quantity of released energy and the Mediterranean trans-Asiatic seismic belt with ~15% of the release energy. The system of oceanic ridges that contributes to about 7% of the annually released seismic energy occur only in the circum-Pacific and Mediterranean-trans Asiatic seismic zones, and accompany the process of plate subduction, where the oceanic plate under thrust the continental plate **(Figure 3).**

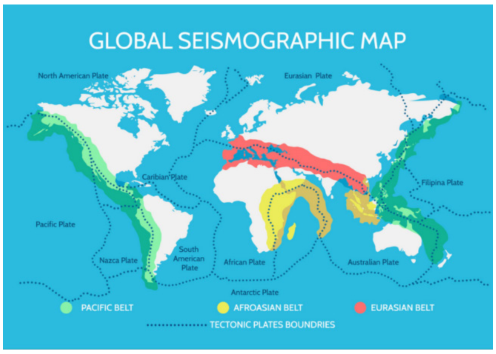

Figure 3. Global seismographic map

During an EQ event, the TEWS receives information from more than 350 globally-located (as well as local) seismic stations through the international seismic monitoring networks **(Figure 4).** As seismic waves travel faster than tsunami waves, detecting an EQ can trigger immediate analysis of the event. The distance of a seismic station from the epicenter of an EQ (the epicentral distance) is expressed in kilometers (km) along the surface, or by the angle (180/ϖ.km) subtended at the Earth's center **(Figure 5 L).**

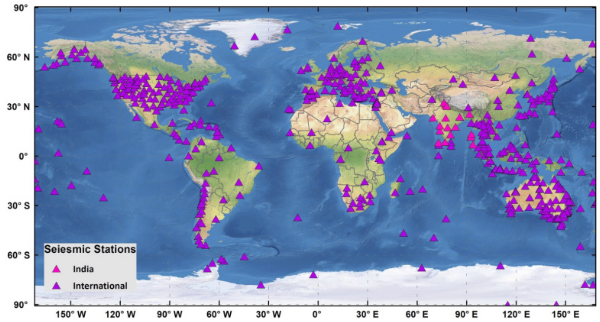

Figure 4. Location of seismic stations across the globe

The distances from the seismic stations to the EQ are estimated from the difference between P (primary / compressive / longitudinal) and S wave (shear) arrival times. P-waves are the first to arrive at a seismograph at a speed range of 1.5-13 km/s, based on the density of the travel medium, shear modulus and Lame parameter. S-waves arrive 1.7 times later than P-waves. The EQ location is determined based on the arrival pattern of the seismic waves. As indicated in **Figure 5 R,** data from one seismic station give only the distance of the epicenter from that station. It could lie anywhere on a circle centered at the station. The data from an additional station defines a second circle, which intersects the first circle at two points, each of which could be the true epicenter. Data from a third station removes the ambiguity, and the common point of intersection of the three circles is the epicenter. To determine the location of an EQ, epicenter travel-times of P- and S-waves to at least three seismic stations are necessary. However, inputs from eight seismic stations are required for the precise localisation of an EQ.

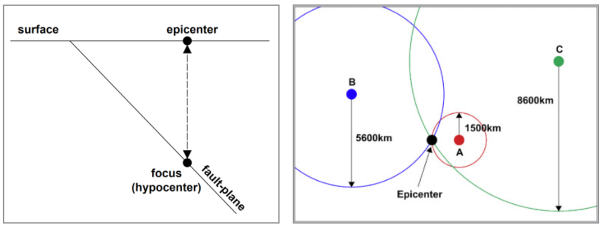

Figure 5. Epicenter and localisation of the EQ by triangulation

Confirmation for a tsunamigenic EQ

When the epicenter of EQ is located in the ocean, the next immediate step is to ascertain whether it leads to a tsunami. The size of the tsunami is related to the seismic moment (or equivalently the magnitude) of the undersea EQ. Moment magnitudes measure the amount of stress energy released in an EQ. They are calculated after determining the fault throw (distance the fault moved), the area broken on the fault (depth and length), and the rigidity of the fault rocks (the springiness of the rocks). For a given fault and faulting mechanism, the co-seismic deformation (combination of dynamic and static motions that occur when faults rupture) is linearly dependent on the fault dislocation (or a slip that is the relative movement between the down-going-footwall

and the overlying - hanging wall- plates). Thus, higher the magnitude, larger the slip, and more pronounced the vertical seafloor deformation, results in a bigger tsunami. Hence the amplitude and period/wavelength of the resulting tsunami depend on the vertical seafloor co-seismic displacement which in turn depends on EQ magnitude, focal depth, faulting mechanisms, and the heterogeneity of the slip distribution.

The concept involved in the tsunami detection and reporting system followed by all TEWS operational in the Pacific, Atlantic, Caribbean and Indian oceans is based on the robust and proven Deep Ocean Assessment and Reporting of Tsunamis (DART) developed by the US National Oceanic and Atmospheric Administration (NOAA), Pacific Meteorological Environmental Laboratory (PMEL). A tsunami wave in deep ocean creates a small but measurable change in pressure that will persist for a period of 20mins. The principle is based on monitoring and analysing any such changes using subsea-located pressure variation detectors that trigger an alarm by sending a warning message to an acoustic receiver mounted in the moored surface buoy (MSB). The MSB, in turn, relays the message through a satellite data link to respective control center that can issue a warning to vulnerable communities.

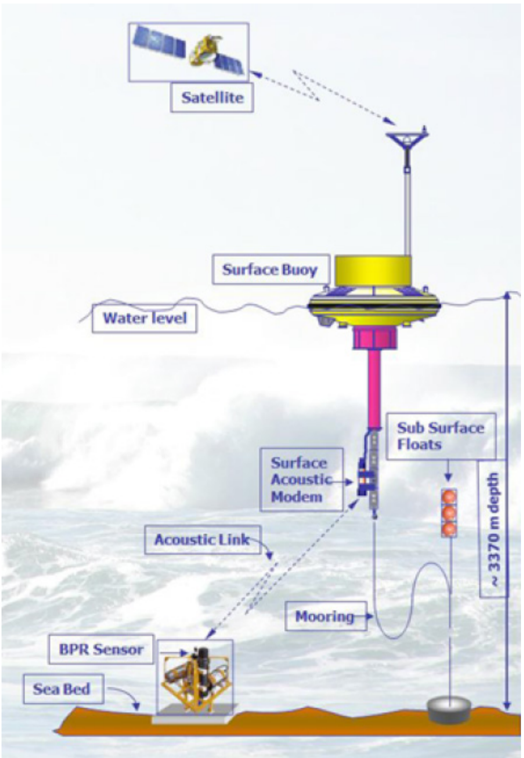

Figure 6. Principle of offshore-moored DART

An offshore-moored DART node **(Figure 6)** involves a system using a Bottom Pressure Recorder (BPR) deployed in identified locations in deep-oceans, and the locations are based on the fault line and the shoreline to be protected **(Figure 7).** The BPR is accompanied by an integral pressure averaging subsystem and a deep-ocean pressure recorder unit. The pressure sensor having a measurement sensitivity better than 2×10^{-7}, can measure a water column change of <1mm in a 6000m water column. A co-located battery-powered electronic processor acquires the signals from the pressure sensor continuously, and the in-built algorithm continuously analyses the water column pressure changes (differentiates tsunami and regular tidal variation) and indicates the possibilities of a tsunami event. The subsea equipment and the buoyancy package are mounted on a frame that is moored with an anchor weight and an acoustic release, making it possible to retrieve by sending a release command to the acoustic modem. The software in the BPR processes the acquired pressure data based on the predictive Newton Forward Extrapolation (NFE) algorithm, developed by the NOAA. By analysing the characteristics of tsunami waves whose amplitudes and durations ranging 10-500mm and 5-30min, respectively, it is reported that the Kalman Filter (KF) algorithm has a better detection performance over the NFE technique for tsunami wave amplitudes < 30 cm. The NFE is found to have a better detection performance for wave durations <10min. For wave durations >10min, KF has a better detection performance. In addition to this, Mofjeld and Artificial Neural Networks (ANNs) algorithms are also being explored for enhanced detection.

The BPR telemeters the data acoustically with time-stamped pressure readings and system status parameters. The transceiver in the MSB receives the acoustically transmitted data from the BPR. The MSB transmits the data to the INMARSAT satellite terminal, which, in turn, transmits it to the shore-based TEWS through satellite telemetry, mostly INMARSAT. Based on the recent study conducted for the Indian TEWS (ITEWS), minimum of 3 tsunami buoys with a healthiness reporting interval of ~6h (to comply with Safety Integrity Level SIL4 level of on-demand reliability) are required for monitoring the Sumatra subduction zone and provide early warning to the Indian coastline. The hard-to-maintain offshore infrastructure (CAPEX and OPEX) is justified by the social cost involved in detecting a likely deadly tsunami that could occur in an average period of ~450 years with intervals ranging from a dormant period of over 2000 years to multiple tsunamis within the span of a century.

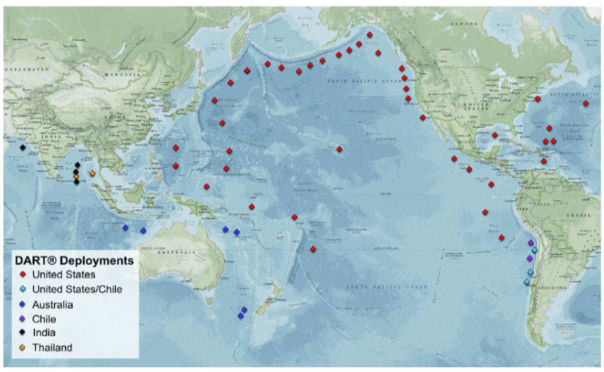

Figure 7. Global distribution of offshore-moored DART buoys

Energy in tsunami waves and its propagation

When the ocean floor is abruptly lifted or dropped, the entire water column is pushed up and down, in which <95% of the potential energy of the displaced water is gravitational and < 5% is elastic energy resulting from compression of the ocean floor or water column. The potential energy of the vertical motion is converted to kinetic energy and propagates away from the source as a tsunami. The total energy transmitted by tsunami wave is one of the most fundamental macroscopic quantities for interpreting the size of a tsunami, as well as for understanding the physical processes of tsunami propagation and coastal impacts. As a typical example, the water column height (~ 6cms) recorded at station 23227 during a low intensity tsunamigenic earthquake is shown in **Figure 8.**

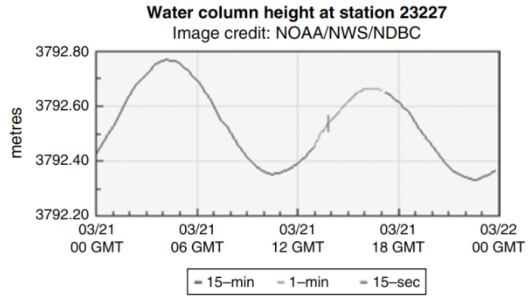

Figure 8. Tsunami event captured by DART buoy

The quantity of potential energy (mgh, typically in Giga Joules) released in the progressing tsunami wave front is the product of the height (h) recorded by the BPR, equivalent mass of water lifted (m) over the water column and the acceleration due to gravity (g). The magnitude of Dec 2004 Mw 9.0 Sumatra–Andaman Islands EQ that occurred in Dec 26, 2004 had a massive sea floor fault rupture zone 1300km in length and 150km in width, with displacements on the fault of 20m. It is reported that the event could have resulted in a tsunami with about 80–100cm from crest to trough height in the open Indian with shore waves as tall as 50m, reaching 5 km inland (near Meubolah, Sumatra) resulting in ~230,000 casualties.

Globally, real-time tsunami forecasts are carried out based on a two-step process. Firstly, construction of a tsunami propagation scenarios via inversion source functions, and secondly, coastal predictions by running high-resolution site-specific flooding models in real-time. Tsunami propagation analyses are based on linear wave theory, non-linear shallow water NSW (long wave) modeling based on integration of Euler or Navier-Stokes equations. They are done with an assumption of vertically invariant horizontal velocity and hydrostatic pressure and higher order approaches based on time-domain Boussinesq equations (that are derived based on assumption between wave non-linearity and frequency dispersion) over NSW equations effective for intermediate water depth and near-shore modeling. The application of numerical models needs precise inputs on specifying initial conditions, dynamic bottom boundary conditions, regional topology, grid and time steps, as well as bottom friction factors for accurate predictions. As a typical example, the travel time Directivity map for the September 12 M 8.4 EQ simulated by MoES-INCOIS is reproduced in **Figure** 9.

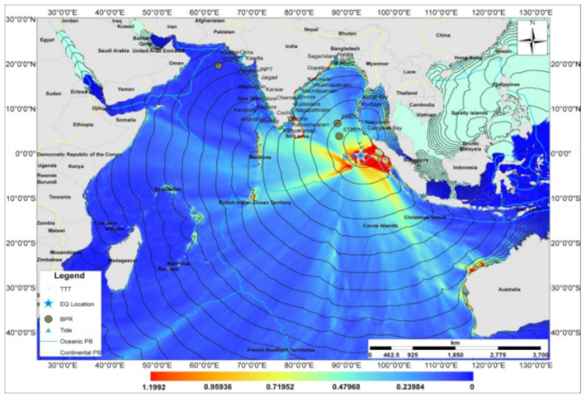

Figure 9. Propagation pattern of tsunami in Indian Ocean

Shoreline impact assessment

The tsunami propagates throughout an ocean basin as a wave with period of around 15–30min. The entire water column participates in the motion. The velocity of the wave, v, dependent on the water depth, d, and acceleration due to gravity, g, is given by. The wavelength is velocity x time period. Despite having a height of only a few cm in the open ocean, its height increases as it approaches the shore. The increase in wave height is accompanied by more dynamic and complex phenomenon as non-linear and dispersive effects are predominant. For a dispersive tsunami, various sine wave components will have different wave speeds **(Figure 10).** The transformation properties depend on the characteristics of the beach and complexities in bathymetry. The energy dissipation mechanism that plays a major role in determining maximum run up (leading to inundation) is the bottom friction, which is the dissipation caused by the flow interaction with the seafloor, where bottom irregularities lead to flow separations and resulting turbulence. Energy dissipation will also result due to mixing with sediment and debris entrainment.

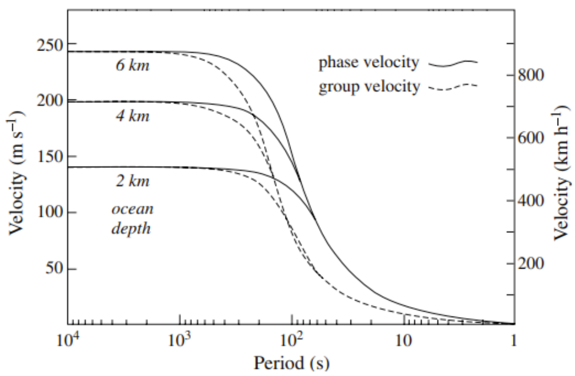

Figure 10. Propagation pattern of tsunami in Indian Ocean

The tsunami open-ocean propagation and inundation simulation of a 2004 tsunami (with ~2 million grid points) carried out by MoES-INCOIS is shown in **Figure 11.** Tide gauges play an important role in validating the run-up heights for validating the numerical models. Globally, measurements from DART buoys and coastal tide stations show good agreement with the forecasts obtained in real-time, suggesting that the propagated energy and the source location are the key for predicting tsunami impacts.

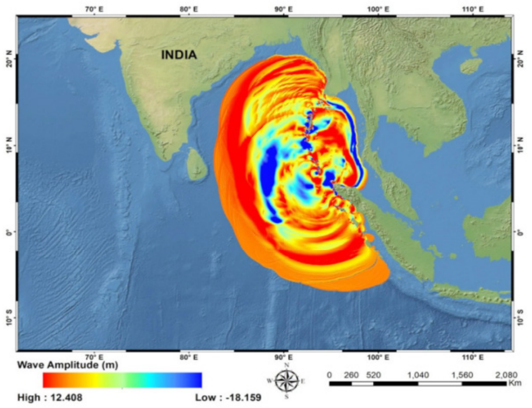

Figure 11. Inundation pattern simulating a 2004 tsunami

Maturity of the Indian Tsunami Early Warning System

In response to the 2004 devastating disaster that claimed the lives of ~230,000 people in 14 Indian Ocean rim countries, the Government of India established the Indian Tsunami Early Warning System (ITEWS) with the Ministry of Earth Sciences (MoES) as the nodal ministry. The Indian Tsunami Early Warning Centre (ITEWC) was established at the Indian National Centre for Ocean Information Sciences (INCOIS), Hyderabad, in 2007 and National Institute of Ocean Technology (NIOT) to develop, maintain, and disseminate the sea level data to ITEWC. Since the establishment of the ITEWC, it has been serving as the primary source of the tsunami advisory for India and, after October 2011, as a Tsunami Service Provider (TSP) for the whole Indian Ocean region along with Australia and Indonesia. The ITEWC detects, locates, and determines the magnitude of potentially tsunamigenic EQ occurring in the ocean; estimates the travel time and run-up heights of tsunamigenic waves using pre-run tsunami simulation models.

The ITEWC receives seismic information from a network of 17 broad-band seismic stations (established by IMD) in real-time through VSAT, as well as from >350 globally located seismic stations from the international seismic monitoring networks. Tidal data is received from 21 tide gauges along the Indian coastline and islands through INSAT, as well as from more than 300 global stations. The network of buoys is used to detect, measure, and monitor tsunamis, from the two tsunamigenic source regions of the Indian Ocean in real-time using satellite communication. Each tsunami buoy is strategically placed at 30-min tsunami wave arrival times (from hypothetical tsunami sources), so that it offers sufficient warning time (**Figures 12, 13).** At the same time, the buoys are far enough from the EQ zones so that the tsunami wave signal can be clearly distinguished from the seismic Rayleigh wave.

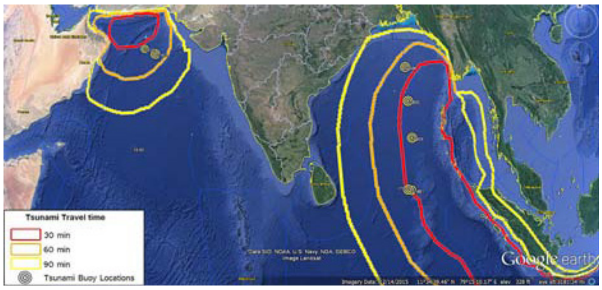

Figure 12. Placement of tsunami buoys in the Indian seas

The ITEWC houses a high-performance computing (HPC) system for estimating the tsunami travel time and run-up heights of the tsunamigenic waves, using pre-run tsunami simulation models comprising pre-simulated scenarios for the both Andaman-Sumatra-Java and Makran subduction zones. It is based on the database that is developed for different hypocenter (10, 20, 33, 40, 60, 80 and 100 km) and magnitudes (6.5, 7.0, 7.5, 8.0, 8.5, 9.0 & 9.5) for 975 simulations points, each with separation of half a degree, covering all tsunamigenic sources in the Indian Ocean. The 50,000 pre-trained models model results help to decide the initial estimates of the impact of the tsunami. ITEWC has the SOP for generating and issuing tsunami information to national and international warning centers. At the national level, information is disseminated to designated agencies including the MoES, MHA, NDMA, NDRF etc. Since its inception in 2007, the tsunami buoys have detected 12 water level variations in the deep oceans (ranging from 7.4cm to 20.6cm) that were triggered due to earthquakes of magnitude ranging from 6.5 to 7.9Mw (occurred in both land and in the ocean) with focal depths extending till 73kms. Significant water level changes recorded by the Indian Tsunami buoys during EQ events are shown in **Figure** 14.

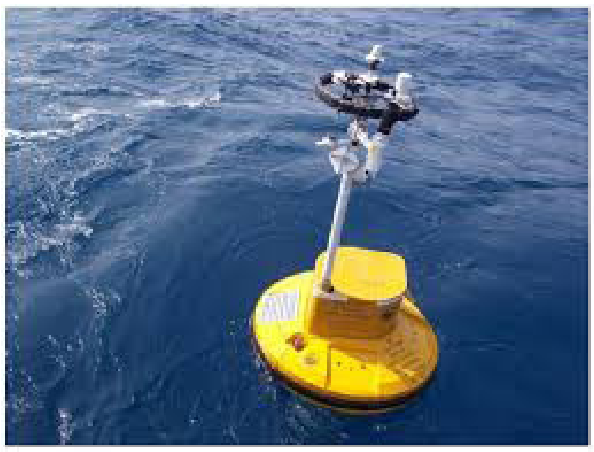

Figure 13. Tsunami buoy deployment by NIOT

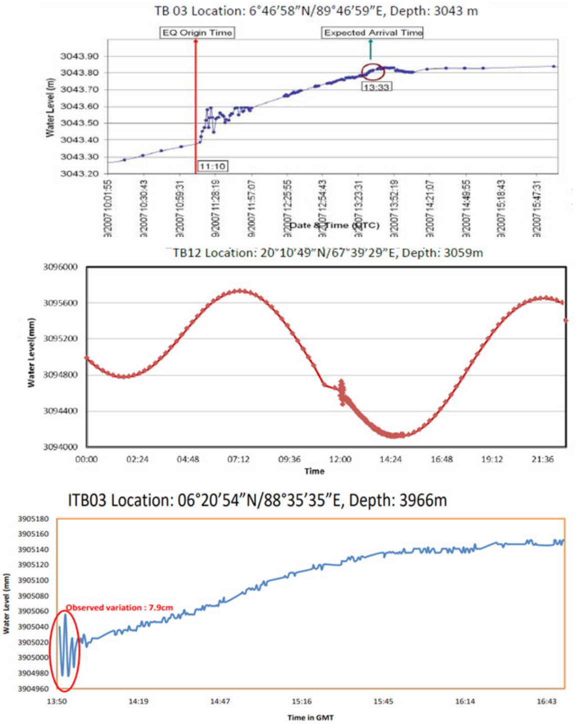

Figure 14. Water level events recorded by tsunami buoys

In the next part...

The continuous efforts that helped to improve Mean Time Between Failure of the buoy from 0.3 years in 2007 to 0.9 years till-date, optimising the number of buoys in the offshore-moored network, demonstration of submerged tsunami buoys and hybrid satellite telemetry, challenges associated in estimating the energy in a tsunami wave enabling precise forecasting of the impacts of tsunami and the protocols adopted for dissemination of tsunami event to the public shall be discussed.

Acknowledgements

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About the Authors

Sundar Ranganathan is a Scientist–E in the Ocean Observation Systems (OOS) Group at the National Institute of Ocean Technology (NIOT), Ministry of Earth Sciences, India. He has over 20 years of experience in the design and development of ocean observational systems and currently oversees the end-to-end management of ocean data from all NIOT observational platforms. He holds a Bachelor's engineering in Computer Science & Engineering and M Tech in Ocean Technology from IIT Madras. He has authored more than 20 publications in indexed journals and holds two national patents. He also serves as an Ambassador for Ocean Best Practices for India region and Task Team member for various best-practices initiatives. He is also a professional member of IEI, IEEE, and the Marine Technology Society (MTS).

M. Arul Muthiah, Scientist-F and Head of the Ocean Observation Systems Group at NIOT, Chennai, has 20+ years of experience in designing, developing and maintaining offshore autonomous data acquisition platforms. He led the indigenous development of a moored buoy data acquisition system transmitting 200+ real-time parameters. A key contributor to India's first underwater ocean observatory near the North Pole, he received the National Geosciences Award (2016) from Honorables President of India and the Meritorious Scientist Award (2008). Holding a B.E. (Electrical) and M.E. (VLSI), he has authored 28+ publications, holds five patents, and is an active IEEE and MTS India member.

Dr. N. Vedachalam is Scientist-G and Director of DeepSea Technologies Group in National Institute of Ocean Technology (NIOT), Ministry of Earth Sciences, India. His 30 years of experience include industrial power, process, offshore and subsea domains at Aditya Birla group, General Electric &Alstom Power Conversion in France. Technical exposure includes development of multi-megawatt subsea power and control systems, offshore renewable energy systems, unmanned and manned underwater vehicles, ocean observation technologies and industrial systems. His research interests include energy, subsea robotics and reliability. He has more than 100 publications in indexed journals, holds an international patent and two national patents in subsea robotics and subsea processing. He is a member of various national committees and review boards.

Email: veda1973@gmail.com

Prof. R.Balaji is the Director at National Institute of Ocean Technology, Ministry of Earth Sciences. He is on deputation from IIT Bombay, where is a Professor in Department of Civil Engineering since 2011. Prior to that, he was working as Senior Coastal/Port Engineer at Sogreah Consultants, in Dubai. He obtained his Masters and Ph.D degrees in Ocean Engineering from IIT Madras. He has authored more than 80 publications in peer reviewed journals and 82 conference papers. He has bagged multiple excellence awards, including the Professor S.P. Sukhatme Excellence in Teaching Award in 2024. Apart from teaching and research, his experience includes waterfront development projects in India and abroad. His primary area of expertise includes port, harbor, marina, coastal infrastructural design and developments. He is a member of various national committees and review boards.

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Effect of Extreme Environment and Isolation on Subjective Time Estimation in Antarctica

Azizuddin Khan

Abstract: Antarctica—the world's most extreme and isolated continent—offers a natural laboratory for understanding how the human brain perceives, adapts, and occasionally distorts time.

When cut off from the normal cues of daylight, temperature, and social activity, the human sense of duration begins to shift. Minutes can feel like hours; days can dissolve into one another.

This study explores how **extreme environment and isolation influence subjective time estimation** among Indian summer expeditioners stationed at three distinct settings:

1. **Voyage (Ship)** – dynamic, socially rich, and environmentally active;
2. **Bharati Station** – isolated, quieter, and logistically demanding;
3. **Maitri Station** – more established, communal, and routine-driven.

A total of **57 participants** completed time estimation tasks involving both short (4-second) and long (210-second) intervals under varying cognitive load.

Findings revealed that **expeditioners at Bharati Station consistently overestimated time**, while those aboard the Voyage or at Maitri produced more accurate judgments. The results suggest that environmental monotony, limited interaction, and psychological isolation distort temporal awareness.

These insights shed light on how humans adapt psychologically to polar conditions—and by extension, to any long-duration mission in space, submarines, or deep-sea habitats.

1. Introduction: When Time Bends in the Cold

Human life is regulated by time—from the ticking of biological clocks to the rhythmic alternation of day and night. Yet our perception of time is not fixed. It depends on attention, emotion, and environmental cues.

In normal conditions, sunrise and sunset, social activity, and daily work routines provide temporal anchors. In Antarctica, these anchors vanish.

The sun may circle endlessly above the horizon, creating **24-hour daylight** in summer, while winter brings months of darkness.

Temperature plunges below −40 °C, winds exceed 100 km/h, and silence dominates. The sense of time becomes elastic.

Polar scientists and explorers have long described this phenomenon. The same day can feel both fleeting and endless—a paradoxical slowing and speeding of time.

2. The Human Clock: Biological and Cognitive Foundations

2.1 The Biological Clock

Humans possess internal oscillators that regulate sleep, body temperature and hormonal cycles. This **circadian rhythm**, synchronised to the 24-hour light-dark cycle, helps organise perception of time.

In Antarctica, continuous daylight or darkness disrupts this rhythm, leading to sleep disturbances, mood swings and disorientation. Without external cues, the body's rhythm "free-runs," typically extending to 25 or 26 hours.

Studies by *Aschoff* and *Wever* (1981) demonstrated that people isolated from natural light begin drifting from normal time, sleeping and waking later each day. Such biological desynchronisation is mirrored psychologically as a **distorted sense of duration**.

2.2 The Cognitive Clock

Cognitive theories focus on **attention and memory**.

- When attention is intensely focused, more mental "events" are recorded, making time feel longer (*storage-size theory*).
- When attention drifts or is divided, fewer mental markers are stored, compressing time perception (*attentional gate model*).

Thus, the same minute can feel long during boredom and short during excitement.

In Antarctica, reduced sensory variety and social isolation diminish external events, causing subjective expansion of time—minutes that feel stretched.

3. Antarctica: The Ultimate Human Laboratory

The Antarctic continent isolates individuals physically and psychologically more than any other environment on Earth.

- **Temperature:** –10 °C to –60 °C;
- **Wind:** frequent gusts exceeding 100 km/h;
- **Humidity:** extremely low, creating desiccation and fatigue;
- **Sensory deprivation:** vast white landscapes with little variation;
- **Confinement:** small teams housed together for months;
- **Communication gaps:** limited contact with family and civilisation.

Such conditions mimic aspects of **space missions** and **submarine deployments**. The Indian Antarctic Program—run by NCPOR—thus doubles as a psychological research platform for understanding isolation's impact on cognition.

Earlier studies emphasised stress, sleep and mood. Few, however, examined **time estimation**, a subtler but powerful indicator of adaptation.

4. Research Objectives

The research set out to examine:

1. How **environmental isolation** alters subjective time estimation among expeditioners.
2. Whether **station context** (Voyage, Bharati, Maitri) produces measurable differences.
3. How **task method** (verbal vs. reproduction) and **duration** (short vs. long) influence accuracy.
4. What patterns emerge that may inform future expedition or space-mission planning.

Hypotheses

- Isolation would slow perceived time, leading to **overestimation** of intervals.
- Environments rich in social interaction (Voyage, Maitri) would **preserve temporal accuracy**.
- Short intervals would be **overestimated** and long intervals **underestimated**, consistent with prior cognitive findings.

5. Participants and Setting

A total of **57 Indian expeditioners** participated (age range = 24–63 years, mean ≈ 35 years), divided equally across the three locations:

Site	Description	Participants
Voyage	Ship journey from Cape Town to Antarctica – socially dynamic, physically active	19
Bharati Station	Newer base with smaller teams, higher isolation, intense workload	19
Maitri Station	Established base with larger community and structured routines	19

All were physically healthy and psychologically screened prior to deployment.

Testing occurred during the **Antarctic summer (January–April 2020)**, when 24-hour daylight prevails.

6. Methodology

6.1 Experimental Design

Two experiments employed a **split-plot factorial design**.

- **Experiment 1:**
  - o 3 Conditions × 2 Methods (Verbal Estimation vs. Reproduction)
  - o Single duration = 210 s (≈ 3.5 min)
- **Experiment 2:**
  - o 3 Conditions × 2 Durations (4 s and 210 s)
  - o Verbal estimation only

Both experiments assessed **accuracy and direction of error** (over- or underestimation).

6.2 Task Procedure

Participants observed lists of words on computer screens using a custom Visual Basic program.

Each list contained 30 items (15 animals, 15 fruits) presented for 4 s each, with 3-s intervals, producing total exposure ≈ 210 s.

Participants completed tasks under three **cognitive-load levels**:

1. *Low Load:* passive observation
2. *Medium Load:* respond only to fruit names
3. *High Load:* memorise all items

Immediately after viewing, they either **estimated** total duration verbally or **reproduced** it by pressing a key for the same duration.

6.3 Data and Analysis

Time judgments were expressed as **judged / actual duration ratio**.

- Ratio > 1 = Overestimation
- Ratio < 1 = Underestimation

Data were analysed using **ANOVA**, examining main and interaction effects, with Scheffé post-hoc comparisons at $\alpha = 0.05$.

7. Results

7.1 Station Differences

Station	Mean Ratio	Trend
Voyage	0.96 (SD 0.52)	Slight underestimation
Bharati	1.20 (SD 0.44)	Consistent overestimation
Maitri	0.87 (SD 0.32)	Most accurate

Statistics:

Condition $F(2, 55) = 3.87$, $p < 0.02$;

Method $F(1, 55) = 5.21$, $p < 0.02$.

Significant difference between **Bharati > Maitri ($p = 0.03$)**.

Interpretation:

Expeditioners at Bharati—experiencing greater isolation—felt time move slower, whereas those at Maitri and on Voyage, exposed to dynamic activity, judged durations more accurately.

7.2 Duration Effect

Duration	Mean Ratio	Direction
Short (4 s)	1.24 (SD 0.56)	Overestimation
Long (210 s)	1.07 (SD 0.43)	Near accurate

$F(1, 55) = 7.78$, $p < 0.001$ → **short intervals appear longer**—a universal bias.

7.3 Method Effect

Verbal estimation was **more precise** than reproduction, likely due to lower attentional demand and absence of motor delay.

These finding contrasts earlier European studies, underscoring the impact of task familiarity and fatigue under expedition conditions.

8. Discussion

8.1 Isolation Slows the Internal Clock

Isolation reduces sensory input and social stimulation, leading to **temporal dilation**—the brain's pacemaker seems to tick faster, generating more "time pulses."

At Bharati Station, smaller teams and longer solitary hours fostered boredom and self-awareness, lengthening perceived time.

Voyage participants, occupied with shipboard duties and camaraderie, experienced compressed, busier time.

8.2 Attention and Cognitive Load

High cognitive load expanded perceived duration, supporting *Ornstein's storage-size theory*.

Each cognitive event contributes to perceived length. When minds wander or under-engage, fewer markers accumulate, shortening perceived time.

Thus, **attention acts as a gatekeeper of time**—a central insight linking psychology and physiology.

8.3 Biological Rhythms and Light Exposure

Even in 24-hour daylight, circadian desynchronisation affects hormonal balance (melatonin suppression, cortisol shifts).

These physiological oscillations feed back into neural timing networks, explaining subtle cross-station differences.

Voyage participants, exposed to alternating indoor/outdoor light, likely maintained healthier rhythms than those in window-limited Bharati cabins.

8.4 Comparison with Global Research

Polar and space analog research—from *Palinkas (2003)* to *Tortello et al. (2020)*—reports similar distortions.

In Arctic or Antarctic overwintering crews, monotony and isolation exaggerate perceived duration; social engagement mitigates it.

8.5 Implications for High-Reliability Operations

In confined missions—polar, space, submarine, or offshore rigs—misjudging time affects:

- task sequencing and coordination;
- communication scheduling;
- sleep regulation; and
- perceived stress or workload.

Thus, maintaining temporal accuracy is essential for operational safety.

9. Broader Psychological Insights

9.1 Time as a Mirror of Mind

When external structure disappears, humans rely on internal pacing. This makes time perception an **index of mental state**.

Overestimation correlates with anxiety and vigilance; underestimation with engagement and flow.

By measuring time errors, psychologists can non-invasively monitor adaptation, stress and boredom in real-time.

9.2 Adaptive Mechanisms

Over successive weeks, many expeditioners informally reported that "days started to blend."

Such adaptation—blurring distinctions between hours—may be a protective cognitive adjustment, reducing emotional strain.

The mind simplifies experience to preserve stability, showing remarkable plasticity under stress.

10. Practical Recommendations

1. **Structured Daily Routines:**

   Maintain consistent schedules for meals, work and rest to reinforce temporal anchors.

2. **Light Management:**

   Use artificial dusk/dawn lighting to simulate natural circadian cues.

3. **Social Interaction:**

   Encourage group recreation and shared responsibilities to synchronise social clocks.

4. **Cognitive Engagement:**

   Introduce mental challenges—learning modules, reading, creative projects—to maintain attentional flow.

5. **Psychological Monitoring:**

   Incorporate short digital time-estimation tests in crew health protocols; deviations may flag emerging isolation stress.

6. **Training Before Deployment:**

   Educate expeditioners on psychological effects of monotony and provide coping strategies, including mindfulness and structured reflection.

11. Limitations and Future Work

Despite its strong design, the study faced logistical constraints:

- Sample limited to 57 participants.
- Conducted during **summer only**—future winter data could reveal stronger effects.
- Emotional correlates (stress, loneliness) not quantitatively measured.
- Cultural homogeneity—mostly Indian participants—may limit generalisation.

Future research should integrate **neurophysiological tools** (EEG, actigraphy, heart-rate variability) and **qualitative diaries** to map emotional texture of temporal experience.

12. Relevance Beyond Antarctica

12.1 Space Exploration

Space missions replicate Antarctic isolation—restricted crew, confinement, altered light cycles.

Distorted time perception could impact:

- mission scheduling;
- communication timing with Earth;
- psychological endurance.

Insights from this research directly inform astronaut-training protocols and habitat design.

12.2 Submarines and Offshore Platforms

Crew members operating in windowless underwater environments exhibit comparable circadian disruption.

Implementing structured lighting and group routines based on Antarctic findings can mitigate cognitive fatigue.

12.3 Remote Scientific Stations

With climate research expanding into polar zones, ensuring psychological resilience becomes vital for sustained operations.

13. Integrative Framework

A **tri-layer model** linking environment, cognition and emotion:

Layer	Key Elements	Observable Outcome
Environmental	Light cycles, temperature, isolation	Biological rhythm drift
Cognitive	Attention, memory, task load	Time estimation distortion
Emotional	Mood, boredom, social contact	Temporal bias magnitude

This integrated model provides a foundation for designing interventions—environmental (lighting), cognitive (task variation) and social (group cohesion)—to maintain psychological equilibrium in extreme missions.

14. Concluding Reflections: Integrating Law, Engineering and the Human Clock

In engineering disciplines, precision in timing defines reliability. Similarly, in psychology, precision in perceived time defines mental harmony.

The Antarctic study reaffirms that **time perception is both a physiological rhythm and a social construct**, constantly negotiated between body, brain and environment.

Key Lessons:

1. **Isolation dilates time**—the quieter the mind's environment, the slower its clock ticks.
2. **Engagement contracts time**—purpose and social interaction restore rhythm.
3. **Circadian alignment safeguards cognition**—artificial cycles can substitute for natural sunlight.

4. **Simple cognitive measures reveal deep adaptation**—how we estimate seconds can foretell resilience or strain.

As humankind ventures farther—from polar ice to lunar bases—the science of subjective time becomes more than academic curiosity. It becomes **a necessity for survival in confined frontiers**.

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About the Author

Prof. Azizuddin Khan, is currently the Head, Psychophysiology Laboratory, Department of Humanities and Social Sciences, Indian Institute of Technology Bombay, Mumbai. Prof. Khan's research bridges neuroscience, psychology and human factors engineering. His Antarctic work contributes to India's pioneering efforts in understanding cognitive resilience in extreme environments—offering lessons for polar explorers, astronauts and anyone who has ever felt time stand still.

Email: khanaziz@iitb.ac.in

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COMARSEM 2026 organized by **IMEI Kochi** branch in association with **DG Shipping**

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- Developing maritime clusters to address emerging challenges indigenously
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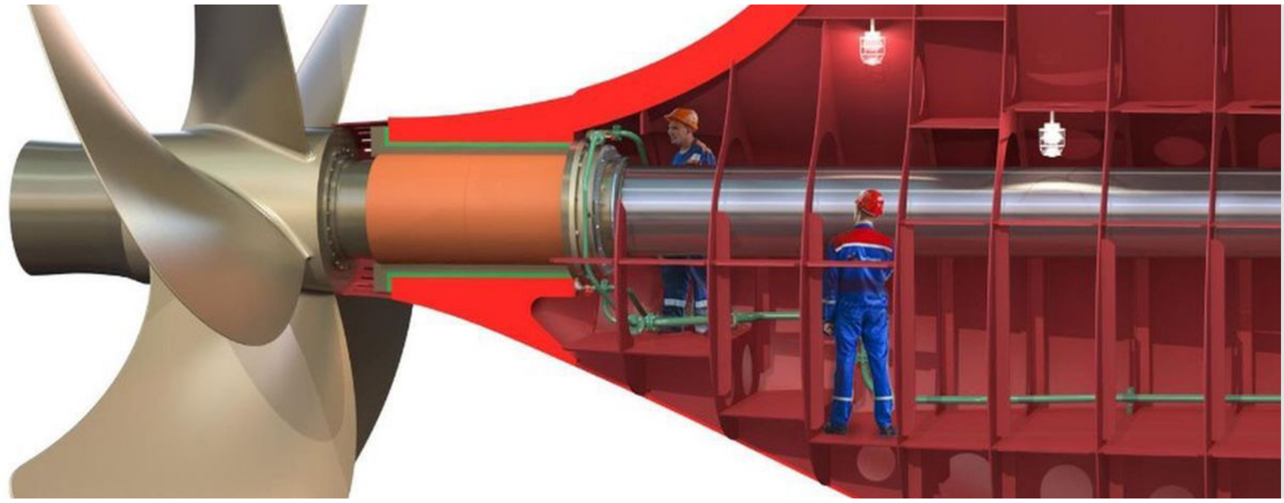
Water Lubricated Stern Bearing



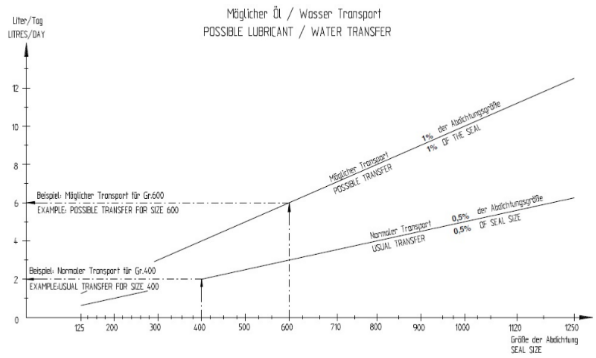
Ashesh Y Garg

Abstract: Water lubricated stern bearing with Elastomeric/composite material and modified stern boss design having a single stern bearing eliminating the stern tube cylinder as seen in a conventional Oil lubricated bearing design. The new design gives advantage to lower/ same capital investment as compared to an oil lubricated conventional stern tube design during the new building stage. No risk of oil pollution from the stern tube/ seals, lower operating costs in terms of spares and fuel saving due to reduced frictional drag at the stern bearing, reduced time during the docking of the vessels and last but not the least the overhaul of the stern bearing can be done in floating condition to the extent of replacing the bearing.

Introduction

The majority of the vessels in the current age are installed with Oil lubricated stern tube having stern sealing system with lip seals at the aft when using mineral oil, The lip seals will always migrate some amount of fluid across the seals and there is some oil leakage that is happening even with a fully functional seal system, some makers like SKF have defined the rate of leakage across the seals which is shown in the graph below which is considered as acceptable depending on the shaft diameter.

> *No risk of oil pollution from the stern tube/ seals, lower operating costs and fuel saving due to reduced frictional drag at the stern bearing*



In the current times where we have regulation and governing bodies like EPA (Environmental protection agency) of USCG who have defined the design of the seals to prevent oil /water interface with a neutral chamber of air (Air guard design) that are to be applied when using mineral oil as lubricant for the stern bearing or use of Environmentally friendly Lubricating oil (EAL) which is made from Plant based products.

Both the above designs of lubricating the stern bearing and seals suffer with complexities, it is worthwhile to mention deliberate pollution of EAL in the sea is still considered as pollution by the EPA (USCG) and have stated on means to adopt water lubricated stern tube in the future to eliminate Oil pollution at sea.

Water lubricated stern bearings have been in use since 1874 on SS Britanicia, using Lignum Vitae (type of wood) as bearing material having shaft protected with a bronze liner in the past. However, due to corrosion effect of sea water on the liner and inspection required by class which required periodic removal of the shaft for inspection of the liner. The oil lubricated bearing was a better choice with condition-based monitoring of the stern bearing where it is practically not required to withdraw the tail shaft as that was required for a water lubricated stern tube bearing.

With the development of composite materials, the bearings makers such as Kemel, SKF, Wartsila, Thordon etc have on their product list bearings that can with stand

bearing pressure support boundary lubrication and hydrodynamic lubrication with water as lubricant.

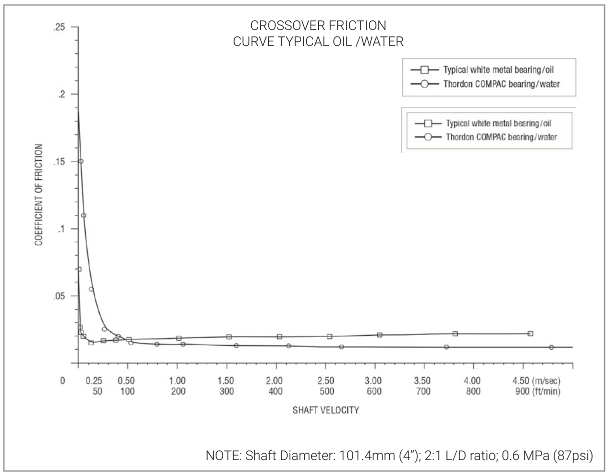
COMPARISON OF OIL AND WATER AS LUBRICANT FOR THE STERN BEARING

Sno	Water Lubricated stern bearing	Oil lubricated stern bearing
1	Viscosity of water 1 cSt at 20 deg centigrade / 0.63 cSt at 40 degrees centigrade	68 cSt at 20 degree centigrade / 25 cSt at 40 degrees centigrade
2	Thermal conductivity of water 0.6 W/m K	Thermal conductivity of Oil 0.152 W/m K
3	Specific heat at 20 degrees centigrade is 1J/Kg Deg	Specific heat at 20 degrees centigrade 0.44J/Kg Deg
4	Frictional Drag is less 11 percent when compared to oil	
5	Bearing Type that can be applied –composite with a bearing pressure of 0.6 MN/m2	Bearing type that can be applied – white metal / composite with a bearing load of 0.8MN/m2
6	No Pollution risk	EAL is also a considered as pollution.
7	Cheap and readily available all over the globe	Must be procured and stored specifically EAL are 10 time more expensive than the mineral grades

Water has its clear advantages as a Lubricant with better heat transfer and thermal conductivity.

It however has the following discredits to be used as a lubricant.

1. Does not support for boundary lubrication as compared to oil till the hydrodynamic lubrication is set in with higher shaft speeds.
2. The sea water which is used as lubricant is corrosive to the other parts of the shafting which will need to be protected.
3. The sea water will need to be treated to remove mud and other particles that could damage the bearing.



NOTE: Shaft Diameter: 101.4mm (4”); 2:1 L/D ratio; 0.6 MPa (87psi)

TRIBOLOGY: Tribology is the scientific study of friction, lubrication, and wear. It is derived from the Greek word “Tribos” which means “to rub”.

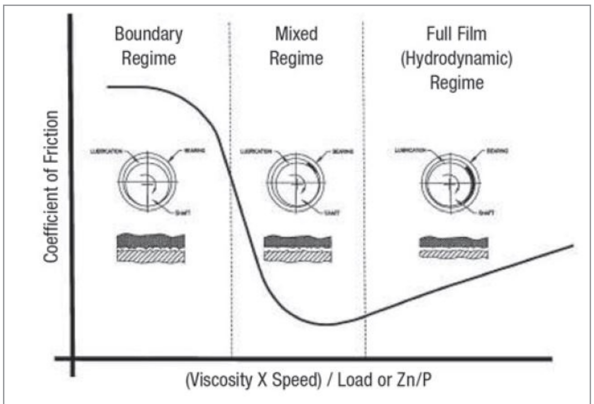
Friction:is usually defined as a force that resists the motion of an object. With a water lubricated bearing, friction occurs when a shaft applies a load to a bearing. When the shaft turns, the friction between the shaft and bearing resists the rotation and therefore a certain amount of torque is required to keep it turning. This torque does not do any useful work and is converted into heat. The magnitude of the friction force F_f is dependent on a value called the coefficient of friction (μ) and the ‘normal’ applied load (N).

The relation is as follows: $F_f = \mu N$

Because the composite bearings like many other synthetic bearing materials, is a poor conductor of heat, the dissipation of frictional heat is a significant consideration in bearing design. Thus, if the load on the shaft is increased, then the friction force will increase, along with the frictionally generated heat. If the heat cannot be dissipated to a large heat sink or through a lubricant, the surface temperature of the bearing will rise.

The figure above demonstrates the results of testing with a Thordon COMPAC water lubricated bearing and a typical oil lubricated white metal bearing. The oil lubricated bearing starts with a lower friction level, which then drops very rapidly to its lowest friction level before slowly climbing back up.

Lubrication: The friction force for water lubrication starts higher because of water’s poor lubricity and requires a higher speed to achieve hydrodynamic operation. This is due to the low viscosity of water. An interesting observation is that in the high-speed range, the water lubricated frictional force is lower than with oil. Once hydrodynamic operation is achieved, friction increases. However, the higher viscosity of oil results in greater shearing forces and higher friction than with water combined with the greater cooling effect of water results in a bearing running at a lower temperature as compared to that with oil lubrication. This is illustrated by a typical "Stribeck curve" which plots the coefficient of friction against the hydrodynamic parameter Zn/P. The curve is divided into three main lubrication regimes.



The Stribeck curve, illustrating the buildup of hydrodynamic film

In the first (Boundary) regime, direct contact exists between the shaft and the bearing resulting in high friction values. In this region of the curve, high bearing self-lubricity is of significant benefit. As the shaft speed increases, we move into the second (Mixed) regime of the curve where the hydrodynamic film starts to build and effectively "lift" the shaft from the bearing surface. The result is less shaft to bearing contact and friction drops rapidly. Further increases in speed take us into the third (Hydrodynamic) regime where the hydrodynamic film builds sufficiently to eliminate all direct contact. As speed continues to increase, friction begins to increase because of the increasing shear resistance imparted by the viscosity of the lubricant. The transition between lubrication regimes during operation of a bearing depends primarily on lubricant properties, velocity, and load. The curve profile and definition of transition points will depend on the bearing geometry, clearance ratio, self-lubricity of the bearing material and surface finish. A higher viscosity lubricant results in the generation of a hydrodynamic film at a lower shaft speed and effectively moves the transition points to the left. Increasing the viscosity, however, also increases the minimum operating coefficient of friction. Lowering the coefficient of friction of the bearing material results in decreased friction at shaft speeds below the point where full hydrodynamic operation occurs. The geometry of the bearing, and, whether the bearing is grooved also affects the curve. A continuous bearing surface without grooves allows the hydrodynamic film to build quicker than one with grooves. Hydrodynamic calculations show that the necessary speed to achieve

> ***Water has its clear advantages as a lubricant with better heat transfer and thermal conductivity***

a hydrodynamic film is double that for an ungrooved bearing. Wet lubrication also has the added benefit of being able to carry away frictionally generated heat, the enemy of all bearings. This is especially significant with all the bearing makers because the low thermal conductivity of the material does not allow much heat to be dissipated through the bearing wall (metallic bearings have much higher thermal conductivity and can dissipate more heat through the bearing wall). Wet lubrication can be supplied by several methods varying in complexity and performance. There are drip feed systems (normally oil), which are appropriate for slow to intermediate speeds where heat buildup is not a concern. Bath systems are also used - where the bearing is fully or partially submerged in a limited quantity of lubricant. The limiting factor with bath systems is that the whole bath can become overheated if the assembly generates significant heat. A third method is a continuous flow of fresh cool lubricant from an external source, usually force-fed. This method is essential for applications such as marine propeller shafts, vertical pumps and turbines where high RPM and/or significant loads lead to levels of heat generation which cannot be dissipated by a bath of lubricant.

Wear: Wear is the destructive removal of material from contacting surfaces moving relative to one another. Wear can take several forms and, as a highly complex process, is difficult to predict.

i) Adhesive Wear: Adhesive wear occurs when minute peaks of two rough surfaces contact each other and weld or stick together, removing a wear particle. Adhesive wear of composite/elastomeric bearing materials is very minimal at normal temperatures and pressures but becomes the dominant wear mode as the operating temperature reaches maximum operating limits. The maximum operating temperatures of bearing materials are defined to try and avoid this mode of wear. The amount of adhesive wear is related to the friction between the two surfaces, the pressure on the working surface, and the type and amount of lubrication provided.

ii) Abrasive Wear: Abrasive wear involves the wearing of a softer surface by a hard particle. Examples are sandpaper or a grinding wheel (two body abrasion) or sand particles between a bearing and a shaft (three-body abrasion). Actual abrasive wear will vary with the quantity of abrasives present and with the size, shape, and composition of the abrasive particles. The best approach to minimizing abrasive wear is to reduce or

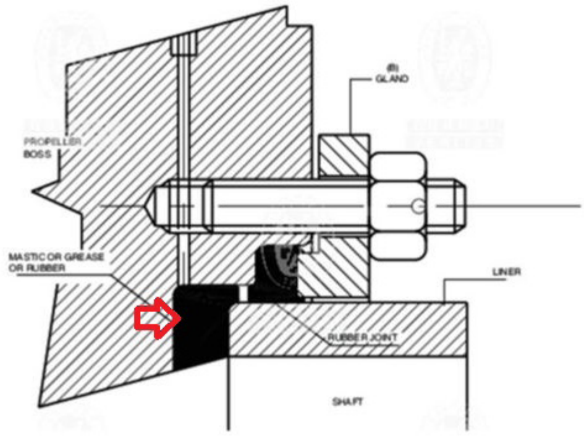
> *Wet lubrication also has the added benefit of being able to carry away frictionally generated heat, the enemy of all bearings*

eliminate the quantity of abrasives by using filters or clean water injection. If this is not possible, then a satisfactory alternative for minimizing abrasive

wear is to have one surface very hard and the second relatively soft and compliant. Abrasive particles are allowed to be pushed into the softer surface and roll or slide through the contact area with very little damage to the shaft or bearing. The elastomeric nature of bearings facilitates abrasive wear resistance because the material flexes when it encounters abrasive particles. With shaft rotation the particles are moved along the bearing surface until flushed out through a lubrication groove. With more rigid materials the abrasive particles tend to become embedded in the material and may cause shaft wear. A continuous flow of fresh lubricant (as in a propeller shaft application), and grooves in the bearing, will help to flush out abrasive particles and reduce the amount of wear.

SYSTEM DESIGN: Companies Like Wartsila and Thordon have come out with a design concept where the stern tube is eliminated from the design and the stern boss casting is modified to accommodate the stern bearing. The design concept is the same however this is named the EVOTUBE by Wartsila and T-BOSS by Thordon.

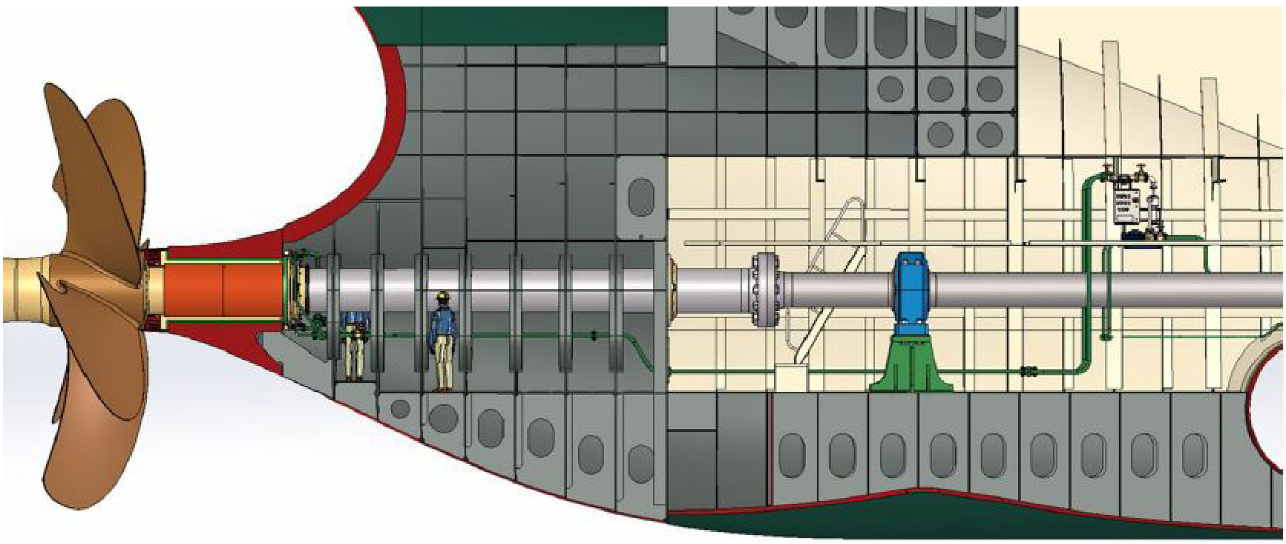
The design is such that it can be applied to the new building of the vessel. however, would face challenges to retro fit on existing vessel as the stern boss casting will need to be modified which is easily done at the new building. There is no limitation on the application of this design on the size of the vessel and can be applied to large as well as small vessels. The design of the water lubricated stern bearing would require only one forward seal in the engine room and sea water for lubrication of the bearing is fed from the engine room using a sea water treatment plant with filters to ensure uniform water quality. The shaft in way of the bearing is protected with a bronze/Epoxy liner which is sealed at the propellor boss as per drawing which is shown below.



The Liner can be inspected as required in service using an endoscope without the need to withdraw the tail shaft.

The aft of the bearing is installed with an inflatable seal which is retracted when in service and can be inflated on a stationary shaft when the vessel is afloat to allow persons to work from the engine room side on the forward seal overhaul or bearing overhaul.

The bearings installed are of the elastomer / composite type having a length to diameter ratio of 2:1 and bearing pressure of 0.6 MN/m2 whereas for class calculation it is considered at 0.55 MN/m2. The forward stern tube bearing is in the engine room like the other intermediate bearings of the shafting system. The aft stern tube bearing is installed with tapered key design in segments where the lower half is without grooves for better hydrodynamic



lubrication. The tapered key design enables the bearing segments to be withdrawn into the engine room during the overhaul of the bearing and thus enabling the renewal of the bearing without the need to withdraw the tail shaft.

The propellor weight will need to be supported using external hooks to enable withdrawal of the bearing.

The aft section of the ship will be designed with framing to enable access the stern bearing from the engine room, this design enables a shorter engine room where the main engine is positioned closer to the propellor thus giving the advantage of larger cargo space as compared to a vessel with conventional stern tube design thus improving the Energy efficiency design Index (EEDI) of the vessel.

The Design is patented by Wartsila additionally Thordon bearing Inc, ABS, the design house the Shanghai merchant Ship Design and Research Institute (SDARI) and the National Technical University of Athens have collaborated to bring forward the design, ABS has in principle granted approval to the design.

In addition, a shorted shaft line with one less bearing implies a different dynamic behaviour both in terms of torsional vibration as well as lateral vibration, known as whirling. To compensate for whirling, the intermediate bearing must also move afterwards so that the bearing span is acceptable as far as whirling vibration is concerned. While keeping the engine intact, the shorter shaft line would increase the torsional stiffness of this system and therefore the barred speed range would increase. The torsional stiffness of the system and therefore the barred speed range would increase towards higher rpm, together with higher torsional vibration amplitudes and stresses on the shaft line. Depending on the power train technical characteristics, such a reduction in length could cause the torsional stresses to exceed the IACS transient shear stress limit. Therefore, the installation of a torsional damper may be considered. The additional mass , inertia and damping coming from the torsional damper installation decreases the torsional vibration amplitudes, potentially to an extent that the barred speed range may be eliminated.

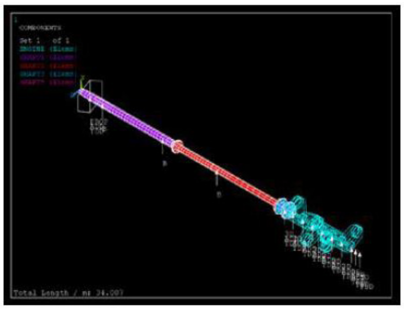
The elimination of the stern tube cylinder casting together with its piping and oil storage tank, opens up a new space which together with the trimming of the stiffeners around it, can create new chamber with sufficient size to allow for human inspector entry to a temporary opening in the bulkhead of the engine room. Such an inspection chamber would serve the purpose of shaft line inspection, seal inspection, aft bearing inspection and bearing replacement from inside the vessel, while the vessel is afloat. Such an installation would eliminate shaft line withdrawal, while the vessel is afloat.

SHAFT ALIGNMENT: ABS has studied the shaft alignment for a 3800 TEU container vessel which is described below. According to class rules the shaft line is subjected to satisfactory shaft alignment. An independent model is created for the original design using in house ANSYS customized finite element software. Based on the standard engineering procedure and practices for plan approval. The mathematical model is solved and post processed using static steady state analysis to determine the bearing reaction loads, the shaft inclination and relative misalignment angles between the shaft and the bearings. The modeling involves 6 degree of freedom pipe type of elements with shear effect to model intermediate and tail shaft, while the propellor is modeled as a thin disc with mass and inertia of propellor as per pertinent original plan. The engine crankshaft is geometrically modelled by meshing the crankshaft as a solid model and converting it into super elements using the sub structuring technique. The bearings are modelled as linear spring -damper elements with radial stiffness and damping and gap as clearance. All additional weights (crank throw weights, chain forces, etc.) are modelled as point loads. The bearing reactions are assessed based on the ABS Rule limits as well as the bearing maker limits. The same applies for shaft inclination as well as misalignment angles. More detailed bearing modeling on the Fluid Structure Interaction (FSI)between the oil or water film between the shaft and the bearing is performed to ensure that metal to metal contact of film breakage, which would cause increase bearing wear or even damage and failure, is avoided.

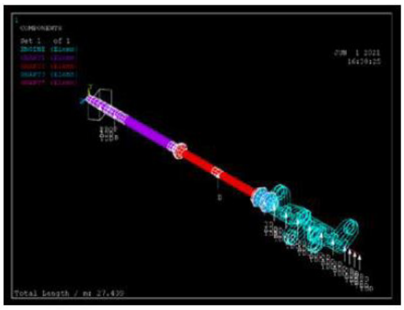
The aft of the bearing is installed with an inflatable seal which can be inflated on a stationary shaft when the vessel is afloat

To validate the proposed model the initial simulation is carried out for the original design which contains 2 stern tube oil lubricated bearings. The results are compared to those of the shipyard during the original plan approval process. Once the comparison is satisfactory the proposed modification is implemented on the model, namely, the shortening of the shaft and the move of the Main Engine afterward by 2m, as well as the elimination of the forward stern tube bearing and the replacement of the aftmost oil-lubricated bearing with a water lubricated bearing.

See figure shown below.



Original Design

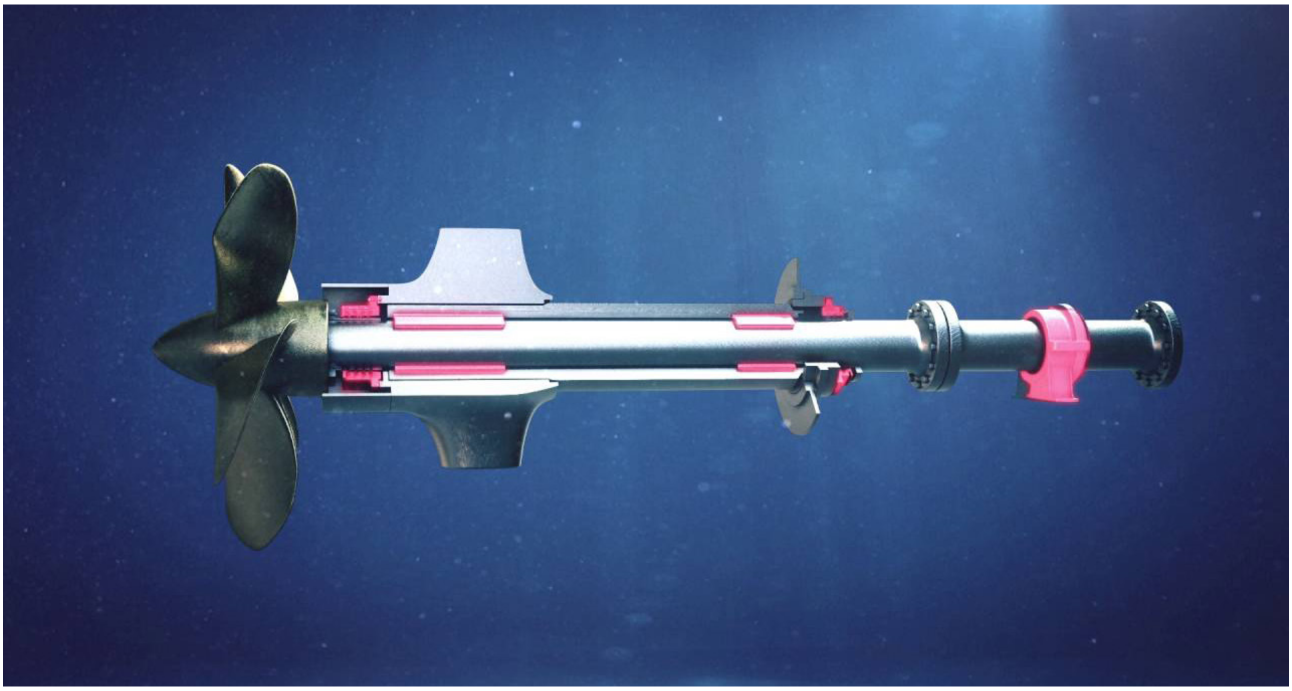


Shortened Design

The shaft alignment of the modified design was carried out including hot static and cold static as well as dynamic conditions including propeller loads for port and starboard vessels turning, for various propeller depths. Hull deflections were also considered in the analysis, as per the ABS Rule requirements for drydock or lightship, ballast and laden conditions. The bearing offsets both those of the shaft line and of the engine were optimized for best possible bearing load distribution using an ABS inhouse proprietary genetic algorithm for mathematical optimization. The result showed that for the modified design, all the bearing loads were well within acceptable limits including misalignment angles below IACS limits of 0.3 mrad. An FSI also confirmed that the water film pressure distribution was acceptable as well as the thickness under all loading conditions.

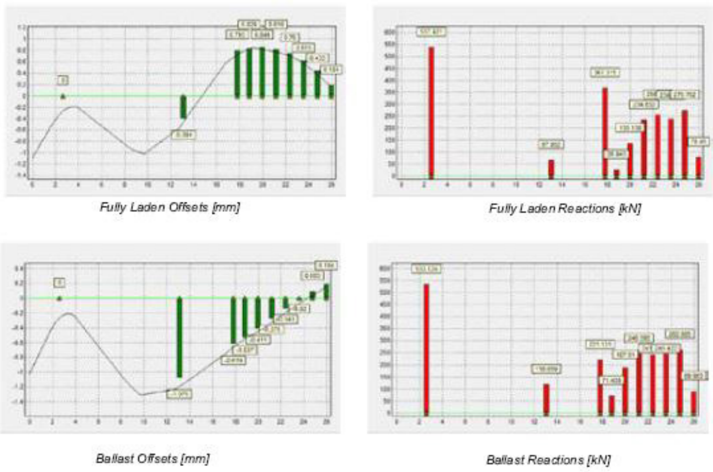
The criterion of the "Engine shear force -bending moment envelope" was also examined and was found to be within the engine maker's limits. To examine the possibility of accelerate bearing wear during the operational life of the vessel , a sensitivity analysis was conducted considering the bearing loads as well as misalignment angles for zero and maximum wear down of the aft most bearing (10-15 mm) , throughout the analysis the bearing load and misalignment angle values were found to be satisfactory both in terms of makers limit and ABS Rule limits.

All in all, a total win-win design which should be our industry standard going forward



• Shaft Alignment Optimization

	Optimised Drydock offsets [mm]	Fully Laden Hot Static Offsets [mm]	Ballast Hot Static Offsets [mm]
ASTB	0	0	0
I/M Bearing	0	-0.394	-1.075
M/E 1	-0.146	0.792	-0.619
M/E 2	-0.146	0.828	-0.536
M/E 3	-0.146	0.846	-0.41
M/E 4	-0.146	0.816	-0.276
M/E 5	-0.146	0.75	-0.143
M/E 6	-0.146	0.615	-0.02
M/E 7	-0.146	0.433	0.092
M/E 8	-0.146	0.184	0.184



All bearings are positively loaded and within their maker's limits

VIBRATION: The vibration assessment involved torsional, lateral, and axial vibration of the modified shaft line. The original design features a critical speed at about 47 rpm, where the tail shaft and intermediate shaft stresses exceeded the IACS continuous torsional stress limits and thus a barred speed range for torsional stress was imposed.

CONCLUSION: The design offers several advantages as compared to the conventional stern tube design with aft

and forward seals. The most obvious and important ones being on the zero-oil pollution risk and ability to overhaul the seals, bearings without the need to the vessel to go on blocks and replacement of the bearing can be done in a time frame of 24 hours. The initial capital cost of the system is the same as that for a conventional oil lubricated stern tube system however there is a reduction in operating and overhaul cost as lesser number of seal parts are required for the system and saving in cost of the LO. There is also a fuel saving potential which is calculated basis the losses seen due to the frictional drag of the LO as compared to that of water for a water lubricated stern bearing. For a typical 950 mm shaft the annual saving in the fuel cost is 50000 US Dollars. Also, the composite/ Elastomeric bearing that are produced have zero carbon emission during production which is not the case with white metal bearings. All in all, a total win-win design which should be our industry standard going forward.

ACKNOWLEDGEMENT

My colleague Mr Klaus Jorgensen (Senior marine Engineer) in our new building machinery team who is a Pioneer in this field and we have been working together for last 5-6 years on the concept of water lubricated bearing design.

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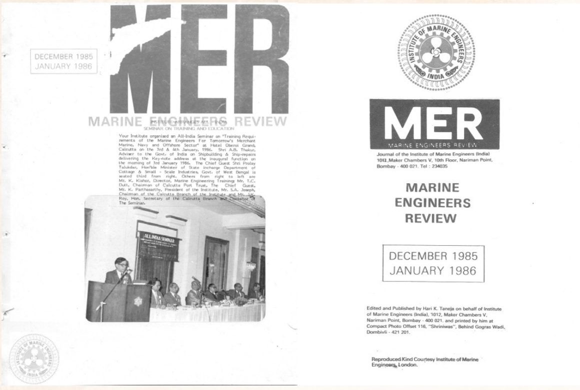
[4] ABS Enhanced Shaft Alignment Guide 2015, 2022.

About the Author

Ashesh Y Garg, is a Seniour Machinery Specialist in Fleet Technology, Maersk Line Fleet Management and Technology.

Email: ashesh.garg@maersk.com

Going Astern into MER Archives...



The Editorial **"What Do the Engineers Read"** critically examines how the marine engineers keep themselves updated with what is happening in technological advances in their world so as to avoid obsolescence? This is very relevant even today! The editorial examines the **reading habits** and **intellectual curiosity** of marine engineers in the 1980s. The author observes that while engineers expertly handle complex machinery, few show genuine interest in studying beyond operational manuals or company instructions. This lack of engagement, he argues, stems not from inability but from a **shipboard culture focused on routine performance rather than learning.**

The study mentioned in editorial states that engineers get their information of upto 45% through their contacts, 28% through customers, 12% through formal literature, 10% from company research! The Editorial laments that **most professional engineering journals** are written in a **very mathematical tone** far removed from practicing engineers in the real world. This mathematical presentation makes these journals utterly incomprehensible for the practicing engineer! However, on a happy note, the MER(I) has stayed close its objective of being easily comprehensible to marine engineer!

Micro-Organisms in marine fuel: Fouling and Corrosion

by E C Hill & G C Hill

This paper examines how bacteria, yeasts and fungi thrive at the fuel-water interface in ship fuel tanks, leading to sludge formation, filter blockage and microbially influenced corrosion (MIC). These organisms degrade hydrocarbons, produce organic acids and hydrogen sulphide, and accelerate pitting and tank-bottom corrosion. The authors stress that microbial contamination arises mainly from water bottoms and poor housekeeping. Regular water drainage, fuel monitoring and biocide use are essential preventive measures to maintain fuel quality, engine reliability and structural integrity of marine fuel systems.

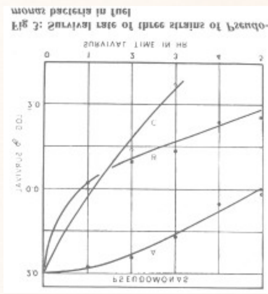


Fig 3: Survival rate of three strains of Pseudomonas bacteria in fuel

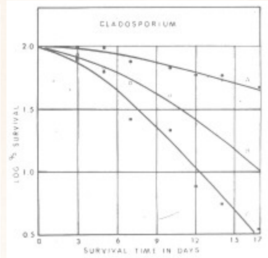


Fig 4: Survival rate of three strains of the fungus *cladosporium*

Table 1: Distribution of viable micro-organisms in fuel and associated water

Fuel sample	*No of oganisms in water (ml)*			*No of organisms in fuel (ml)*		
	Bacteria	*Yeasts*	*Fungi*	*Bacteria*	*Yeasts*	*Fungi*
M1	42 000	1200	100	2	51	10
M2	1740	2750	50	0	26	0
M3	17 000	7900	2350	1	122	1
L1 (CO)	290 000	150	0	0	66	1
A8	40 000	6400	0	0	7	0
A9	1600	300	50	1	3	1

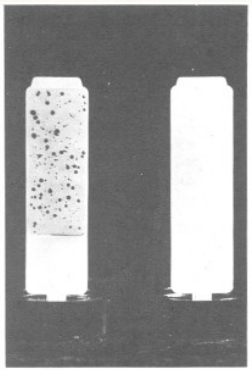
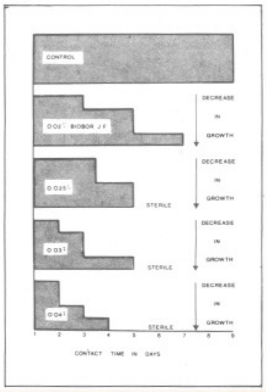


Fig 5: Dip slides showing (left) 10^7 bacteria/ml detected after 24h incubation (right) fuel proved negative.

Fig 6: Anti-microbial activity of Biobor JF



From their work, practical measures include:

- Good housekeeping: Maintain clean fuel tanks, remove water bottoms regularly, avoid contamination during bunkering, ensure tank vents, fuel water separators are functioning.
- Water removal: Regularly drain free water, inspect for sludge/biomass at tank bottom, sample interface for microbial presence.
- Fuel system design: Minimise areas where water can accumulate or interface between water/fuel exists; avoid stagnant zones; ensure floating suction draws clean fuel.
- Fuel quality control: Monitor fuel for microbial contamination (e.g., microbial counts, ATP assays, visual inspections for slime), particularly after long storage or bunkering events.
- Biocide usage + monitoring: Where microbial contamination is detected, apply approved biocides per manufacturer instructions; however, avoid indiscriminate use (resistance, sludge release).

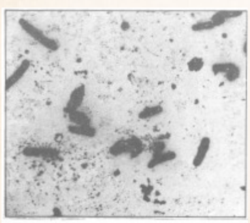


Fig 1: Bacteria in fuel water-bottom (×3750)

Fig 2: Fungi prolificating in fuel sludge (×375)

- Corrosion monitoring: Inspect tanks/piping for signs of MIC (pitting, under-film corrosion, sludge accumulation), particularly in water bottoms.
- Fuel additive/tracking changes: Recognise that changes in fuel composition (bio-blends, low sulphur fuels) may increase microbial risk; ensure compatibility of additives and monitor microbial activity accordingly.
- Sampling and analysis protocols: Develop routine sampling of water bottoms, fuel/water interface, tanks surfaces; record microbial counts/trends; integrate into preventive maintenance programmes.

Reducing Boil-off rates from Membrane type LNG carriers

By E Verschuur, W S Wayne, P J C Le Nobel, Y Shibamura, Shell International Marine

The paper investigates methods to reduce cargo boil-off in membrane-type LNG carriers, addressing the unavoidable evaporation of liquefied natural gas (LNG) caused by heat ingress through insulation and tank structures. The authors present laboratory investigations and full-scale vessel data to quantify boil-off rate (BOR) influences, particularly focusing on membrane-type containment systems. Key findings include that optimising insulation thickness, limiting thermal bridges (e.g., from support structures), enhancing tank pre-cooling and reducing vapour space heat input can substantially lower BOR. The study reports that better control of ambient and tank-wall heat flux, combined with operational strategies such as minimising voyage time and managing cargo filling levels, can reduce LNG losses and improve energy efficiency. The paper emphasises siting of structural supports and insulation continuity as critical design factors for reducing boil-off in membrane-type carriers.

Fig 1: Gaztransport containment system.

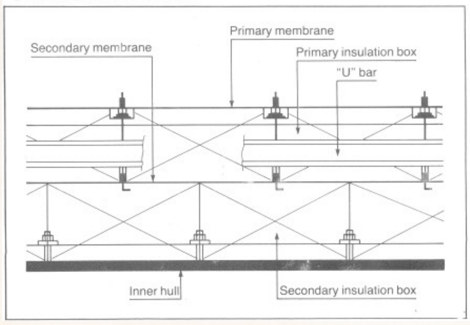
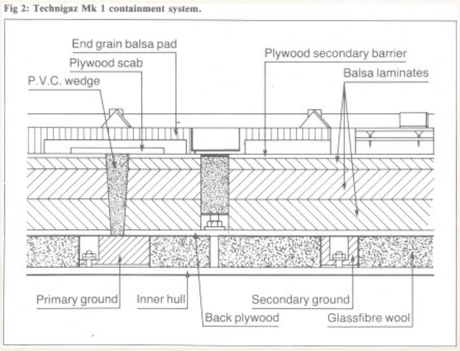


Fig 2: Technigaz Mk 1 containment system.



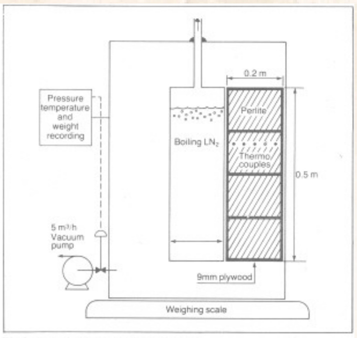


Fig 3: Six element Gaztransport test rig.

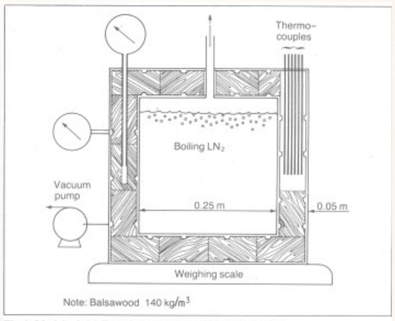


Fig 4: Model of the Technigaz Mk 1 containment system

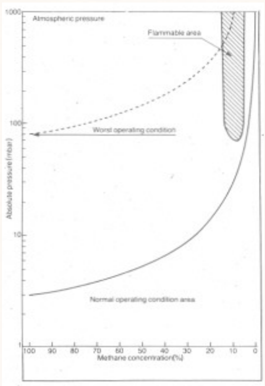


Fig 5: Effect of rig ingress on flammability of insulation space.

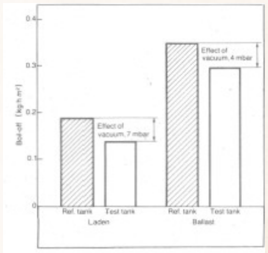


Fig 6: Effect of vacuum, averaged *Genota* data.

The study concludes that reducing boil-off rates in membrane-type LNG carriers requires an integrated approach combining improved insulation design, minimised thermal bridges, and optimised operational practices. Through enhanced containment efficiency and better heat-flux management, LNG losses can be significantly reduced, improving voyage economy, cargo retention, and the overall energy performance of LNG transport.

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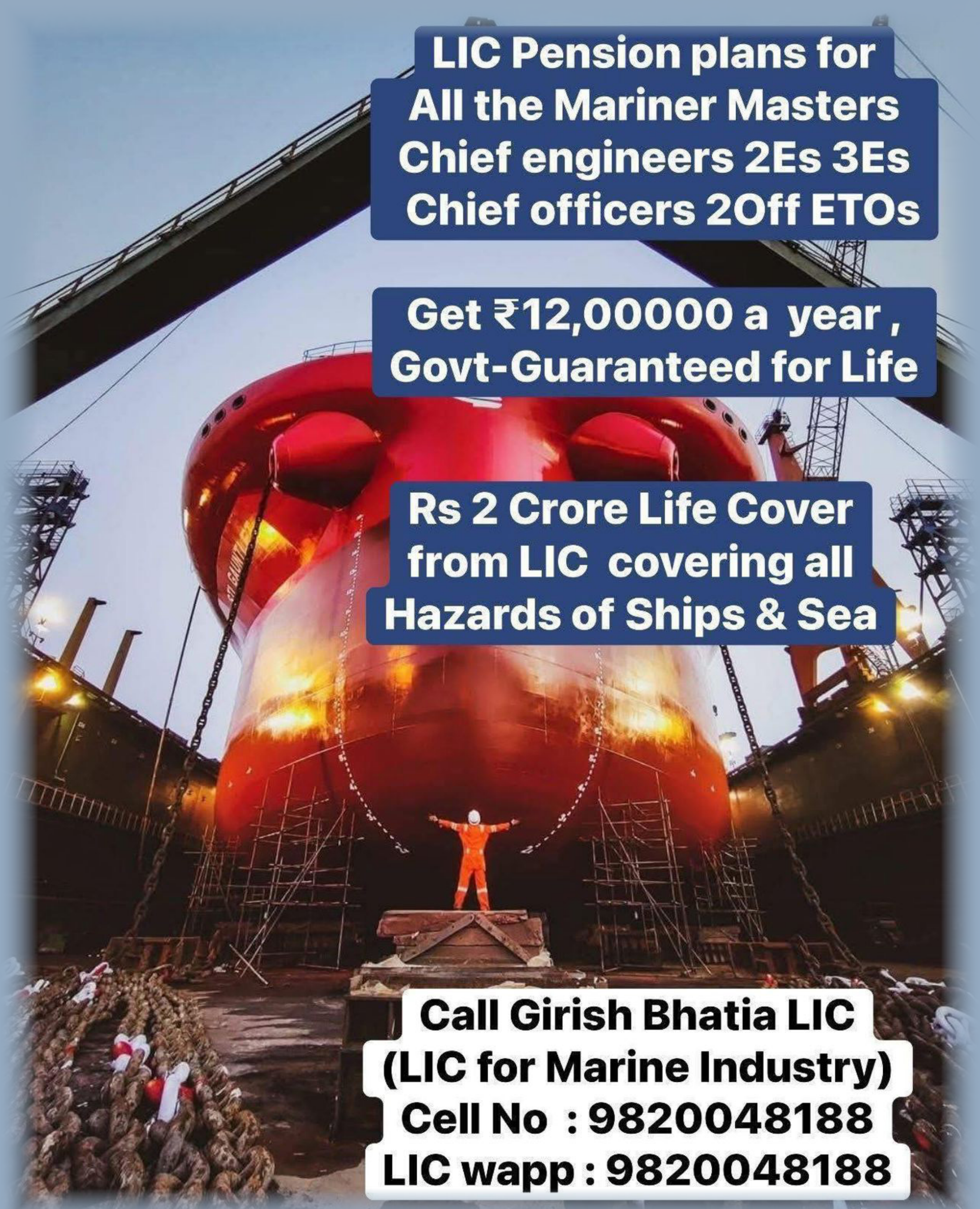

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