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Dynamic Behaviour of Cylindrical Shells Immersed in Fluid Media

Mrs. Pallavi M. Khatavkar[1], Mr. Om U. Chavande[2]
[1]*Professor, Department of Civil Engineering, SCOE, Pune*
[2] *M.E Structural Engineering, Department of Civil Engineering, SCOE Pune*

Abstract: The Submerged Floating Tunnel (SFT) emerges as an innovative and futuristic alternative for underwater transportation, offering enhanced connectivity across deep and wide water bodies while preserving the natural beauty and functionality of marine ecosystems. Its development represents a pioneering solution in civil and marine infrastructure, integrating advanced structural and hydrodynamic principles. The structural design of an SFT is inherently a multidisciplinary challenge, involving elements from structural engineering, fluid mechanics, hydrodynamics, marine engineering, and finite element analysis (FEA). This study investigates the dynamic behaviour of a submerged cylindrical shell, simulating an SFT, under the influence of underwater explosion loading. Using advanced simulation tools within ANSYS software, multiple design configurations were analyzed to evaluate the tunnel's structural response in terms of deformation and stress distribution. By systematically varying tunnel length, tether spacing, and tether angle, this project aims to identify optimal configurations that minimize damage and enhance the stability of SFT systems under extreme dynamic loading conditions.
Keywords: Submerged Floating Tunnel, structural engineering, fluid mechanics, hydrodynamics.

I. INTRODUCTION

The objective of this research is to analyze the structural behaviour of a Submerged Floating Tunnel (SFT) when exposed to dynamic loads resulting from underwater explosions. Utilizing the advanced simulation capabilities of ANSYS, the project seeks to simulate and understand the effects of such shock events on the tunnel structure. The primary aim is to evaluate how varying key design parameters — specifically tunnel length, tether spacing, and tether angle — influence the dynamic response, including deformation, stress distribution, and overall structural stability.

The Submerged Floating Tunnel concept, also known as an Archimedes Bridge, represents a novel approach to crossing deep water bodies without interfering with surface navigation or marine habitats. However, given its submerged and flexible structural system, the SFT is inherently vulnerable to dynamic forces, particularly those originating from underwater explosions or seismic events. Hence, understanding its response to such loads is crucial to developing robust, safe, and efficient design frameworks for future implementation.

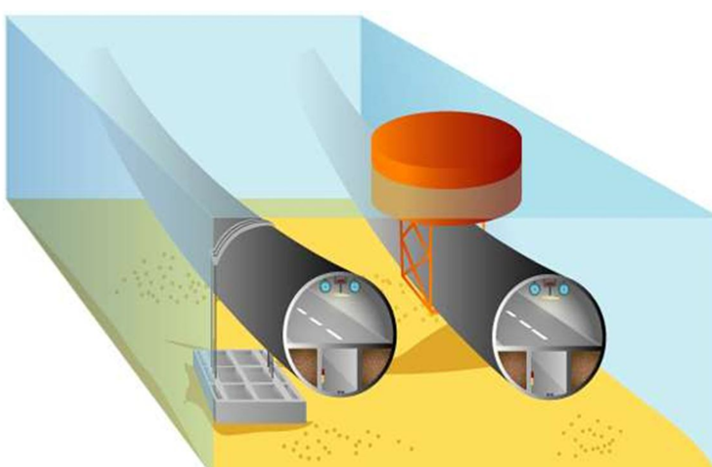

Fig. 1 Typical Figure a Submerged Floating Tunnel

II. LITERATURE REVIEW

The behavior of submerged cylindrical structures under dynamic loading has been extensively studied in the context of marine engineering and defense applications.

Feng et al. investigated the dynamic stability of laminated cylindrical shells submerged in various fluids, highlighting the influence of fluid-structure interaction on vibration characteristics and stress responses. Their research demonstrated the significant damping effects imparted by the surrounding fluid, which modulate the natural frequency and deformation patterns of submerged shells.

Macapagal et al. explored the failure characteristics of cylindrical structures exposed to underwater shock loading. Their findings revealed the formation of localized stress concentrations and delamination failures in composite materials, emphasizing the importance of accurate modeling of material properties and boundary conditions.

Zhang et al. analyzed functionally graded combined shells subjected to external hydrostatic pressure. Their study contributed to understanding the critical buckling pressure and vibration characteristics of composite cylindrical structures, offering valuable insights into the use of advanced materials in submerged environments.

These studies collectively underscore the complexity involved in modeling submerged cylindrical structures, particularly under transient dynamic loading such as underwater explosions. The current research builds upon this foundation by applying these concepts to the specific case of an SFT, with an emphasis on design parameter optimization using FEA tools.

III.METHODOLOGY

The methodological approach to this study follows a structured path beginning with the development of a realistic 3D model of the SFT, incorporating the tunnel, tether supports, fluid domain, and explosive charge. ANSYS software is employed for both modeling and simulation. The steps include:

1) Geometry Creation: A cylindrical shell represents the tunnel, surrounded by a fluid domain to simulate water. Tethers are modeled as inclined or vertical elements anchoring the tunnel to the seabed.
2) Meshing: A refined mesh is applied, particularly around areas expected to experience high stress gradients, such as tether junctions and blast impact zones.
3) Material Assignment: Appropriate material properties are defined for the structural shell, tethers, and fluid medium.
4) Boundary Conditions: Fixed supports are assigned to tether ends, and fluid-structure interaction (FSI) elements are defined to simulate dynamic interaction.
5) Explosion Modeling: The underwater explosion is modeled using a pressure-time history derived from standard TNT charge blast profiles.
6) Transient Dynamic Analysis: An explicit solver is used to capture the highly nonlinear response of the structure over time.

The outputs focus on key performance indicators such as maximum displacement, equivalent stress, and directional displacements.

1) Data Collection: Accurate and comprehensive data is fundamental to any simulation-based study. Data collected for this research include:

- Tunnel Geometry: Diameter, wall thickness, and overall length.
- Material Properties: Elastic modulus, density, Poisson's ratio for the tunnel shell, tethers, and water.
- Boundary and Initial Conditions: Initial pressure, water depth, and tether locations.
- Explosion Parameters: TNT equivalent weight, detonation distance from the tunnel, pressure-time history.
- Tether Configurations: Varying angles (30°, 45°, 60°) and spacings (50 m, 100 m).

These data were sourced from peer-reviewed literature, engineering databases, and relevant technical codes.

2) Modeling of SFT

- A three-dimensional model was constructed in ANSYS to simulate the SFT system. The model consisted of:
- A hollow cylindrical tunnel submerged within a water domain.
- Tether systems modeled as truss or beam elements.
- An explosion source modeled using a spherical pressure pulse.
- Defined interactions between the water domain and tunnel structure.
- Fluid-structure interaction was captured using coupled field elements, ensuring accurate transmission of pressure waves from the explosion to the structure.

3) Modeling Variations: Twelve distinct models were developed by systematically varying the following parameters:
- Tunnel Length: Two lengths were tested — 200 m and 500 m.
- Tether Spacing: Intervals of 50 m and 100 m.
- Tether Inclination Angle (TIA): Values of 30°, 45°, and 60° were analyzed.

Each combination was simulated under identical explosion loading conditions to ensure comparability of results.

4) Analysis: Explicit dynamic analysis was conducted to simulate the propagation of shock waves and their interaction with the tunnel structure. The primary outputs analyzed were:
- Total Displacement: Overall deformation of the tunnel shell.
- Equivalent (von Mises) Stress: Indicators of potential failure zones.
- Directional Displacement: Deformations in X, Y, and Z directions, highlighting instability patterns.

These outputs were evaluated across all twelve configurations to identify trends and optimal parameter sets.

IV. RESULTS AND DISCUSSION

The transient analysis revealed the following key observations:
1) Effect of Tunnel Length: Longer tunnels (500 m) showed increased flexibility and higher peak displacements. However, their larger moment of inertia provided some resilience against localized deformation.
2) Effect of Tether Spacing: Increasing tether spacing from 50 m to 100 m significantly raised displacement levels due to reduced constraint, confirming the importance of adequate support intervals.
3) Effect of Tether Angle: Steeper tether angles (closer to vertical) reduced lateral displacement but increased axial tension, leading to mixed outcomes.

The optimal configuration was found to be Model 8 (500 m length, 50 m tether spacing, 45° TIA), which exhibited balanced stress distribution and minimal displacement.

V. CONCLUSIONS

The dynamic response of a Submerged Floating Tunnel subjected to underwater explosion loading was successfully modeled and analyzed using ANSYS. The study highlights the importance of design parameters in determining structural stability under extreme conditions. Key conclusions include:
1) Doubling tether spacing leads to substantial increases in displacement — up to 80.4% in Z-direction and 53.8% in Y-direction.
2) Increasing TIA generally reduces Z-direction displacement but has a non-linear effect on Y-direction due to tether dynamics.
3) Model 8 proved to be the most efficient configuration, offering optimal balance between structural rigidity and flexibility.

This research contributes valuable design insights for future SFT applications and underscores the need for comprehensive dynamic analysis in early design stages.

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