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Article

Research on rigger equipment for retrieving vehicles from lake depths

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Abstract
This study contributes to ongoing efforts to protect the ecosystem of Lake Khuvsgul by supporting the remediation of hazardous waste and the reduction of pollution within the lake. A key focus of the operation is the analysis and selection of rigger equipment used in the retrieval of sunken vehicles and machinery from significant depths. In 2023–2024, a total of 11 submerged vehicles and machines were successfully recovered from depths ranging from 33 to 171 meters, including a motorboat, a ZIL-130 truck with trailer, a UAZ-469, a TT-4 tracked mountain tractor, and a YAG-6 truck. The retrieval technology was implemented through four sequential stages: preliminary pulling to free the objects from sediment, deep-water lifting, transportation toward the lakeshore, and final extraction onto land. This article presents the engineering calculations, equipment selection, and practical application of rigger systems utilized at each stage, offering insights to support future environmental recovery operations in deep freshwater ecosystems.

Keywords: steel wire rope, winch, pulling force, pulley, shackle

Introduction

Lake Khuvsgul, often referred to as Mongolia's *"Blue Pearl,"* represents one of the country's largest and most significant freshwater reservoirs, accounting for approximately 70% of Mongolia's surface freshwater resources, and nearly 1% of the world's total supply. The lake plays a crucial role in maintaining regional hydrological balance, supporting unique aquatic ecosystems, and sustaining the livelihoods of local communities through fishing, tourism, and the provision of ecosystem services. Due to its pristine environment and global ecological significance, Lake Khuvsgul has long been recognized as a vital component of Mongolia's natural heritage and environmental security.

In recent decades, however, anthropogenic pressure, particularly pollution resulting from submerged vehicles, has raised substantial environmental and safety concerns. Many of these vehicles, remnants of historical and transport activities dating back to the 1970s and 1980s, have corroded over time, releasing hazardous substances such as oil residues, fuel components, and heavy metals into the lake ecosystem. These contaminants pose risks to aquatic biodiversity, water quality, and public health. These issues have prompted the Government of Mongolia to initiate comprehensive mitigation measures at the national level.

Pursuant to the Prime Minister's Order No. 117 (2020), the Minister of Defense's Order A/243 (2024), the Chief of the General Staff's Order A/408 (2024), and the Director of the National Emergency Management Agency's (NEMA) Order A/247 (2024), large-scale retrieval operations were undertaken in 2023 and 2024 to locate, assess, and remove submerged vehicles from Lake Khuvsgul. The primary objectives of these coordinated interventions were to mitigate water pollution, eliminate hazardous materials accumulated on the lakebed, and preserve the long-term ecological integrity of the lake [1]–[3].

These operations represented an unprecedented national initiative, uniting diverse institutional actors, including NEMA, the General Staff of the Mongolian Armed Forces, the Mongolian University of Science and Technology, and the National Defense University, along with a multidisciplinary team of engineers, divers, and environmental consultants. The collaboration established an operational model integrating environmental management, engineering innovation, and national security logistics.

Prior to these efforts, Mongolia lacked any documented technical framework, engineering guidelines, or operational experience concerning the retrieval of submerged vehicles from deep-water environments. As a result, the development of methodological approaches, technical calculations, and operational procedures during these missions constitutes a pioneering contribution to Mongolia's environmental engineering and disaster response capacity. The retrieval operation was implemented through four sequential technological stages: (1) preliminary pulling to loosen and free objects embedded in the sediment, (2) main retrieval involving the vertical lifting of vehicles from the lakebed, (3) horizontal transportation of lifted objects toward the nearshore zone, and (4) final extraction onto the shoreline for inspection and safe disposal [1]-[3]. Each stage required specialized engineering solutions, adaptive techniques, and risk mitigation strategies tailored to the lake's specific environmental conditions, such as water depth, temperature, visibility, and sediment characteristics. The present study analyzes the engineering design, implementation, and outcomes of these four operational stages. The findings not only provide practical insights for optimizing underwater retrieval methodologies under cold, high-altitude freshwater conditions, but also establish a scientific and technical foundation for future large-scale underwater recovery projects in Mongolia and comparable environments worldwide.

Methodology

Calculation and Study of Steel Wire Ropes, Drums, and Winches

The calculation of the required pulling force for the retrieval of submerged vehicles and machinery from Lake Khuvsgul was based on a comprehensive mechanical and hydrostatic analysis. The principal forces acting on the submerged objects included (1) the gravitational weight of the vehicle, (2) the buoyant force (Archimedes' force), (3) the hydrostatic pressure of the surrounding water, and (4) the adhesion resistance generated by the contact between the object and the lakebed sediment. The net pulling force was therefore determined as the resultant of these interacting forces. According to the calculations, the actual weight of submerged vehicles ranged between 1 and 15 tons, while the effective pulling force required for retrieval—considering buoyancy, water pressure, and adhesion—was estimated to range from 0.68 to 5.7 tons**.** Based on these findings, the diameter of the steel wire rope was determined using the maximum breaking force acting on a single strand, as expressed by Formulas (1) and (2):

$$S_{max} = F / (z \cdot \eta\_ec) \ (1) \qquad (1)$$

$$S\_br = S\_max \cdot n\_res \ (2) \qquad (2)$$

Where: S_{max} – maximum force acting on one strand;
F – total pulling load;
z – number of strands in the steel wire rope;
η_{ec} – efficiency coefficient of the pulley system;
n_{res} – reserve (safety) coefficient of the steel wire rope;
S_{br} – breaking force of a single strand.

For lifting equipment, the reserve coefficient (n_{res}), typically ranges between 5 and 10 to ensure safety under repetitive loading. However, in this particular underwater retrieval operation, only a limited number of pulls were required, and the primary operational objective was to minimize rope stiffness and enhance flexibility. Therefore, reserve coefficients of 0 and 3 were adopted for comparative analysis. In underwater conditions, the wire rope must exhibit properties such as thinness, flexibility, corrosion resistance, and ease of fastening. Self-lubricating steel wire ropes were therefore preferred to reduce frictional loss and wear.

The diameters of the steel wire ropes were calculated for both reserve coefficient values (0 and

3) based on the breaking force and are presented in Table 1.

Table 1.

Steel wire rope diameter for different vehicle types and pulling conditions

	Indicator	Object model, size			
		Boat	ZIL-130, trailer	UAZ-469	Tractor TT-4
1	Loaded weight, tons	1.0	15.0	2.45	3.9
2	Pulling force, tons	0.68	5.7	0.1	5.5
3	Breaking force of steel wire rope, N (n=0)	6671	55917	981	53955
4	Steel wire rope diameter, mm (n=0)	8.1	11.5	8.1	11.5
5	Breaking force of steel wire rope, N (n=3)	20012	167751	2943	161865
6	Steel wire rope diameter, mm (n=3)	9.7	18.0	8.1	18.0

These calculations provided essential parameters for selecting appropriate winch capacities and drum diameters, ensuring that the retrieval system maintained sufficient safety margins under various water depths and sediment conditions. The determined wire rope dimensions and strength values served as the engineering basis for designing and implementing the underwater retrieval mechanism.

Calculation of drum geometric dimensions

Based on the preliminary selection of steel wire rope parameters, geometric calculations were performed for drums intended to wind steel wire ropes of nominal diameters d = 12, 14, 16, 18 mm and rope lengths of 140 m, 180 m, and 220 m. The drum geometry and winding capacity were computed using the following relations, where the equations account for minimum drum diameter requirements, turn counts, layer stacking, and total rope capacity.

Minimum Drum Diameter

The minimum permissible drum diameter Dd was taken proportional to the steel wire rope diameter d_{swr} according to:

$$Dd \geq d_{swr} * e \quad (3)$$

where e is a sizing coefficient (dimensionless) recommended to ensure safe bending radius for the rope and to limit fatigue.

Number of Rope Turns on the Drum (Single Layer)

The number of turns of wire rope on the drum for a single layer, $z_{w.t}$, is given by:

$$z_{w.t} = l_{w.t} / (\pi * Dd) \quad (4)$$

where $l_{w.t}$ is the length of rope to be wound and Dd is the drum diameter.

Total Number of Turns

The total number of turns on the drum z_{total} accounts for operational turns, reserve turns, and supplementary turns due to multilayer winding:

$$z_{total} = z_{w.t} + z_{res} + z_{sup} \quad (5)$$

where z_{res} is the number of reserve turns and z is the number of supplementary turns required for multilayer winding and rope anchoring.

Required Drum Length for Single-Layer Winding
The required axial length of the drum for single-layer winding $L_{s.l.}$ is:

$$L_{s.l.} = z_{total} * t \quad (6)$$

where t is the effective pitch (axial spacing) per turn and typically approximates the rope diameter for closely wound layers.

Steel Wire Rope Capacity on the Drum
For multilayer winding, the approximate rope capacity l_{cap} (length of rope that can be wound on the drum) is computed as:

$$l_{cap} = \pi*D_d*z_1 + \pi*(D_d + 2*d_{swr})*z_2 + \pi*(D_d + 4*d_{swr})*z_3 \quad (7)$$

where z_1, z_2, z_3 are the number of turns in the first, second, and third layers, respectively.

The geometric parameters calculated for the three-rope length scenarios (220 m, 180 m, 140 m — corresponding to lake depths plus reserves and bidirectional operation) are summarized in Tables 2–4 below.

Table 2.
Steel wire rope length 220 m drum geometric dimensions

№	Indicator	Steel wire rope diameter, mm			
		12 mm	14 mm	16 mm	18 mm
1	Drum diameter, mm	250	300	350	400
2	Drum diameter considering rope diameter, mm	262	314	366	418
3	Length wound during operation, m	220 (lake depth 100 m + 20 m reserve, both sides)			
4	Number of ropes turns on the drum	267	223	191	168
5	Total number of ropes turns on the drum	274	230	198	175
6	Required drum axial length for winding, mm	1098	1074	1058	1048
7	Number of single layers of winding	91	77	66	58
8	Rope capacity of the drum, m	236	237	238	239

Table 3.
Steel wire rope length 180 m drum geometric dimensions

№	Indicator	Steel wire rope diameter, mm			
		12 mm	14 mm	16 mm	18 mm
1	Drum diameter, mm	250	300	350	400
2	Drum diameter considering rope diameter, mm	262	314	366	418
3	Length wound during operation, m	180 (lake depth 80 m + 20 m reserve, both sides)			
4	Number of ropes turns on the drum	219	183	157	137
5	Total number of ropes turns on the drum	226	190	164	144
6	Required drum axial length for winding, mm	903	885	873	865

7	Number of single layers of winding	75	63	55	48
8	Rope capacity of the drum, m	194	195	196	197

Table 4.

Steel wire rope length 140 m drum geometric dimensions

№	Indicator	Steel wire rope diameter, mm			
		12 mm	14 mm	16 mm	18 mm
1	Drum diameter, mm	250	300	350	400
2	Drum diameter considering rope diameter, mm	262	314	366	418
3	Length wound during operation, m	140 (lake depth 80 m + 20 m reserve, both sides)			
4	Number of ropes turns on the drum	170	142	122	107
5	Total number of ropes turns on the drum	177	149	129	114
6	Required drum axial length for winding, mm	709	695	687	682
7	Number of single layers of winding	59	50	43	38
8	Rope capacity of the drum, m	152	153	155	156

Winch Power Calculation and Study

Based on static fluid pressure calculations, the maximum required load for retrieval has been determined to be 5.7 tons. This load can be towed using the following winches with steel wire ropes of different diameters:

- 4 winches with 12 mm diameter steel wire ropes
- 3 winches with 14 mm diameter steel wire ropes
- 2 winches with 16 mm diameter steel wire ropes
- 1 winch with an 18 mm diameter steel wire rope

The required engine power for each winch is determined using Equation (8) and is presented in Table 5. The electric motor power required for pulling the load is calculated as follows:

$$P_{c.ч} = \frac{F \cdot v}{\eta} \quad (8)$$

where: $\eta = 0.85$ - Mechanical transmission efficiency coefficient, F - Total load (N), v – Pulling speed (m/s).

Table 5

Winch electric motor

№	Indicator	Steel wire rope diameter, mm			
		12	14	16	18
1	Drum Diameter, mm	250	300	350	400
3	Maximum Pulling Force, N	*F*=5.7*1000*9.81=55917			
4	Load per Winch, N	13979	18639	27959	55917
5	Electric Motor Power, kW	5.4	7.2	10.9	21.7

Calculation of Drum Metal Structure

Based on preliminary calculations of the drum corresponding to the steel wire rope diameter, modifications were required to design a new winch that meets our technological specifications. The structural strength of the drum was analyzed by varying its length while maintaining a constant

drum diameter of 250 mm [9–12]. For the circular cross-section of the drum, the diameter was set at 250 mm, the wall thickness at 14.2 mm, and the drum lengths at 1195 mm, 903 mm, and 709 mm.
An axial force of F=5.7×1000×9.81×5.5=307,543.5 NF = 5.7 \times 1000 \times 9.81 \times 5.5 = 307,543.5 \, \text{N}F=5.7×1000×9.81×5.5=307,543.5N was applied along the drum axis. The structural strength of the drum was evaluated using ANSYS software (Figure 1), with a safety factor of 5.5.

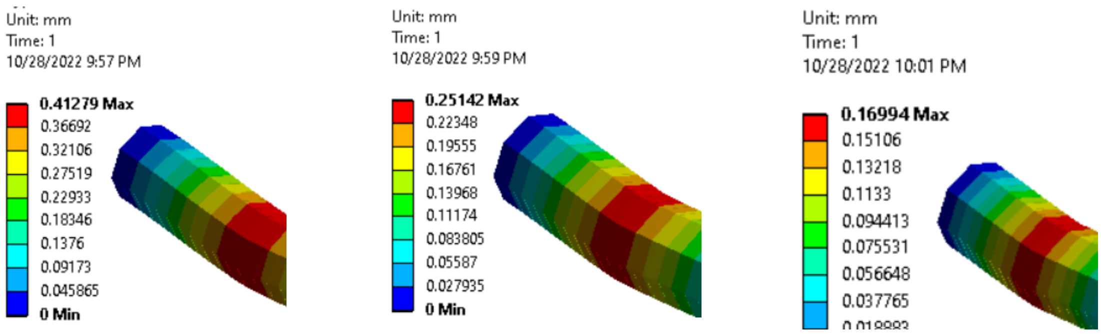

Figure 1. Deformation of the drum metal structure

From the calculations of the drum metal structure, the axial deformations were determined as 0.41279 mm for a drum length of 1195 mm, 0.25142 mm for 903 mm, and 0.16994 mm for 709 mm.

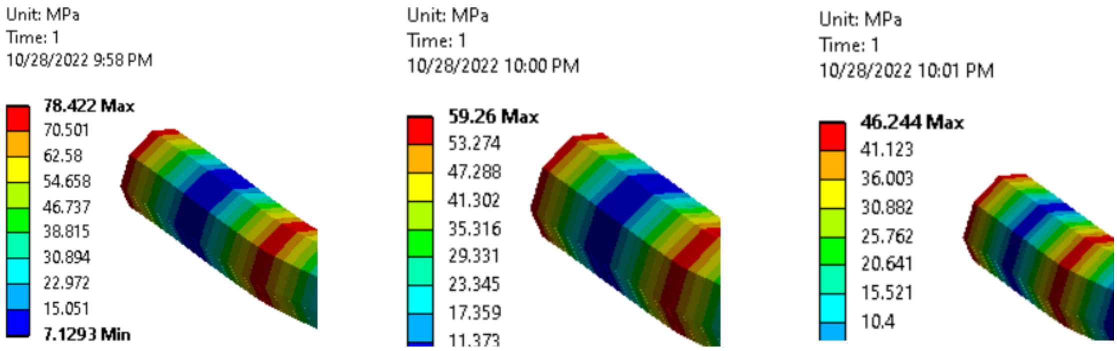

Figure 2. Strength of the drum metal structure

According to the results shown in Figure 2, the calculated strength values of the drum were 78.422 MPa for a length of 1195 mm, 59.26 MPa for 903 mm, and 46.244 MPa for 709 mm.

Results and Discussion

Steel wire rope selection calculation

Based on the steel wire rope selection calculations, it can be seen that vehicles and machinery submerged in the lake can be recovered using steel wire ropes with diameters ranging from 10 mm to 18 mm. For retrieving a vehicle or machinery with a maximum load of 5.7 tons, the following winches are required:

- 12 mm diameter, 240 m long steel wire rope, 4 winches with 5.4 kW power
- 14 mm diameter, 240 m long steel wire rope, 3 winches with 7.2 kW power
- 16 mm diameter, 240 m long steel wire rope, 2 winches with 10.9 kW power
- 18 mm diameter, 240 m long steel wire rope, 1 winch with 21.7 kW power

From the drum metal structure calculations, the strength values were 78.422 MPa for a 1195 mm, 59.26 MPa for a 903 mm, and 46.244 MPa for 709 mm drum lengths. Given that the steel strength limit is 250 MPa, the drum can withstand a 307543.5 N load. Based on the ANSYS simulation results, a drum for winding the steel wire rope can be constructed using a 250 mm outer diameter, 14.2 mm wall thickness, and 1195 mm long steel pipe.

From here, we have refined our study and decided to use two AMW5000 winches with a capacity of 5 tons and three AMW3200 winches with a capacity of 3.2 tons, considering factors such as the calculation of steel wire ropes, water depth, metal structures of lifting equipment, dimensions, weight, and capacity in the process of retrieving machinery. These winches are equipped with steel wire ropes of 18 mm and 22 mm in diameter, each with a capacity of 240 meters. To monitor the height at which the object is being pulled, we have determined how many layers of steel wire ropes will be wound on the drum, how many single wound layers, the length of wire rope single layer, and the length of wire ropes wound in each layer (Tables 6, 7, and 8).

Table 6

Diameter of steel wire rope drum winding, m

№	Indicator	Steel wire rope diameter, m	
		0.022	0.018
1	Winch model	AMW5000	AMW3200
2	Winch steel wire rope capacity, m	240	240
3	Winch drum diameter, m	0.3	0.18
4	Diameter of drum winding one full layer, m	0.344	0.216
5	Diameter of drum winding two full layers, m	0.388	0.252
6	Diameter of drum winding three full layers, m	0.432	0.288
7	Diameter of drum winding four full layers, m	0.476	0.324
8	Diameter of drum winding five full layers, m	0.52	0.36
9	Diameter of drum winding six full layers, m	0.564	0.396
10	Diameter of drum winding seven full layers, m	0.608	0.432

Table 7

length of steel wire rope drum winding, m

№	Indicator	Steel wire rope diameter, m	
		0.022	0.018
1	Winch model	AMW5000	AMW3200
2	Winch steel wire rope capacity, m	240	240
3	Length of steel wire rope winding one full layer in the first level	1.08016	0.67824
4	Length of steel wire rope winding one full layer in the second level	1.21832	0.79128
5	Length of steel wire rope winding one full layer in the third level	1.35648	0.90432
6	Length of steel wire rope winding one full layer in the fourth level	1.49464	1.01736
7	Length of steel wire rope winding one full layer in the fifth level	1.6328	1.1304
8	Length of steel wire rope winding one full layer in the sixth level	1.77096	1.24344
9	Length of steel wire rope winding one full layer in the seventh level	1.90912	1.35648

Table 8

Length of steel wire rope full winding along the drum, m

№	Indicator	Steel wire rope diameter, m	
		0.022	0.018
1	Winch model	AMW5000	AMW3200
2	Winch steel wire rope capacity, m	240	240
3	Number of drum windings	30	39
4	Length of steel wire rope for a full winding in the first level	32.4048	26.45136
5	Length of steel wire rope for a full winding in the second level	37	31
6	Length of steel wire rope for a full winding in the third level	41	35
7	Length of steel wire rope for a full winding in the fourth level	45	40
8	Length of steel wire rope for a full winding in the fifth level	48.984	44.0856
9	Length of steel wire rope for a full winding in the sixth level	37.19016	48.49416
10	Total length, m	240.66216	224.83656

Steel wire rope and slinging equipment for retrieving operation

During the threading process materials such as fiber flexible coated green wire ropes, were cut to 4 mm and 6 mm, 8 mm and 16 mm fiber ropes, and steel wire ropes of 10 mm, 12 mm, 16 mm, 18 mm, and 22 mm were used (Figure 3). As part of the threading preparation work, necessary steel wire ropes were braided, then secured with clamping tools and wrapped with fiber ropes to adjust their size for threading, connecting, and fastening. This process was carried out 189 times. Additionally, steel wire rope connections were completed 63 times using shackles appropriate for the load requirements of the task.

Figure 3. Fiber, flexible coated green wire rope, fiber rope, and steel wire rope used during threading

During the securing process for waterway transportation, 5-ton hooks, 5-ton shackles, 3-ton and 5-ton manual hoists, 18 mm steel wire rope slings, and 16 mm fiber ropes were used. Additionally, metal structures of lifting equipment, anchor winches, and power generators were secured using chains, chain tighteners, 16 mm steel wire ropes, and steel wire rope tensioners (Figure 4).

Figure 4. Securing and Slinging Equipment

The results indicate that the selection of steel wire rope diameter, winch capacity, and drum design are critical for safe and efficient retrieval operations in aquatic environments. The structural analysis confirmed that the designed drum can safely withstand the expected axial loads, and the detailed calculations of drum winding and rope length allow for precise operational control. The combination of appropriate winches, steel wire ropes, and slinging equipment ensures both operational safety and efficiency. Furthermore, the methodology presented provides a practical framework for planning similar retrieval operations, taking into account load, depth, and mechanical limitations.

Conclusion

This study demonstrated a systematic approach for retrieving submerged vehicles and machinery from Lake Khuvsgul, integrating steel wire rope selection, winch and drum design, and slinging operations. Structural analysis confirmed that the designed drum and selected winches can safely handle loads up to 5.7 tons. Detailed operational planning, including drum winding and rope management, ensured safe and efficient lifting. As a result, 11 vehicles and machinery were successfully recovered from depths of 33–171 m, as well as hazardous substances. This contributed to the protection of the lake's ecosystem. The methodology provides a practical framework for similar underwater recovery operations.

Conflict of Interests:

The authors declare no conflict of interests.

Authors' Contribution

R.Ya, U.P and N.R conducted calculations and studies on steel cables and towing equipment. G.Ts and A.B carried out research on determining the car's weight. G.D and I.G conducted a towing experiment and research on the cars.

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