EVALUATING POINT ABSORBER-BASED WAVE ENERGY CONVERSION IN THE BLACK SEA USING ANSYS AQWA

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Abstract. This study explores the wave energy potential of the Black Sea, with a specific focus on simulating the performance of a point absorber energy conversion system using ANSYS software. The simulation aims to evaluate the system's operational behaviour under realistic marine conditions specific to the Black Sea. Input data are include key environmental parameters, such as an average significant wave height typically ranging between 0.4 m and 0.6 m. The point absorber is identified as a suitable technology for this environment due to its efficiency in moderate wave conditions. Among the analysed locations, the coastal zone near Sinop shows the highest potential for energy capture. The results confirm movements for wave energy converters and the technical viability of wave energy exploitation in the Black Sea and support further development of sustainable marine energy solutions in the region.

Key words: Wave energy efficiency, weather conditions, waves, wind, Black Sea

1. INTRODUCTION

The growing demand for sustainable energy solutions has intensified interest in harnessing marine renewable resources, particularly wave energy. This study investigates the wave energy potential of the Black Sea, emphasizing the simulation of a point absorber energy conversion system using ANSYS software. The objective is to evaluate the dynamic performance of this system under site-specific marine conditions characteristic of the Black Sea basin. Input parameters – such as average significant wave heights ranging from 0.4 m to 0.6 m, prevailing wind speeds, and sea current patterns – are sourced from established literature to ensure realistic modelling. The point absorber, a device known for its efficiency in regions with moderate wave climates, is examined for its suitability in Black Sea.

2. KEY ENVIRONMENTAL FACTORS AFFECTING WAVE ENERGY EFFICIENCY

Wave energy generation is influenced primarily by wind, which transfers kinetic energy to the water surface. Secondary factors include seismic activity and atmospheric pressure gradients. Figure 1 illustrates the typical formation of waves and the main parameters that influence energy capture efficiency.

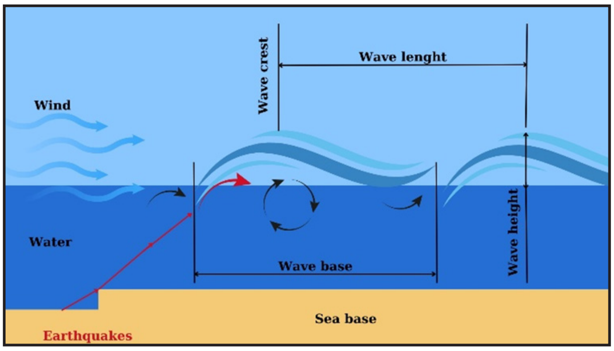

Fig. 1. The formation of the waves.

The main parameters influencing the efficiency of wave energy conversion systems are wind power, sea currents, and atmospheric pressure differentials. To maximize the efficiency of such systems, it is essential to calibrate them according to the specific environmental conditions of the deployment site. Simultaneously, environmental stressors must be considered, as extreme conditions – such as exceptionally large waves or strong currents – can compromise the structural integrity and functionality of the systems if not properly accounted for during the design phase.

3. METEOROLOGICAL CONDITIONS IN THE BLACK SEA

The Black Sea spans approximately 423,500 km² and reaches depths of over 2,200 meters. The basin's stratified waters and enclosed nature influence its energy dynamics. For this analysis, meteorological data were collected from four representative coastal stations: Constanța (west), Sevastopol (north), Sinop (south), and Batumi (southeast), as shown in figure 2.

Wave height data serve as input for the simulation. The following key observations were made:

- **Constanța**: Maximum wave height ≈ 1.4 m; average around 0.5 m, indicating predominantly calm conditions (Çelik, 2018).
- **Sevastopol**: Maximum wave height near 0.4 m (Budea, 2023; Cagatay and Erkal, 2020).
- **Sinop**: Highly dynamic wave regime with peaks up to 3 m; frequent variation due to shifting winds (Cruz, 2008).
- **Batumi**: Mostly calm, with isolated peaks near 2 m (Heath, 2021).

The analysis confirms that a wave height of 0.4 m is a representative and conservative input value for simulation purposes.

Wave height is considered as input in simulation of Point Absorber Systems in Black Sea (Budea, 2023; Cagatay and Erkal, 2020).

Wave height is approximately 0.4 m and this value will be used in simulation as input parameter for ANSYS AQWA.

The meteorological conditions in the Black Sea seem friendly in the Constanta port area, with the maximum wave height reaching 1.4 m in general. The minimum height is 0.1 m, and as an average of the period, the minimum height does not exceed 0.5 m, which indicates a mostly calm sea (Çelik, 2018).

The evolution of wave height in the Sinop area, the maximum wave height is 3 m, and towards the end of the period it does not exceed 1 m (Cruz, 2008).

The Batumi weather station records the lowest values in terms of wave height in the presented analysis. Generally, the waves height not exceed 1 m, with a single maximum of almost 2 m halfway through the period (Heath, 2021), confirming that an input for Ansys simulation of 0.4 m is relevant for the Black Sea.

Fig. 2. Geographical boundaries of the Black Sea.

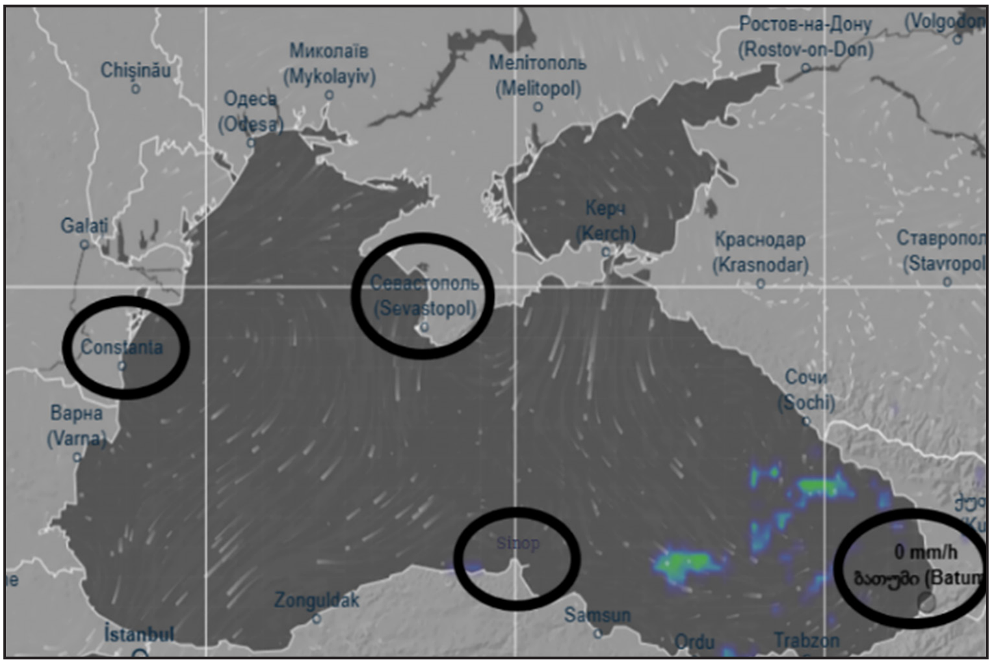

Fig. 3. Study zones along the Black Sea coast.

4. TECHNOLOGY SELECTION: MULTI-BODY POINT ABSORBER

Based on environmental conditions, the Sinop coastal zone emerges as the most promising location for WEC deployment. This site benefits from strong wind exposure and limited coastal obstructions. A multi-body floating point absorber was selected due to its effectiveness in harnessing wave energy in moderate seas. Figure 4 presents the conceptual model. Considering the recorded parameters, the most efficient solution is the implementation of a multi-body point absorber. This technology enables optimal wave energy harvesting and its conversion into electrical power. Additionally, a wind turbine can be installed on the same platform, allowing the integration of wave and wind energy systems to increase overall energy yield.

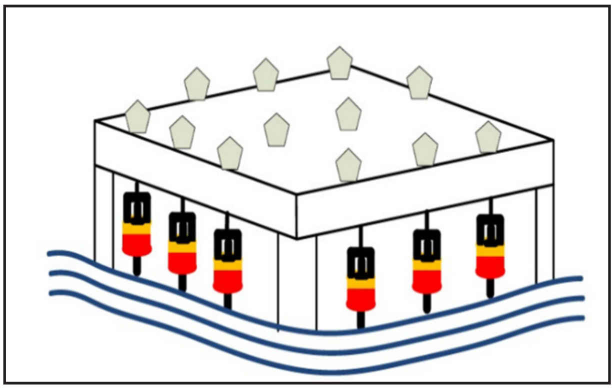

Fig. 4. Multi-body point absorber convertor.

In figure 4, a multi-body point absorber converter is shown. Although they can be floating or submerged, in our case a floating device is recommended. The submerged ones are effective in cases where the waves are created by strong currents. Following the analysis carried out, it was observed that the most energetic waves are created due to the wind, so they are created mainly at the surface.

5. SIMULATION OF WAVE ENERGY CONVERSION USING ANSYS AQWA

The simulation was performed using ANSYS AQWA. The WEC geometry consisted of a $6 \times 5 \times 6$ m body. Figure 5 illustrate the 3D model and mooring configuration.

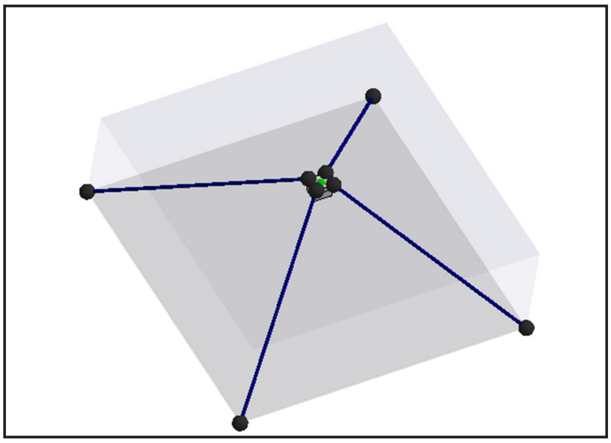

Fig. 5. Geometry of the energy absorber.

In ANSYS AQWA, Froude-Krylov results represent the force coefficients exerted on a floating body due to undisturbed incident waves. They are part of the total wave excitation force and are calculated assuming the body is transparent to the waves (i.e., it does not disturb them). These coefficients are important in ship hydrodynamics, especially in seakeeping analysis, and depend on wave frequency, body geometry, and wave direction. They contribute to the overall wave load together with diffraction forces, forming the complete wave excitation in potential flow theory.

The hydrodynamic behaviour was analysed using Froude-Krylov theory, which quantifies wave-induced forces assuming no wave-body interaction. Coefficients were calculated for incident wave angles of 0°, 45°, and 90°, as shown in figures 6-15.

The dynamics of the energy point absorber due to incident 0° waves (significant wave height is considered to be 7m) during 1800 sec time period is presented in figures 12-15.

The floating converter exhibits continuous oscillatory motion, indicating that energy capture is possible even in low to moderate sea states. This characteristic reinforces its applicability for the Black Sea environment, where flat sea conditions are rare.

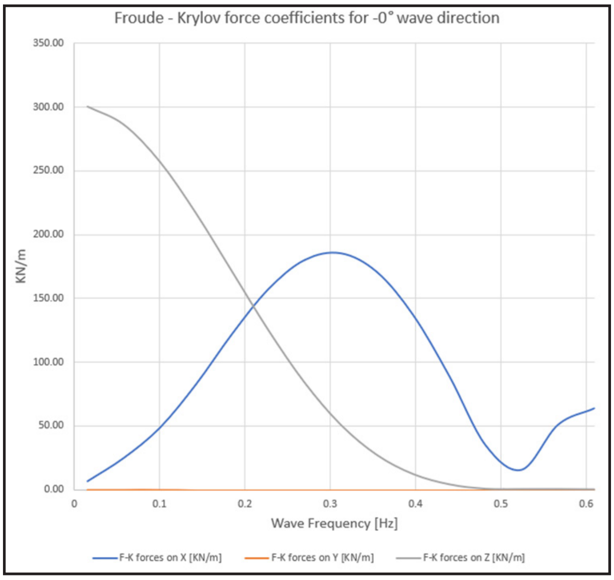

Fig. 6. Froude-Krylov force coefficients for 0 degrees wave direction simulated in ANSYS AQWA.

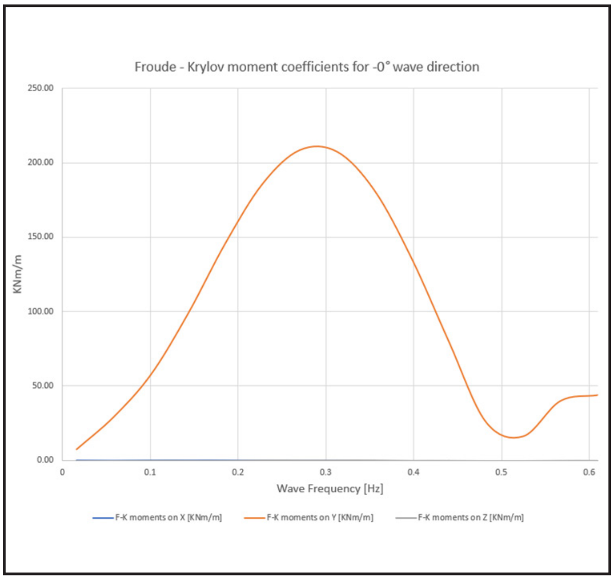

Fig. 7. Froude-Krylov moment coefficients for 0 degrees wave direction simulated in ANSYS AQWA.

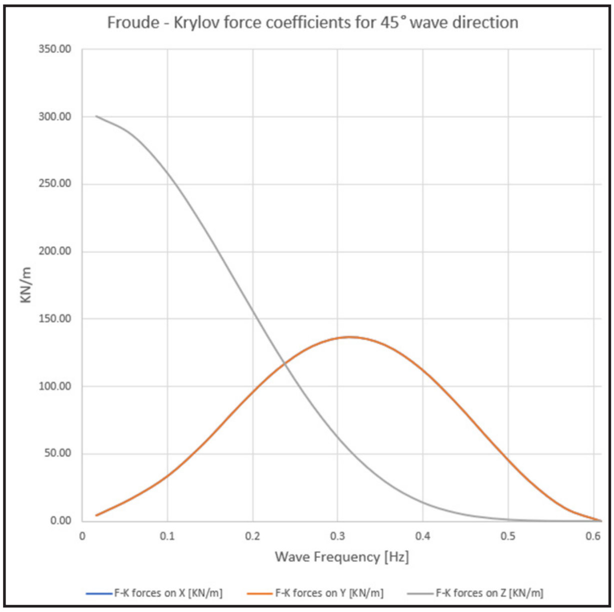

Fig. 8. Froude-Krylov force coefficients for 45 degrees wave direction simulated in ANSYS AQWA.

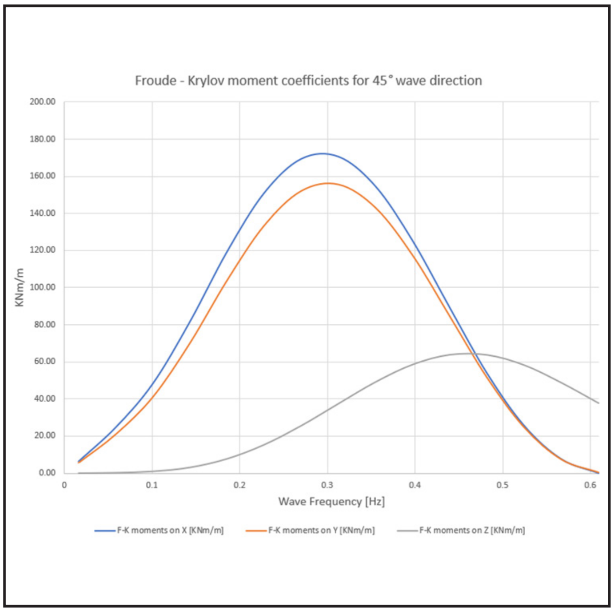

Fig. 9. Froude-Krylov moment coefficients for 45 degrees wave direction simulated in ANSYS AQWA.

Fig. 10. Froude-Krylov force coefficients for 90 degrees wave direction simulated in ANSYS AQWA.

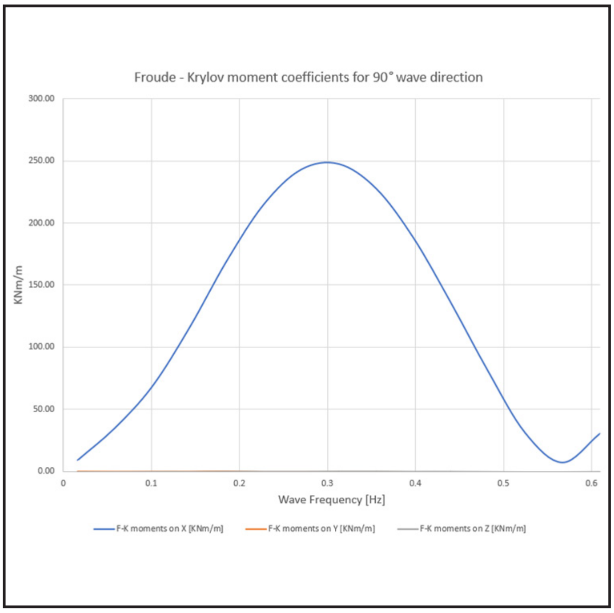

Fig. 11. Froude-Krylov moment coefficients for 90 degrees wave direction simulated in ANSYS AQWA.

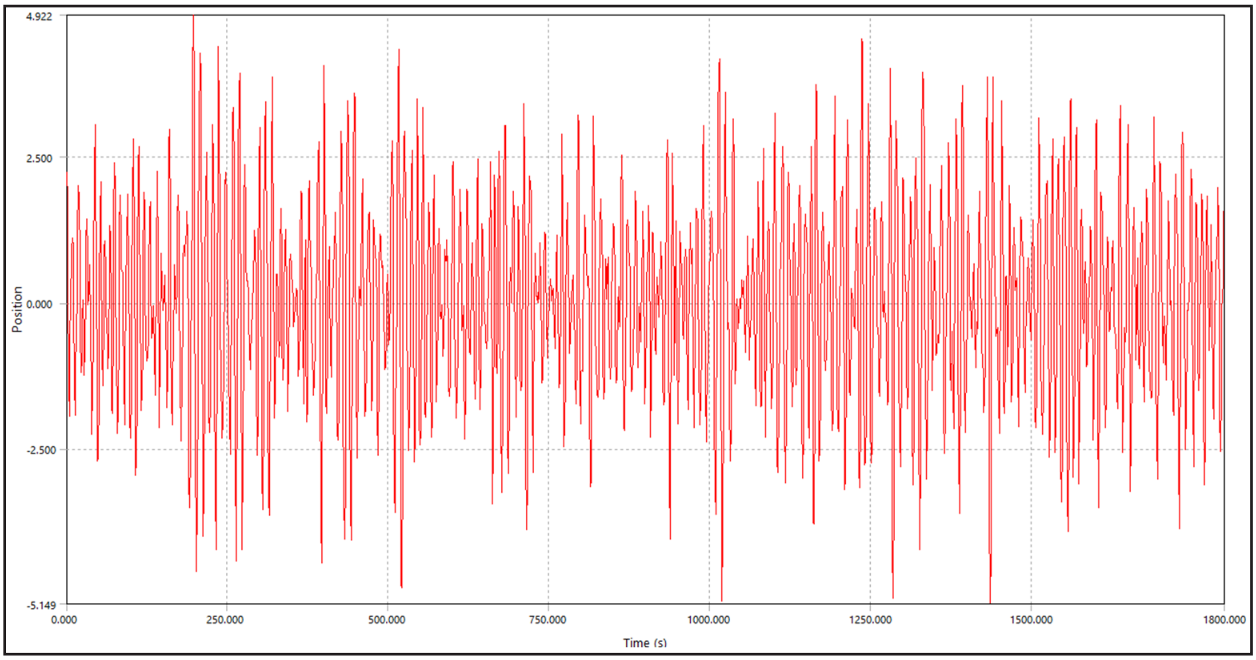

Fig. 12. Motions on Ox direction [m] simulated in ANSYS AQWA.

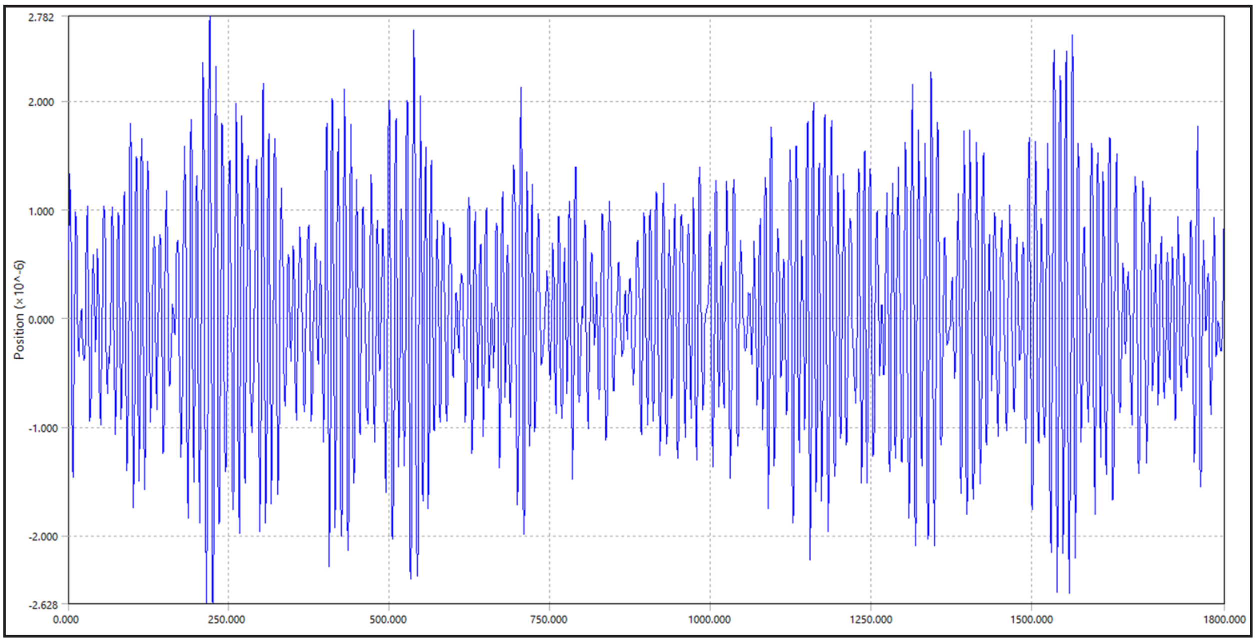

Fig. 13. Motions on Oy direction [m] simulated in ANSYS AQWA.

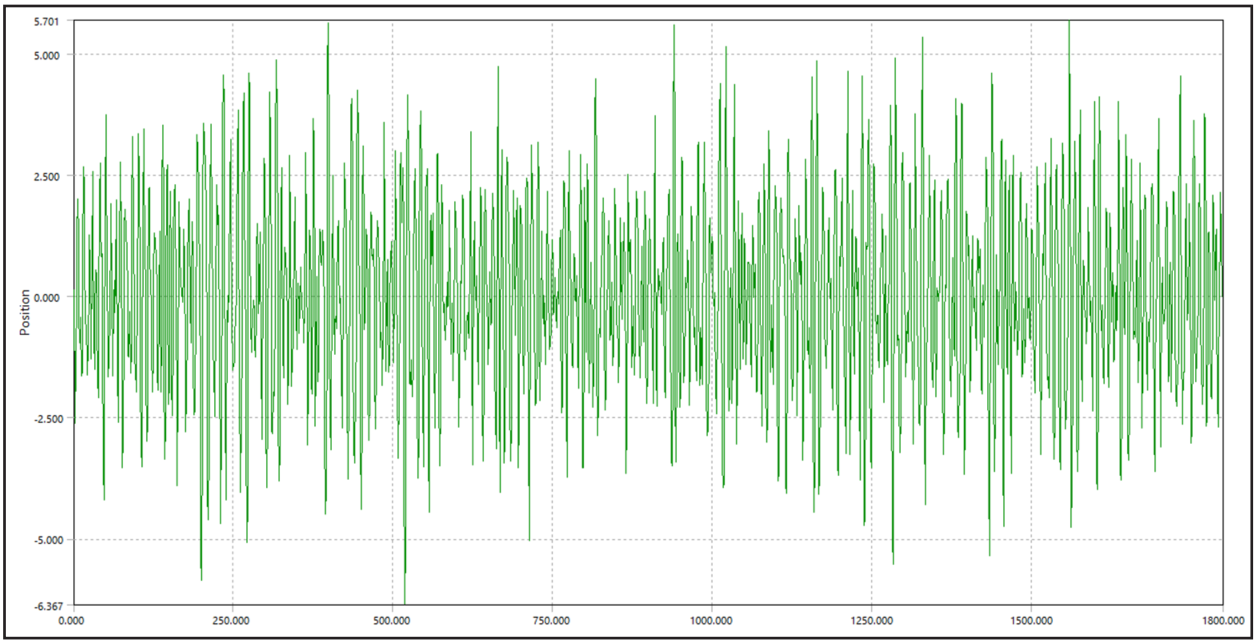

Fig. 14. Motions on Oz direction [m] simulated in ANSYS AQWA.

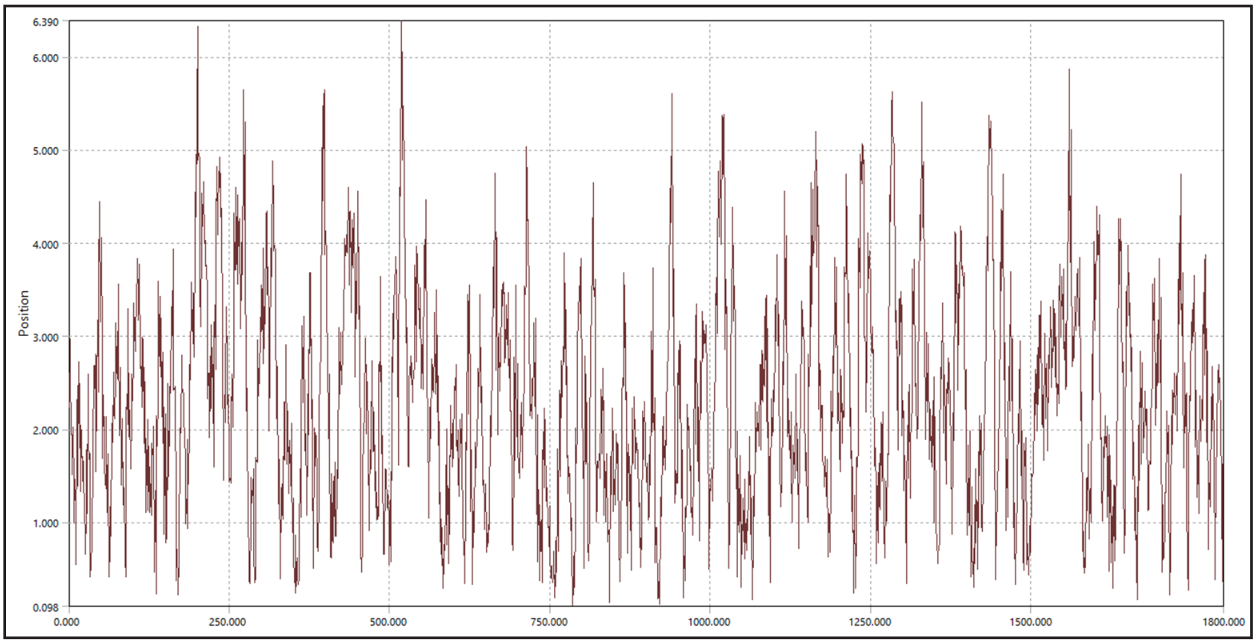

Fig. 15. Distance between initial position and current position [m] simulated in ANSYS AQWA.

6. CONCLUSION

The simulation study confirms that the southern Black Sea, particularly near Sinop, offers favourable conditions for the deployment of point absorber wave energy converters. The area benefits from consistent wave activity, moderate sea states, and geographic positioning conducive to offshore installations.

ANSYS AQWA simulations validate the dynamic performance of a multi-body floating point absorber under Black Sea conditions. The results demonstrate reliable energy capture potential and structural stability. Moreover, the integration of wave and wind technologies on a shared platform could enhance system efficiency and support regional renewable energy goals.

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