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Research Note

Floating Bridge Modeling and Analysis

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This paper presents an overview of a study on the design and analysis aspects of the Lake Urmia Bridge in Iran. For years there have been several detailed investigations on this subject. Here, these alternatives are discussed and, then, results of analyses for a proposed solution, a floating bridge, are presented. These aspects include environmental loads, structure and the mooring system.

INTRODUCTION

Lake Urmia is an isolated lake in the Azerbaijan Province (between the two cities of Tabriz and Urmia) in northwest Iran. The total area of the lake is 4700 square kilometers and the north-south length is about 145 kilometers. The maximum depth of the shallow, saline lake is approximately 15 meters. Climatically, the lake region is located in a semiarid, almost desert, environment, with general precipitation averaging 30 centimeters per year. This precipitation yields great depth fluctuations at different seasons of the year. The maximum wind speed in the region is 36 meters per second. It's flow rate, from the north to the south of the lake, has a maximum value of 1.14 meters per second. Moreover, the highest wave in a range of 100 years had a height of 2.78 meters and a time period of 5.9 seconds [1]. Figure 1 shows a satellite image of the lake indicating its 15 kilometers mouth.

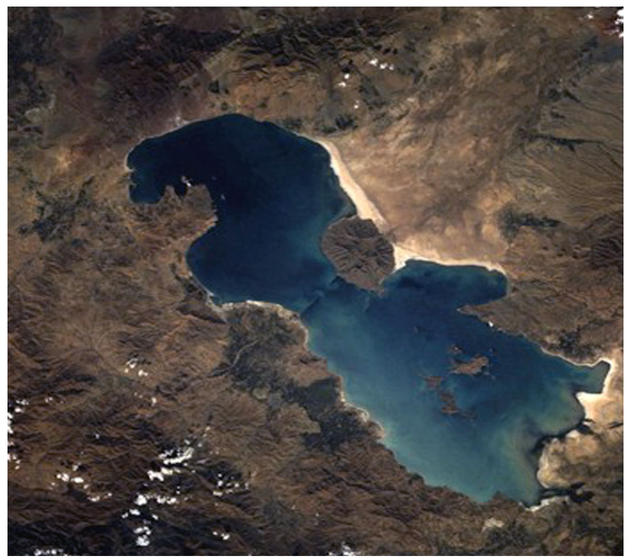

Figure 1. Satellite image of Lake Urmia taken by NASA [3].

The narrow linear features jutting into the lake from opposing shorelines (toward the middle of the lake), are the manmade embankments (constructed road) whose lengths are about 13 kilometers from the Urmia side and 3.4 kilometers from the Tabriz side. This embankment, seen in Figure 2, provides the construction site for the bridge. There is a gap between these two sides, which was considered for probable water elevation and ecologic differences at opposing sides of the embankment.

Figure 2. Embankment for bridge construction site.

According to available reports [2], 6000 vehicles

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cross the lake daily, of which 1200 cross by barge or ferry. One of the difficulties of this kind of transportation lies in the technical defects of the system and the lack of stability of the vessels, preventing their use in harsh environmental conditions.

The motivation for access to a shorter, robust, safe and convenient link in the stormy atmosphere and unreliable condition of Lake Urmia has made the lake's bridge a questionable subject of transportation for years [1].

BRIDGE ALTERNATIVES

A number of alternative bridge configurations have been proposed. Kohansal [1] has described, in detail, the three types of bridge design proposed for the Urmia Lake link as: Fixed, floating and innovational.

Fixed Bridge

Regarding the fixed bridge concept, five different alternatives have been investigated as follows.

Fixed Bridge with Pile and Deck

This design was suggested with 85 m openings. In this design, the superstructure is in the form of a metal strut, which is located on a main pile standing on 12 other piles. This choice has been rejected due to technical and constructional problems.

Fixed Bridge Composed of Pile and Caisson

In previous designs, the main problem was the drowning of the pile group and the decrease of pile length. So, the idea of a composed pile and caisson was presented for the substructure. Caissons, in this choice, could be designed in two types: Concrete box and metallic conical. By considering this choice, the problem of supports was solved but constructional problems remained unsolved.

Fixed Bridge with Tensile Piles

In this concept, a superstructure was considered in discrete components, supported by four pillars. These pillars were supposed to be immersed in water supported by sunken barges.

Fixed Bridge with Cable System

The main problem in a Cable Bridge was to produce stability for the main columns and the location of abutments. For this purpose, a filling was made in the location of the column foundations to remove the mud line and, in time, the installation of box reinforced concrete foundations was suggested. This choice was rejected due to lack of appropriate support for the main columns.

Fixed Bridge with Deck Located on (Pier Open-Ended) Caissons

In this system, instead of an installation of the bridge deck on the pile group, it is placed on huge metal or concrete columns. These hollow columns are supposed to be immersed further and further into the seabed. The heights of these pillars are such that the other end of them will be above the water level.

Floating Bridge

The floating structure concept has been described in [4]. It can be used for different types of conventional structure, such as bridges or quays, passenger terminals, airports and many other structures.

Certainly, the selection of a floating structure is based on technical and economical reasons that can be summarized as follows:

- At deeper water depths, the construction of a fixed foundation is very expensive and may be an inadequate design;
- In regions with very soft mud lines where there is no possibility of fixed foundation construction or there is unacceptable loading capacity, a floating bridge would be a more rational design;
- In places where the construction and performance of the structure is very complicated, it is possible to construct the structure in another place and, then, move it to the design location by floating;
- In ports with high tidal levels where large differences between the structure level and fixed quay elevation are exposed;
- In army situations, where there is limited time for construction;
- In earthquake regions, where, by using a fixed foundation an extreme dynamic response is expected;
- In temporary projects, when the structure is not needed after a period of time;
- In projects when the ecological condition of the site is not expected to change.

In essence, the floating bridges are classified as two different types of discrete and continuous pontoons. Most of the floating bridges in the United States are the continuous type, for example, the first, second and third Lake Washington Floating Bridge [5] and the Original and New West Half of the Hood Canal Bridge [6]. The discrete type of floating bridge has been used in Norway, for example in Bergsoysund [7] and Nordhordland [8]. The choice is normally dictated by different geographic and environmental conditions.

The first floating bridge in the United States has been in use since 1940 and was constructed from

19 reinforced concrete pontoons, which were rigidly connected together to form a continuous structure. Lake Washington with fresh water had, approximately, 72 meters of peaty and organic soil below the mud line level. In 1963, another precast concrete floating bridge, including 23 pontoons, was constructed in Lake Washington and, finally, in 1989, the third floating bridge, using 18 precast reinforced concrete pontoons, was installed there [5].

Both floating bridges in Norway consist of a steel superstructure, arch shaped in plan and placed on concrete pontoons [7,8]. Bergsoysund Bridge was constructed in 1992 from pipe trusses and, in the case of the Nordhordland superstructure, has the shape of an eight-corner box girder. Bergsoysund Bridge has seven floating pontoons without any lateral support. Its shape is an arch with an 845 m span and the radius of the arch is 1300 m. In a vertical direction, the structural system is a continuous arched beam on an elastic foundation. Elastic foundations are the pontoons of a floating bridge. The pontoons have been constructed from light concrete and each pontoon, with a length of 35 m, is divided into 9 watertight compartments. The structural type of the Nordhordland floating bridge is very similar to the previous bridge.

The current velocity and, especially, the bearing capacity of the mud level in Lake Urmia, makes the pile type foundation unsafe and elaborate.

Innovational Designs

Innovational designs are described in [1]. These alternatives were suggested as the following two types.

Mouth Embankment and Fixed Bridge Construction on the Preembanked Bridge Body

The advantage of this choice is the usage of the embanked body of the highway for the installation of the fixed bridge. Since the highway body was completed 20 years ago, it began sinking as the problem of improper seabed soil was removed. However, the seabed at a range of 1400 m (the net bridge length) is thick, leading to problems with seabed reinforcement.

Mouth Embankment and Hydraulic Connection Production by Metallic or Concrete Culvert Burial

One of the main problems in highway construction is the water current speed. To enable continuing north-south flow, the construction of the embankment must be accompanied by a complicated system of culverts and pipes. This, coupled with the large amount of embankment material required to cover the deep mud line, makes this option unattractive.

The above discussions have indicated that the most promising candidate for a Lake Urmia opening would be a floating bridge. This option will now be considered in detail.

PROPOSED FLOATING BRIDGE SPECIFICATIONS

The bridge has been proposed in [1] and has been considered to have a length of 1330 m (without shore connections) and a height of 5 m with a 16 m beam (Figure 3). The continuous reinforced concrete pontoon is the main load carrying element of the bridge. All of the pontoons are 70 m long, 5 m high and 16 m wide. The floating bridge is moored by anchor chains, which transfer the environmental forces, such as wind, wave and current, to the seabed. The concrete thickness in the pontoon varies from 30 mm in the middle bulkheads to 40 mm on the sidewalls. The concrete on the top and bottom is 35 mm and stiffeners with 20 mm thickness are the supports at every 10 m. The pontoon cross sections are unchanged in the whole length of the bridge. Concrete thickness and cross bulkhead thickness are not altered at any part of the bridge, except for local strengthening at the connection points to pontoons and to abutments.

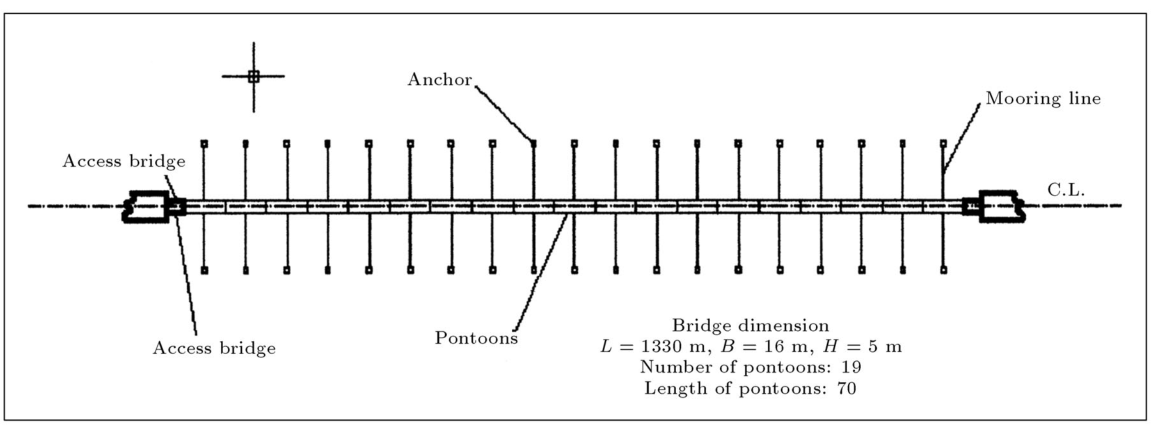

Figure 3. Plan view of the proposed floating bridge [1].

BRIDGE ANALYSIS

For the purpose of engineering analysis, the bridge was considered to be of a floating type moored by the use of mooring wire ropes anchored to concrete slabs at the lake bottom. The design and analysis procedure for the bridge includes the following investigations (Figure 4):

1. Environmental loading study using Computational Fluid Dynamics (CFD),
2. Bridge structure analysis using the Finite Element Method (FEM),
3. Study on mooring system design and analysis involving:
   - Nonlinear numerical analysis of mooring line stiffness using a Maple software code,
   - Design, analysis and optimization for the concrete anchor dimensions of a floating bridge by the Discrete Element Method (DEM).

For every study indicated above, different parallel research was conducted and, here, only some results were explained. The operational region where the bridge was to work had a water depth of 7 meters. Below the seabed, the boring hole consisted of about 15 meters of organic clay and, as a result, the strength of that layer was omitted for safety reasons. Therefore, the water depth was considered as 22 m for the investigations.

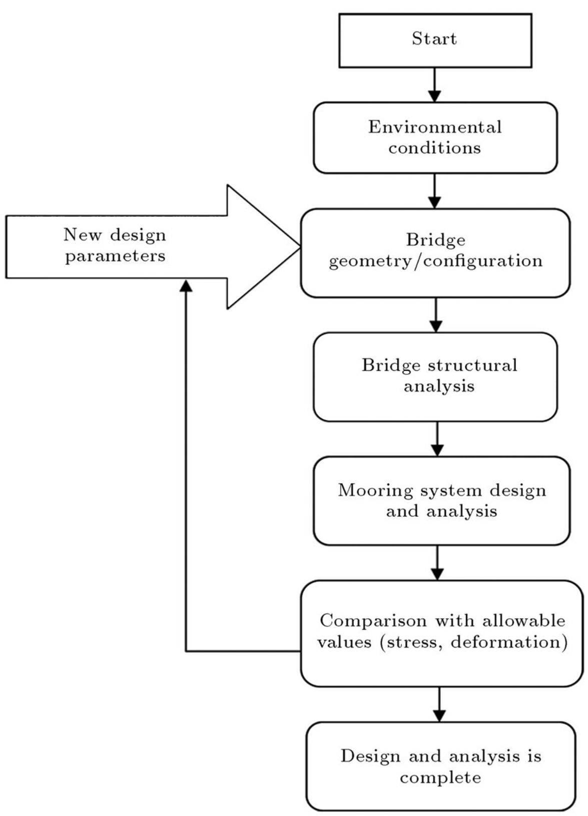

Figure 4. Floating bridge design and analysis algorithm.

Environmental Loading Study

Generally, environmental loading refers to loads acting on the structure generated by waves, wind, current and, sometimes, seismic effects. In this research [9], the above stated loads, except seismic loads, have been investigated and, here, only the brief results for the current load study are presented.

Since the length-beam ratio for the bridge is large and the current is almost perpendicular to the bridge, the modeling has been done in a two-dimensional form. The fluid velocity is 1.14 m/s and no air current is supposed, while water movement causes the adjacent air layer to flow.

The bridge was modeled in version 6 of FLUENT. The calculation domain is meshed by structured quadrilateral elements, as shown in Figure 5. The cells have a number of about 500 around regions with more variations. A more rough mesh was achieved by using the adaptive grid option.

For current analysis, two dimensional unsteady fluid Navier-Stocks equations have been solved numerically for both air and water by using the Finite Volume Method (FVM). Two phased current modeling has been made by a Volume Of Fluid method (VOF) and gravity and surface tension effects have also been considered. Figure 6 illustrates the streamlines around the body indicating flow separation at bridge to be rare. The separation can be improved by curvature in the cross section. The velocity contours shown in Figure 7, meanwhile, show significant pressure at the fore of the bridge. It also indicates a velocity rise at the bottom of the body. As a result of this analysis, the surface deformation is found to be very small and can be neglected.

Pressure distribution on the lower surface can be seen in Figure 8. The figure shows that the hydrodynamic pressure in the upper parts are more

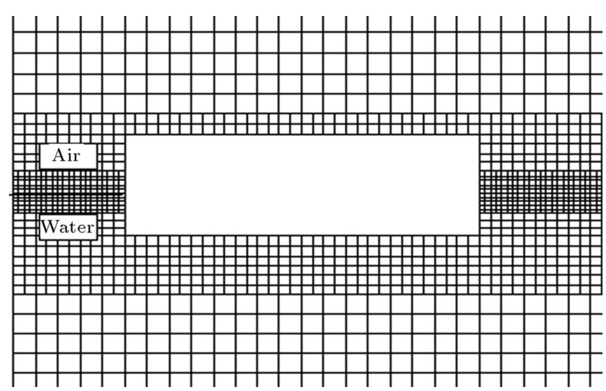

Figure 5. Mesh generation for the bridge cross-section [9].

than the hydrostatic pressure, while at the lower parts, the reverse is true. It must be noted that the modeling has been accomplished at low velocities and may result in different values at higher velocities.

Conclusively, the force per unit length of water has been obtained as the following:

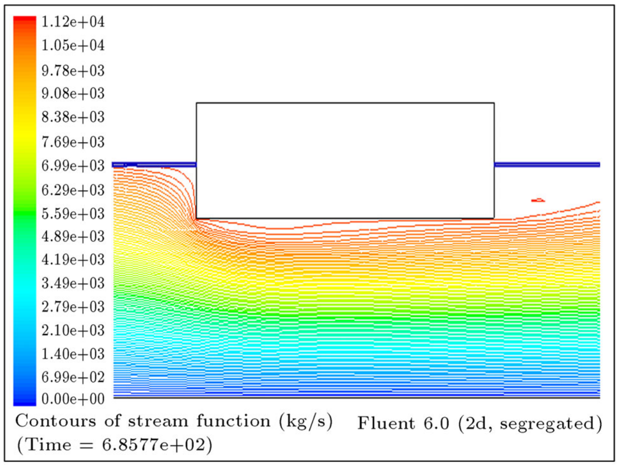

Figure 6. Stream lines around the bridge body (transverse section).

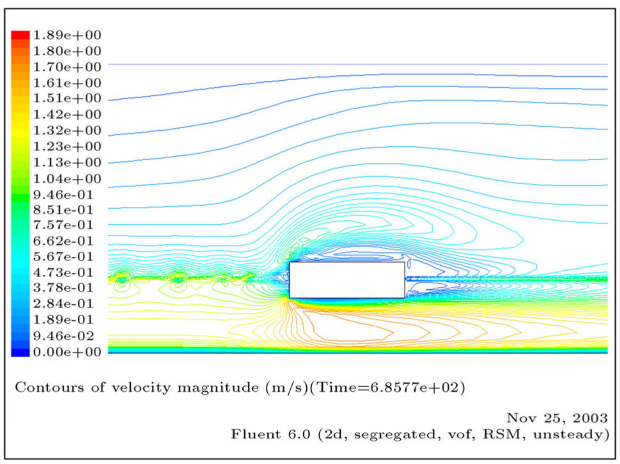

Figure 7. Velocity contours around the bridge body (transverse section).

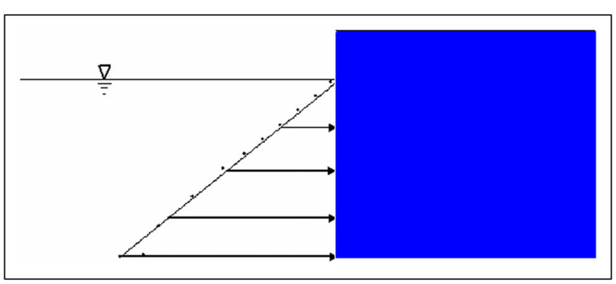

Figure 8. Hydrostatic and static pressure obtained by the numerical solution (points) on front part of the bridge (transverse section).

Pressure force	2319.6 N
Viscous force	21.6 N
Total force	2341.2 N

These values are the net force per unit length of the bridge in the flow direction generated by both water and air. Pressure components generated due to pressure differences in left and right surfaces and the viscous element is due to the frictional resistance of the lower surface. These values and, also, the pressure diagrams can help a lot in the design and optimization of the bridge. Furthermore, by varying water flow velocity and considering air velocity, different operating conditions can be discussed.

Discussion and research on the bridge response to waves is being investigated. It should be mentioned that the significant wave in the region has a height of 2 to 3 meters. Since they do not often face the bridge perpendicularly, one may suppose no specific loading but a drift force, which is being studied in the same manner as the current loading.

Bridge Structure Analysis

Bridge structure analysis was conducted by Daghigh et al. [10] using a finite element method in version 5.4 of ANSYS (FEM). The bridge was modeled using a 3D shell and a nonlinear spring analysis. Buoyant force was also modeled by equivalent spring elements.

Six different loading conditions were examined as:

1. Dead weight of structure,
2. Dead weight and local traffic,
3. Dead weight and unsymmetrical local traffic,
4. Transverse loading including wind/wave and current,
5. End damaged condition,
6. Transverse damaged condition.

The FEM model of the bridge is shown in Figure 9, and some of the results are shown in Figures 10 to 13.

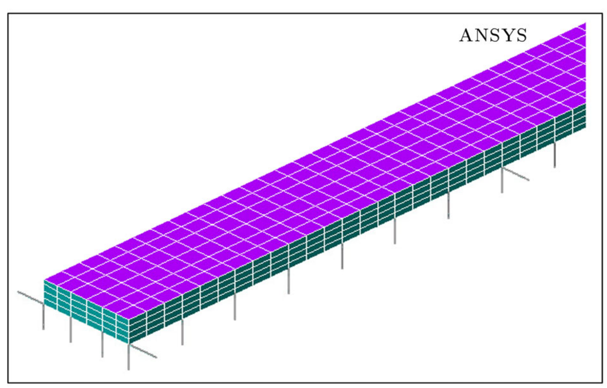

Figure 9. Finite element model of floating bridge [10].

Loading condition 5 is regarded as a case when some compartments are flooded at the end of the bridge. Since there will be no buoyancy force in this position, this part can be assumed as a cantilever beam and stresses or deflection may become significant. Figures 10 and 11 show a typical output for this condition. Such results are considered in overall design procedures and bridge geometry or configuration may be changed to have these parameters in an allowable domain.

The results of this study were as the following:

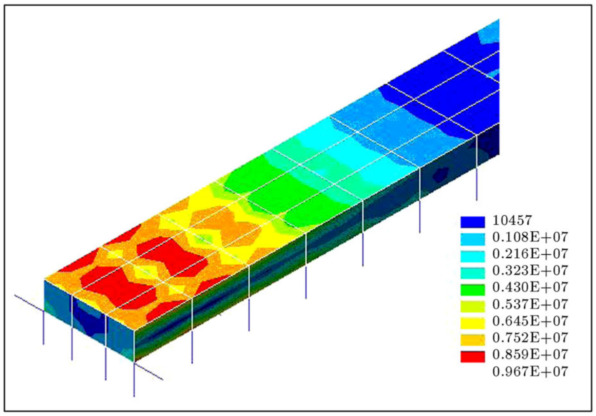

Figure 10. Von Misses stress contour in loading condition 5.

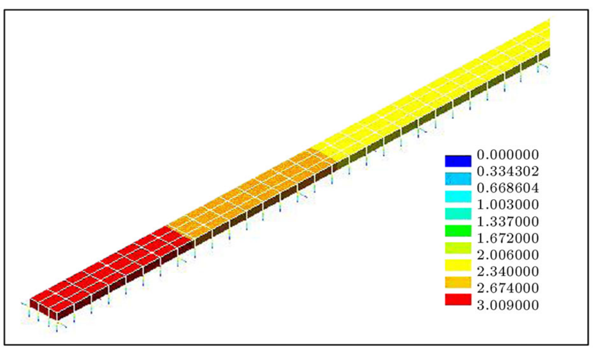

Figure 11. Vertical displacements in loading condition 5.

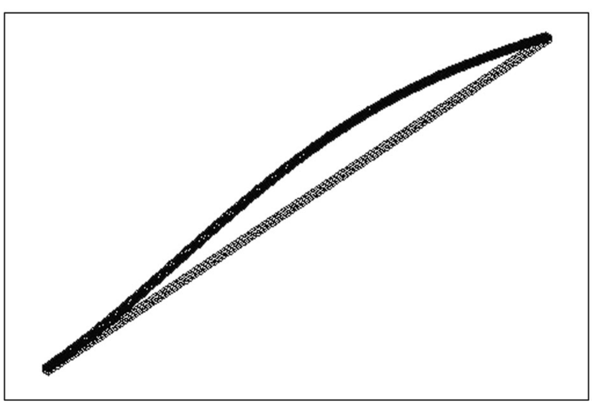

Figure 12. First eigenmode (Y1) for $\theta = 30$ deg.

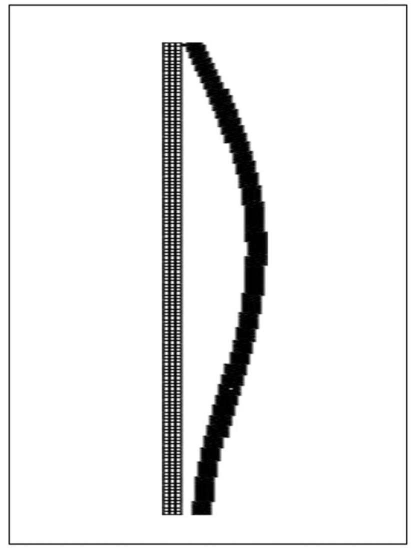

Figure 13. First eigenmode (Y1) for $\theta = 0$ deg.

1. Hydrodynamic loading, static and eigenvalue analysis of a floating bridge can be well predicted by the available finite element model using shell elements for pontoons and linear and nonlinear spring elements for buoyancy and anchor stiffness;
2. For the floating bridge, the heeling angles are in an acceptable range, given by classification rules [10], due to unsymmetrical traffic loading or wind, wave and current loads;
3. It was found that the horizontal displacement of the floating bridge was in a limited range, even using zero orientation of the anchor at the seabed [10].

Study on Mooring System Design and Analysis [3]

Nonlinear Stiffness Study of Mooring Lines

The results of the mooring system analysis were presented by Daghigh et. al [11]. For this study, a numerical program (a Maple software code [12]) was utilized to find the force at the bottom of the wire rope with variations of orientation angle, weight per meter of wire rope, horizontal force at the other end of the catenary, steps of displacement in a horizontal and vertical direction and wire rope length input data. By using this solver, for a mooring line with S.F = 3, the selection was: 6×37 Class, IWRC (Independent Wire Rope Core), EIPS (Extra Improved Plow Steel), $w = 13.9$ kg/m, $d = 57$ mm and $Ts = 224$ tons.

Moreover, two nonlinear springs, K_H and K_V, were found to be the vertical and horizontal spring models replacing the wire rope for structural analysis. The values of forces at the end of the rope were investigated with regard to variations of displacement and the results were obtained, as shown in Figures 14 to 16 [12].

Design and Optimization Made for Anchor Selection

The design and analysis stage for the anchors, which was a trial and error process, was completed using the UDEC Ver.1.83 (Universal Discrete Element Code)

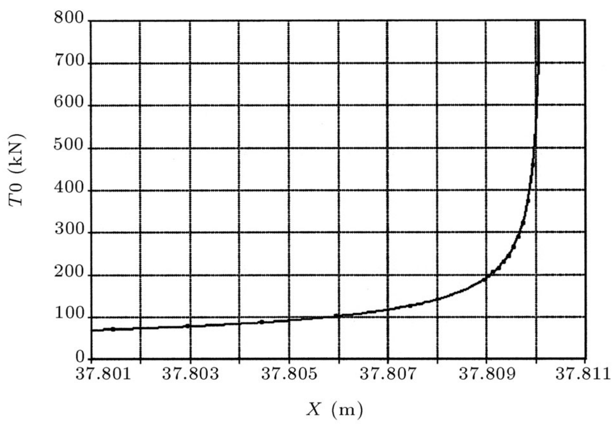

Figure 14. Schematic of the result for nonlinear stiffness study of mooring lines (horizontal stiffness).

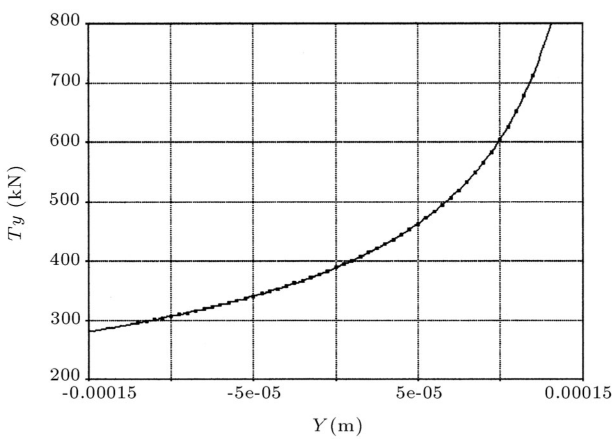

Figure 15. Sample scheme for vertical nonlinear study of mooring line.

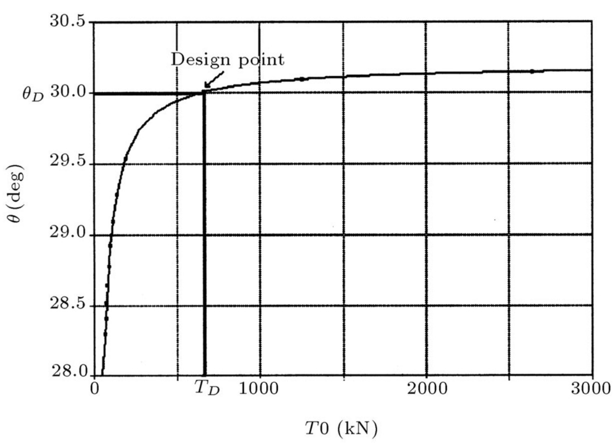

Figure 16. Bottom angle variation due to horizontal force variation at the end of the cable.

software (Discrete Element Method) [11]. To do this, the maximum average force values at the wire rope end were used for design and analysis of the anchors.

The modeling and simulation of blocks by UDEC showed that the block anchor dimensions obtained by conventional rules and standard empirical methods are not able to satisfy the stability condition against sliding (Figure 17). After a set of iterations made in UDEC, the block dimensions were optimized to $9.5 \times 9.5 \times 2.1$ m^3. Furthermore, two types of anchor release, vertical and combined vertical and rotational movement, were analyzed. For both of the situations, UDEC ensured a safe state, as shown by Figures 18 to 20.

CONCLUDING REMARKS

Different alternatives for a bridge over Lake Urmia, connecting the cities of Tabriz and Urmia in Iran, have been discussed in this paper. Moreover, the results of the design and analysis of a suitable alternative, a floating bridge, has been presented.

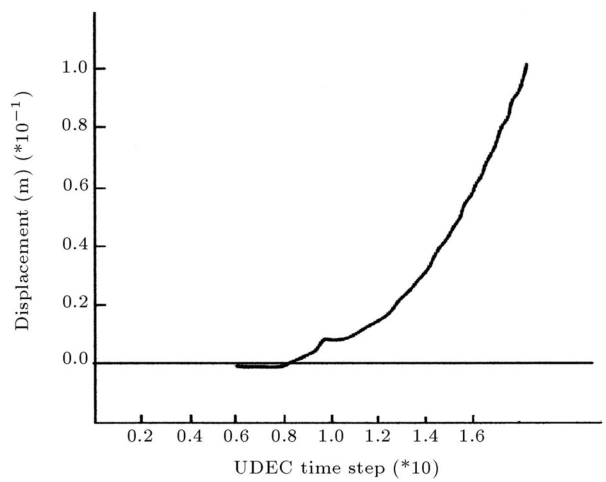

Figure 17. Motion diagram of the block.

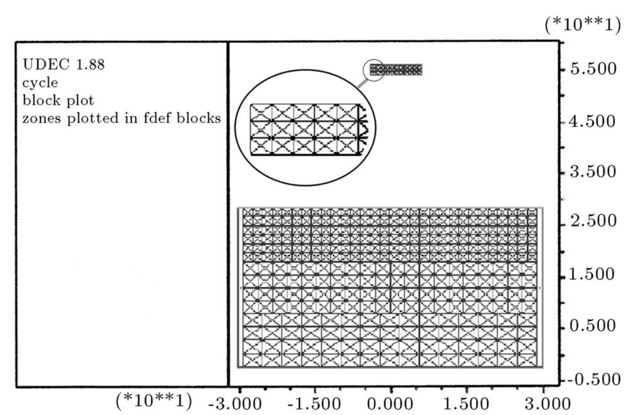

Figure 18. Lay out of the model for anchor release analysis.

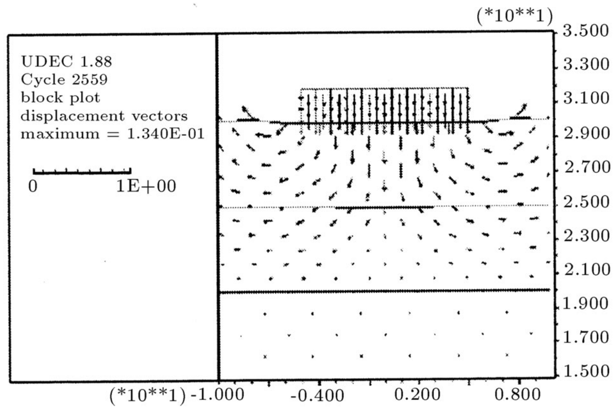

Figure 19. Schematic of displacements and behavior of block after hitting to the sea floor.

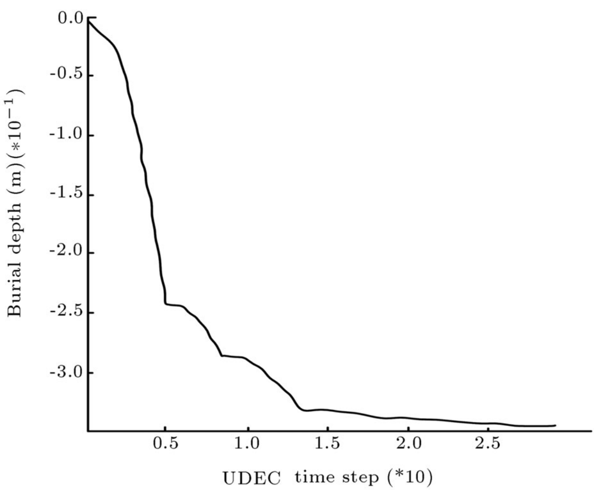

Figure 20. Diagram showing the burial depth of the block.

The presented procedure may be considered as the stages of an optimization software, by which suitable results would be found for the most optimum concept.

From an economical point of view and based on preliminary evaluations, the proposed floating bridge may cost less than half the price of a fixed bridge over Lake Urmia. Furthermore, shorter construction time may be considered as another advantage of this proposal.

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