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Fatigue Life Amphibious Floater based on RAO Slamming Pressure

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***Abstract*— Floater is one of the most important part of amphibious version plane and conducting study of it becomes one of the featured research to support Indonesia's transportation. This paper examined general study of amphibious floater slamming load when landing on the water in the various plane landing situation, starting from stern 5°, stern 10°, bow 5°, bow 10°, heel 0°, heel 5° and heel 10°. Carbon Fiber Reinforced Polymer (CFRP) material is used with 20 and 40 mm thickness. Floater consists of three main parts which are base, keel, and frame. Seaplane is designed to withstand 1000 cycle (500 landing and 500 take off cycle) in a year. This paper confirms that with the thickness of 20 and 40 mm, and heel position of 0°, floater can withstand up to 65,535 years. In contrary, using the 20 and 40 mm layer when landing with any combination position, the floater can't last and only has 0.01 year of fatigue life.**

Keywords—Seaplane, Amphibious Floater, CFRP, Slamming Pressure, Stress Floater, Fatigue Life Floater.

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I. INTRODUCTION

Indonesia, as an archipelago that consists of islands and waters as its territory, demands many sea-based transportation modes. This is also in-line with one of the Government of Indonesia's programs called "Tol Laut" (Sea Toll/Maritime Highways) [1]. Apart from ships, another primary transportation mode to support this program is aircraft, especially aircraft that have capability to land on the waters (amphibious). One of these amphibious aircraft is produced by PT. Dirgantara Indonesia (Indonesia Aircraft Industries). This aircraft is expected to be the primary transportation mode to support the Sea Toll program [2].

Seaplane aircraft is a modified plane developed from normal model that is designed to be able to carry 19 people onboard. This plane is expected to operate in remote locations which have no runway long enough for regular airplanes. The most notable difference between the base model and its amphibious one is the addition of floater located below the aircraft [3]. This floater addition requires aerodynamic and hydrodynamic calculations for this amphibious plane to run well and efficiently [4]. Amphibious floater is equipped with landing gear for land operation, rudders to help the plane maneuver on the waters, and water-tight compartments to prevent leaks [5].

Earlier, V. Karman [6] presents the amphibious aircraft landing analysis. After that, there are many existing research discussing amphibious aircraft including the 19 passengers aircraft performance comparation between normal and amphibious versions [7]. The results say that the amphibious version has 35-80% higher value of drag coefficient compared to its normal version. This drag coefficient difference is caused by the addition of the floater, and it will influence the amphibious version aircraft performance when landing on the water [8]. When landing on the water, the aircraft's floater becomes the first part that contacts the water. This interaction will cause a structural deformation [9]. Apart from this deformation, this water-to-structure interaction will cause other phenomena such as nonlinear free surface motion [10], viscous effects [11], and hydro elastic structural deformation [12] .

Hydro elastic phenomena become urgent to be studied since this will affect the material structure, furthermore, reducing the material's fatigue life [13]. The fatigue life of a material, especially on a ship or other floating platform, is affected by many factors namely material characteristics [14], crack [15],

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structural geometry [16], and so on. This paper discusses the calculation of amphibious floater material fatigue life caused by impact load when landing on the water, on various wave frequencies and floater fall angle (trim and heel).

II. METHOD

The method used to calculate the amphibious floater material fatigue life caused by the impact load when landing on the water consists of several parts:

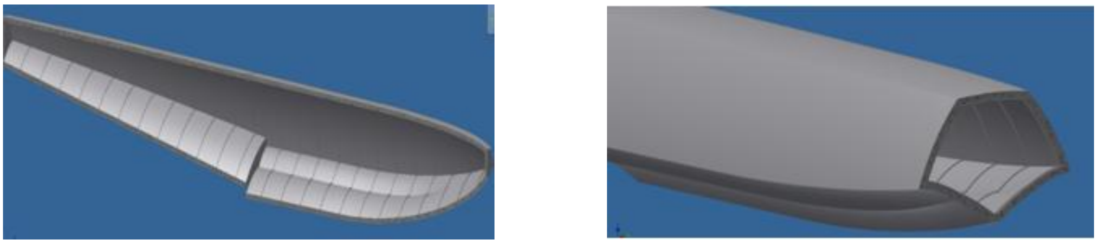
A. Finite Element Analysis

In this paper, Finite Element Analysis (FEA) or Finite Element Method (FEM) is used to calculate the floater's impact load when landing on the water. FEA has been widely used to solve engineering problems starting from simple to complex ones. The main principle of FEA is to split the test object into smaller elements in the hope that these smaller elements are easier to solve. When using the FEA, the analyzed model's material properties and its boundary conditions are defined at the start of the process. This definition will be used to do pressure, stress, and deformation analysis occurred on the model caused by the simulated force. By using FEA/FEM, engineers can analyze efficiently in terms of time and cost. When using FEA method correctly, it is expected to have error margin below 5% compared to the results of experimental method [17].

The part of floater that was used on this paper is illustrated in Figure 1, meanwhile the floater's main dimensions are stated in Table 1. To do the stress analysis, the floater was separated into three parts which were base parts, keel parts, and frame parts. Girder/keel parts were positioned as the vertical support in the center section vertically from the front side to the back side of the floater. Meanwhile frame parts were placed as horizontal support from the right side to the left side of the floater. The frame parts used were 20 frames. The detail of girder/keel and frame is shown in Figure 6.

TABLE 1.
FLOATER MAIN DIMENSION [17]

Items	Full Scale	Model Scale	Unit
Length Over All (LoA)	9.902	1.984	m
Length Water Line (Lwl)	9.57	1.891	m
Length Between Perpendicular (Lpp)	9.902	1.980	m
Beam (B)	1.308	0.261	m
Depth (H)	1.315	0.263	m
Draft (T)	0.740	0.148	m
Scale		1:5	



(a) (b)

Figure. 1. (a) Isometric View Amphibious Floater, (b) Section View Amphibious Floater

B. Material Properties

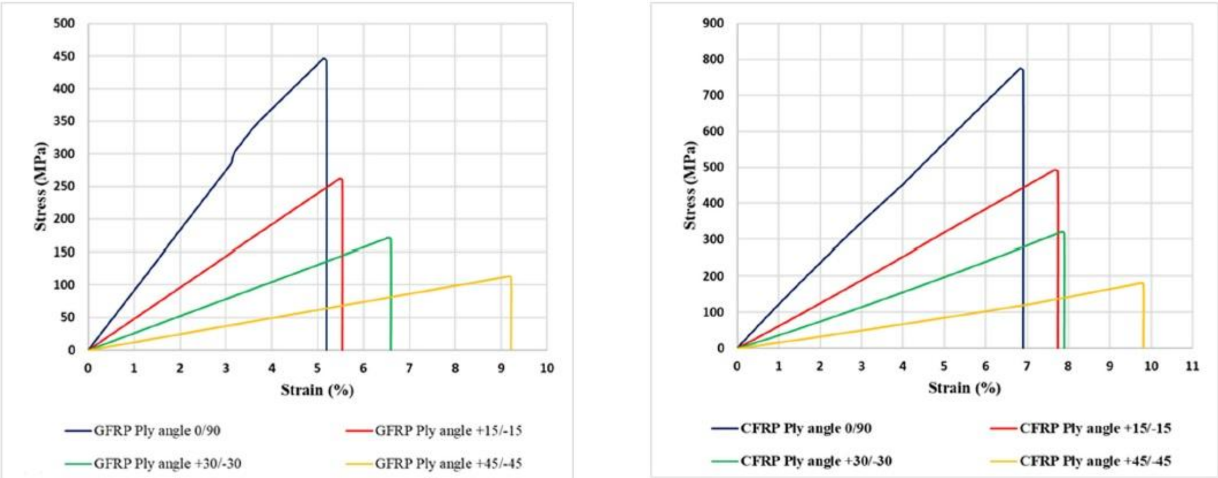
Carbon fiber reinforced polymer (CFRP) was the material used in this paper. The carbon orientation used were (0°/90°), (± 15°), (± 30°) and (± 45°) with each layer has 1 mm thickness [18]. The CFRP's material properties are shown in Table 2 meanwhile its tensile strength and SN-Curve are shown in Figure 2 [19].

TABLE 2.
CFRP MATERIAL PROPERTIES [19]

Items	Full Scale	Unit
Density	1750	kg/m3

CONTINUED TABLE 2.
CFRP MATERIAL PROPERTIES [19]

Items	Full Scale	Unit
Young's Modulus in X direction	91.82	GPa
Young's Modulus in Y direction	91.82	GPa
Young's Modulus in Z direction	9	GPa
Shear Modulus in XY direction	3.6	GPa
Shear Modulus in YZ direction	3	GPa
Shear Modulus in XZ direction	3	GPa
Poison's Ratio in XY	0.05	-
Poison's Ratio in YZ	0.3	-
Poison's Ratio in XZ	0.3	-



(a) (b)

Figure. 2. (a) Tensile Strength CFRP, (b) SN-Curve CFRP [19]

C. Pressure

Pressure value used in this paper were obtained from [20] which the authors have done the study of impact load prediction on seaplane float when landing on the water. The impact load prediction was done by applying slamming load on the trim by stern 5 and 10 degrees, trim by bow 5 and 10 degree, and 0; 5; 10 & 15 degrees angle of heel. The floater fall velocity in this paper was set to 0.762 m/s and falling distance no less than 0.2 to 0.5 meter from the water surface [20].

Numerical method was used to obtain the value of slamming load [21] with meshing size of 0.08; 17,552 elements; and 17,222 nodal points. Frequency was varied from 1, 1.5, 2, 2.5, 3, 3.5, and 4 rad/sec. The results of pressure calculation on trim and angle heel variation caused by floater slamming load are shown in the Figure 3 [21].

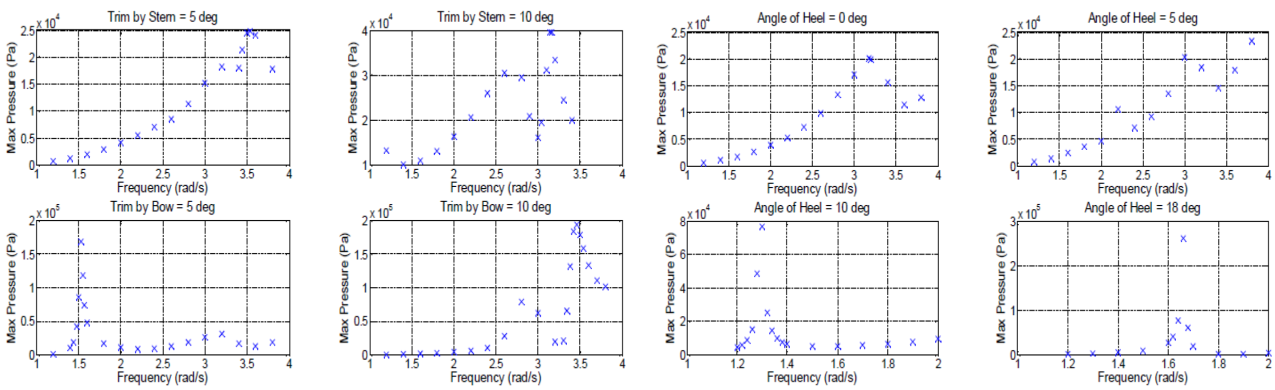


Figure. 3. (a) Pressure slamming trim, (b) Pressure slamming angle of heel [20]

D. Force

After obtaining the pressure value, the next step was to obtain the force value by dividing the pressure by the floater's cross-sectional area or Wetted Surface Area (WSA) as shown in Equation (1).

$$F = Pa \times A \quad 1)$$

Where Pa is pressure of slamming value and A is cross sectional area of floater. To obtain the floater's structure dynamic phenomena when landing, structural damping calculations are the approach used to calculate force. The structural damping (x) is in Equation (2) [12].

$$x = F\, e^{-\zeta \omega_n t} \sin(\omega_d t) \quad (2)$$

$$\zeta = \frac{F}{2m\omega_n} \quad (3)$$

$$\omega_n = \sqrt{\frac{k}{m}} \quad (4)$$

$$\omega_d = \omega_n \sqrt{1-\zeta^2} \quad (5)$$

Where F is force value from Equation (1), ωn is natural frequency of the system, ζ is damping ratio, ωd is damping circular frequency, k is stiffness, m is mass.

E. Fatigue Life

Every material that is applied load into them has fatigue life value which can be calculated or estimated. This value is affected by several things including material characteristics [22], loading frequency [23], and R-ratio [24]. To estimate material's fatigue life, one method commonly used is Palmgreen-Miner rules [25], which can also be used to estimate CFRP-based material's fatigue life [26]. According to Indonesian Aerospace Agency. Seaplane aircraft is designed to withstand 1000 cycle operations (500 landing cycles and 500 takeoff cycles) in the span of 1 year, so that the number of occurrence (n) is 500. Number of cycle to failure (N) is shown in Equation (6).

$$N = aS^{-m} \quad (6)$$

Where a and m can be calculated from SN Curve, S is stress amplitude (at base, at keel dan at frame) in orientation 0/90, 30/-30, 15/-15 and 45/-45. Miner rules can be determined in Equation (7) and the fatigue life (FL) calculation can be determined in Equation (8).

$$D = \sum \frac{n}{N} \quad (7)$$

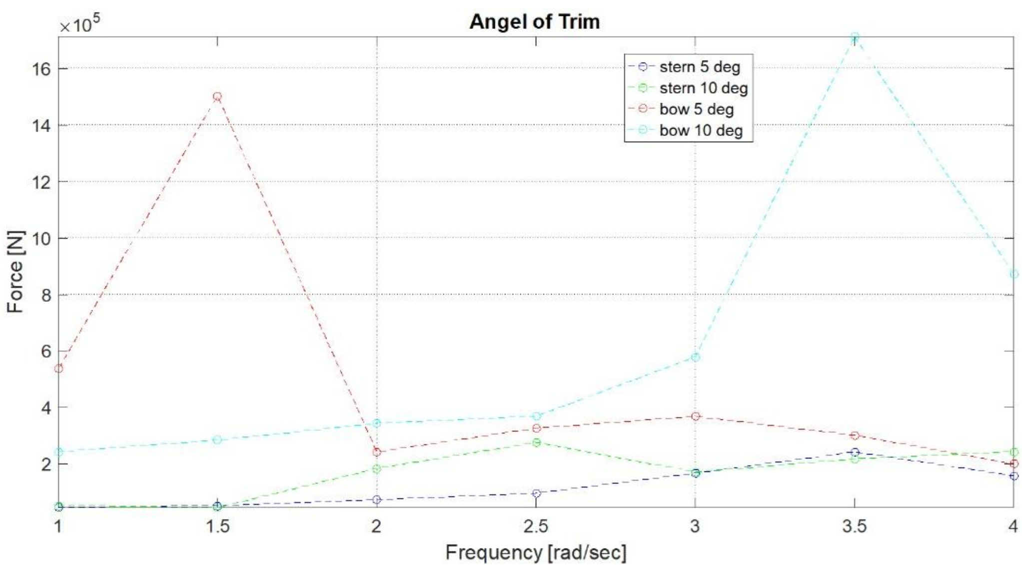
$$FL = \frac{1}{D} \quad (8)$$

Where D = total damage, n = the number of cycles.

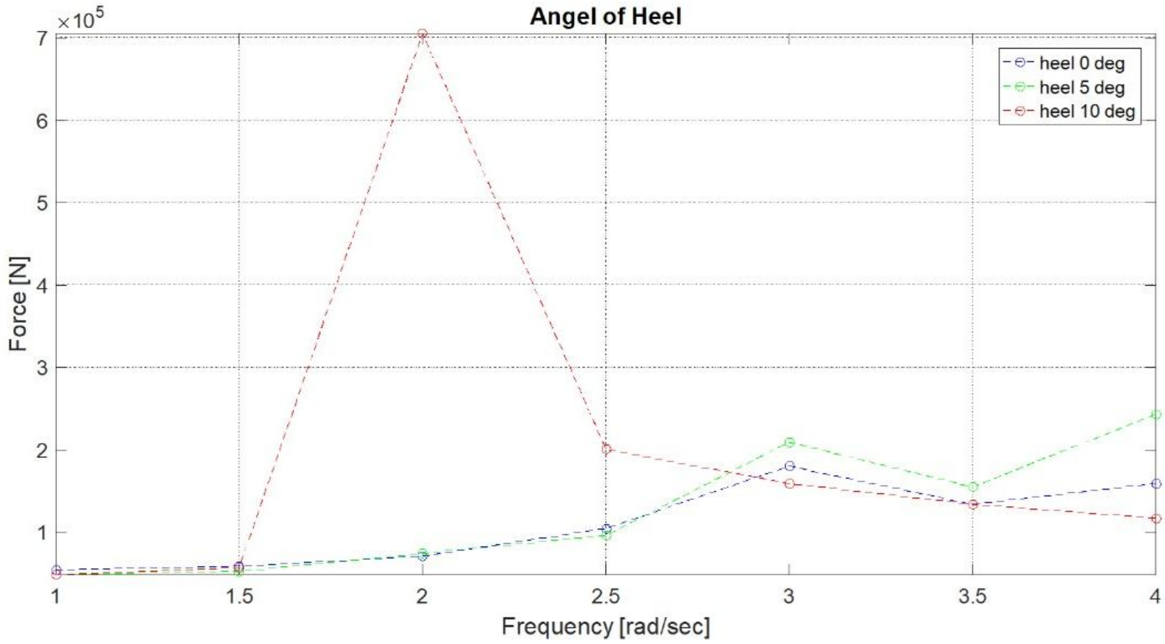
III. Results and Discussion

A. Damping Force Structure Amphibious Floater

Using Equation (1), Figure 4(a) shows the value of the force occurring in the floater varied by floater angle in every height and wave period condition (top-left); the force occurring in the floater on the even-keel condition (top-right); the force occurring in the floater on trim by stern; and the force occurring in the floater on trim by bow condition. Figure 4(b) shows the force value in the floater when it falls from a heel angle. Amphibious floater structural damping force during water landing can be calculated with Equation (2) and is shown in Figure 5.



(a)



(b)

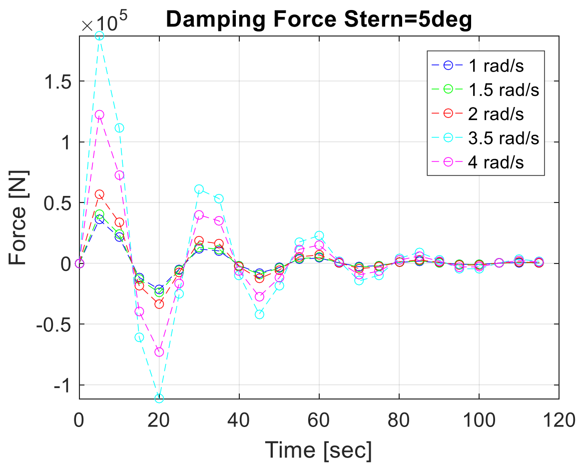
Figure. 4. (a) Variation in angel of trim, (b) Variation in angel of heel

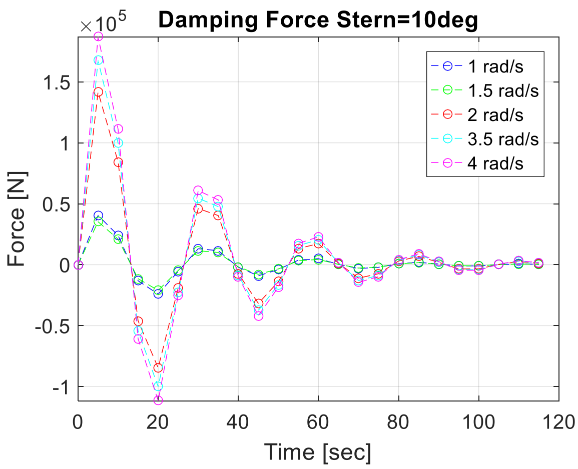
B. Numerical Simulation Structure Amphibious Floater

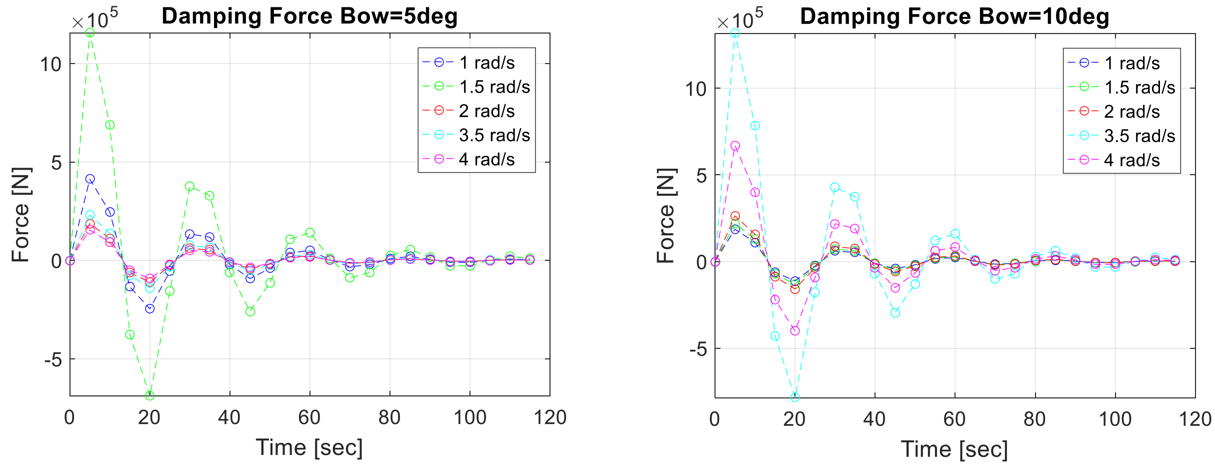
To do the numerical simulation on the CFRP-based material, the ANSYS Composite Polymer Module (ACP Module) is used. CFRP layer directions were varied starting from the (0°/90°), (± 15°), (± 30°) to (± 45°) orientation. The CFRP layer thickness was also varied in this paper. The chosen thickness variations are:

- 20 mm, with details as 10 mm at the base part; 6 mm at the keel part; and 4mm at the frame part,
- 40 mm, with details as 20 mm at the base part; 12 mm at the keel part; and 8 mm at the frame part.

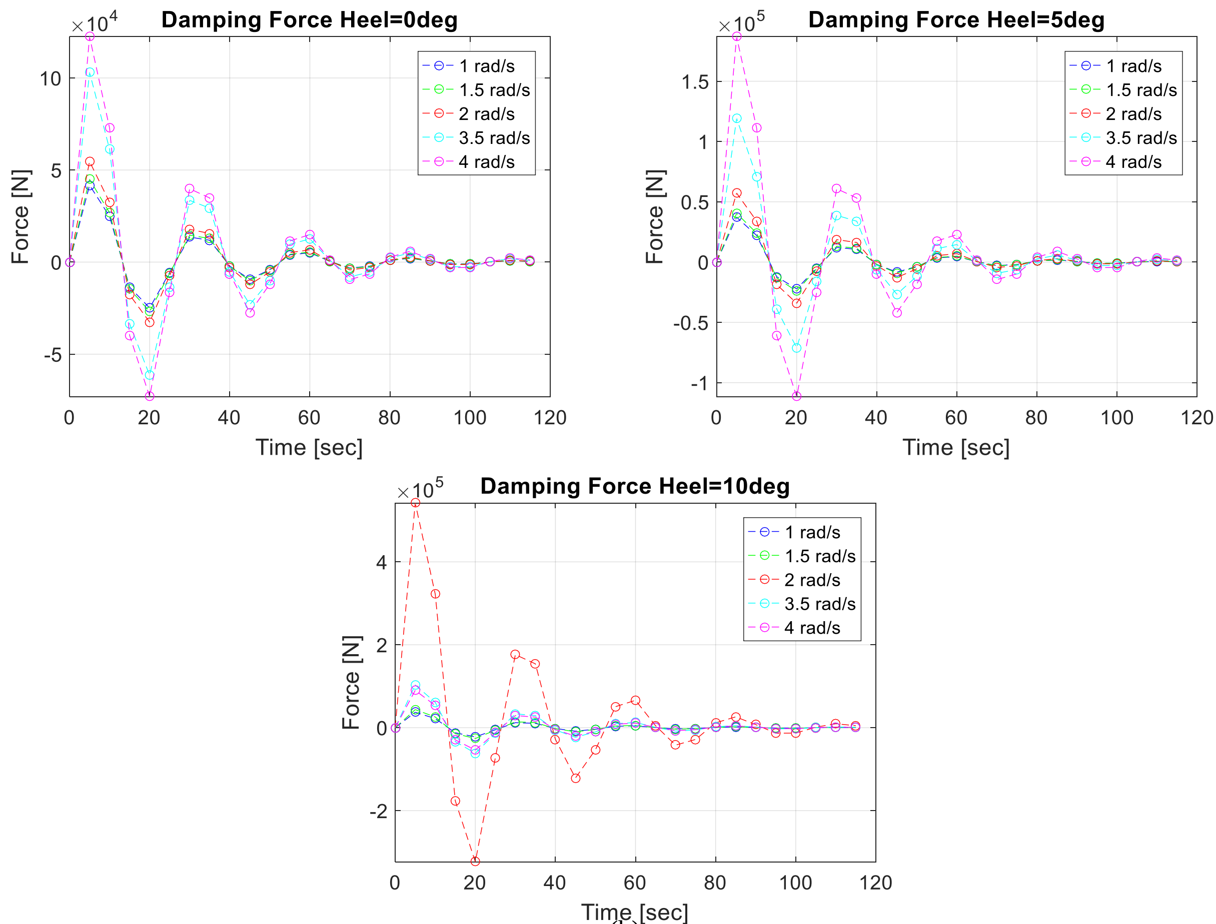
The floater's CFRP thickness variations for 20 and 40 mm are shown in Figure 6. The fiber starting orientation starts from the floater's bottom part towards its upper part. This CFRP layer orientation direction setting is shown in Figure 7(a). Meanwhile the fiber orientation of (0°/90°) is shown in Figure 7(b). After determining the setting in the ACP Module, the numerical simulation continued by using Static Structural Module. This module was used to simulate stress applied to the floater when landing on the water. Meshing size used in this paper was 0.1 mm size, which was already confirmed convergent in the paper [20], are shown in Figure 8. Boundary condition assuming the slamming loads applied to the floater at simple support condition shown Figure 9. The value of amphibious floater damping force was applied as a load in the upper base. The display of meshing, boundary conditions, and RMS force are shown in Figure 7.







(a)



(b)

Figure. 5. (a) Variation in angel of trim, (b) Variation in angel of heel

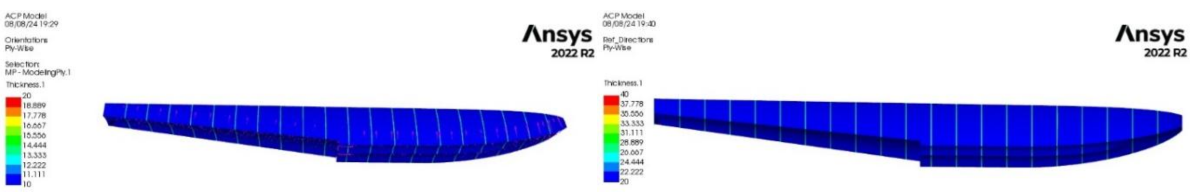
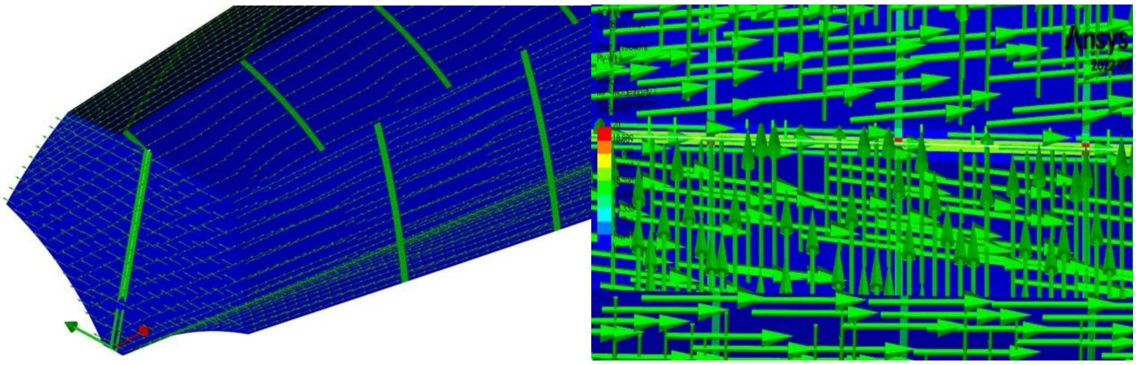


Figure. 6. (a) (a) Thickness CFRP 20 mm, (b) Thickness CFRP 40 mm



(a) (b)

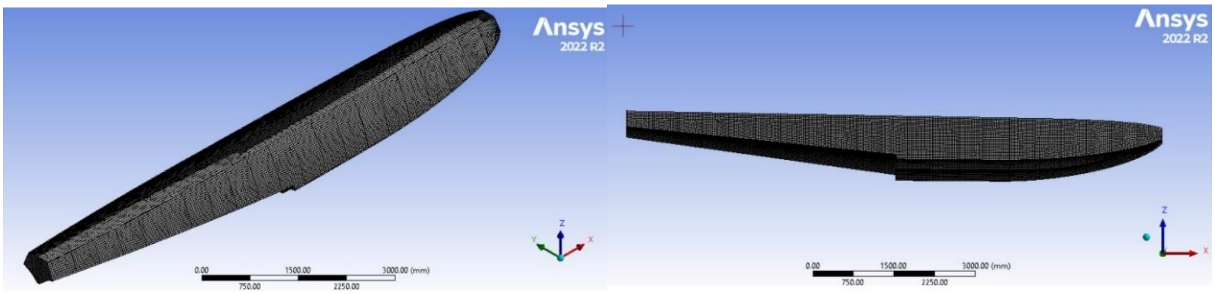
Figure. 7. (a) Orientation layer, (b) Orientation fiber 0/90

C. Stress Structure Amphibious Floater

The stress values were obtained from numerical calculations using input force from Equation (2). In this paper, the stress occurring at the base part, keel, and frame part on the 20 and 40 mm thickness were obtained. The stress values on the 20 mm thickness layer are shown in Figure 10, Figure 11, and Figure 12. In the other hand, the stress values on the 40 mm thickness layer are shown in Figure 13, Figure 14, and Figure 15.

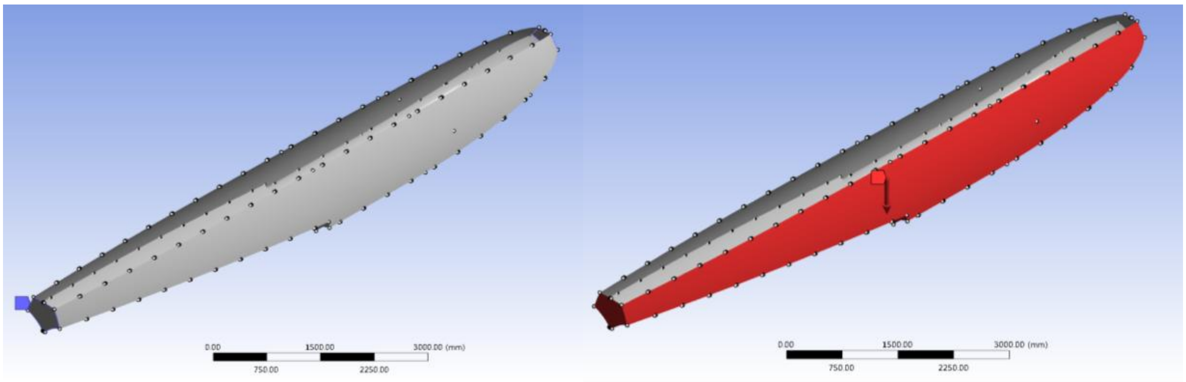
D. Fatigue Life Structure Ampbihious Floater

According to the stress value calculation shown in Figure 10 to Figure 15, the fatigue value in each part (base, keel, and frame part) could be calculated in every fiber layer variation. SN Curve and CFRP orientation, which were used as fatigue life calculations according to Figure 2(b), the value of N could be then calculated from each part using Equation (6). Finally, Equation (7) and (8) were used to calculate the floater's total damage and fatigue life. The value of fatigue life from each orientation are shown in Table 3.



(a) (b)

Figure. 8. (a) Meshing isomatric view, (b) Meshing side view



(a) (b)

Figure. 9. (a) Boundary condition, (b) Load condition

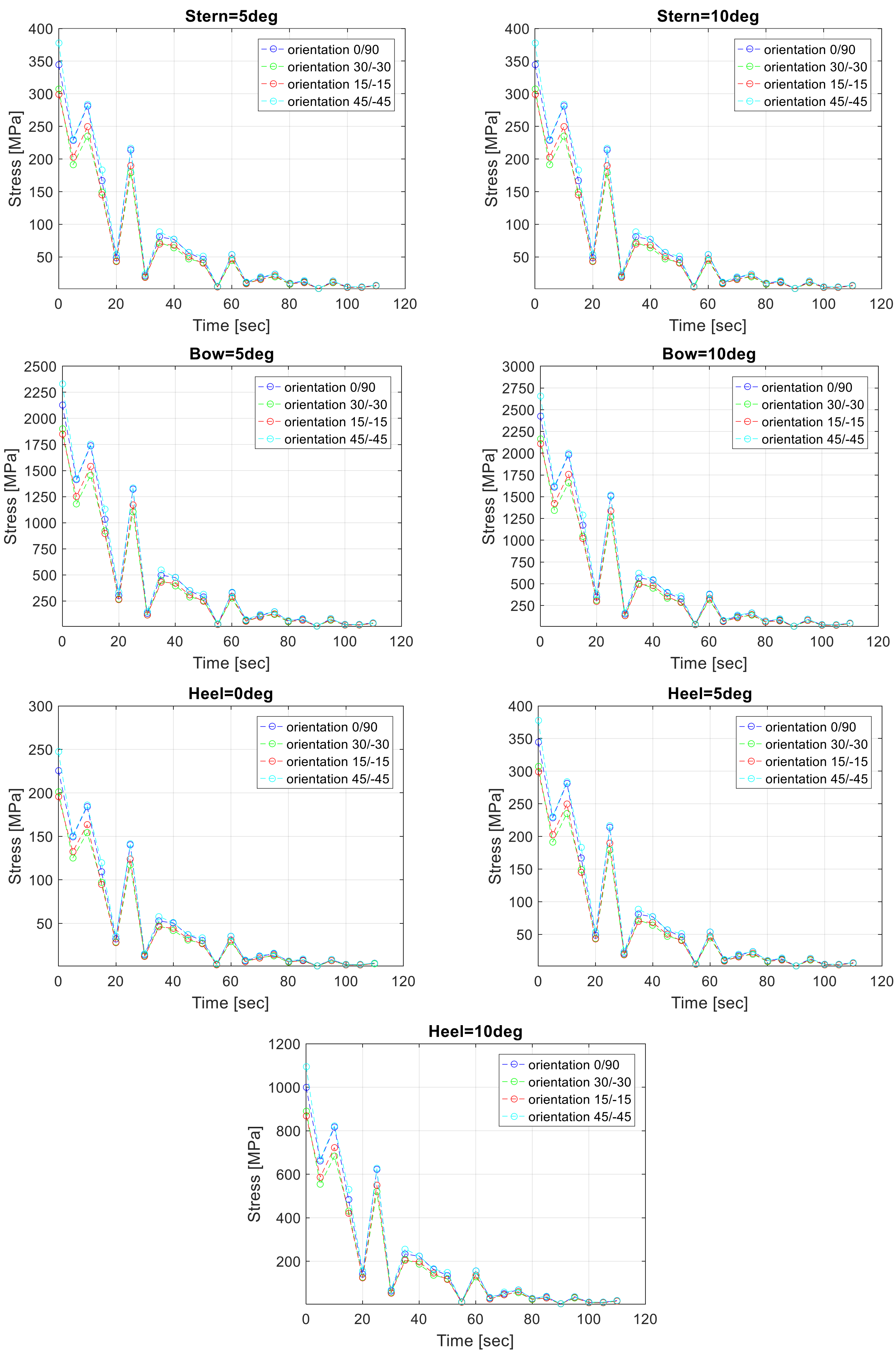


Figure. 10. Stress at base thickness 20 mm

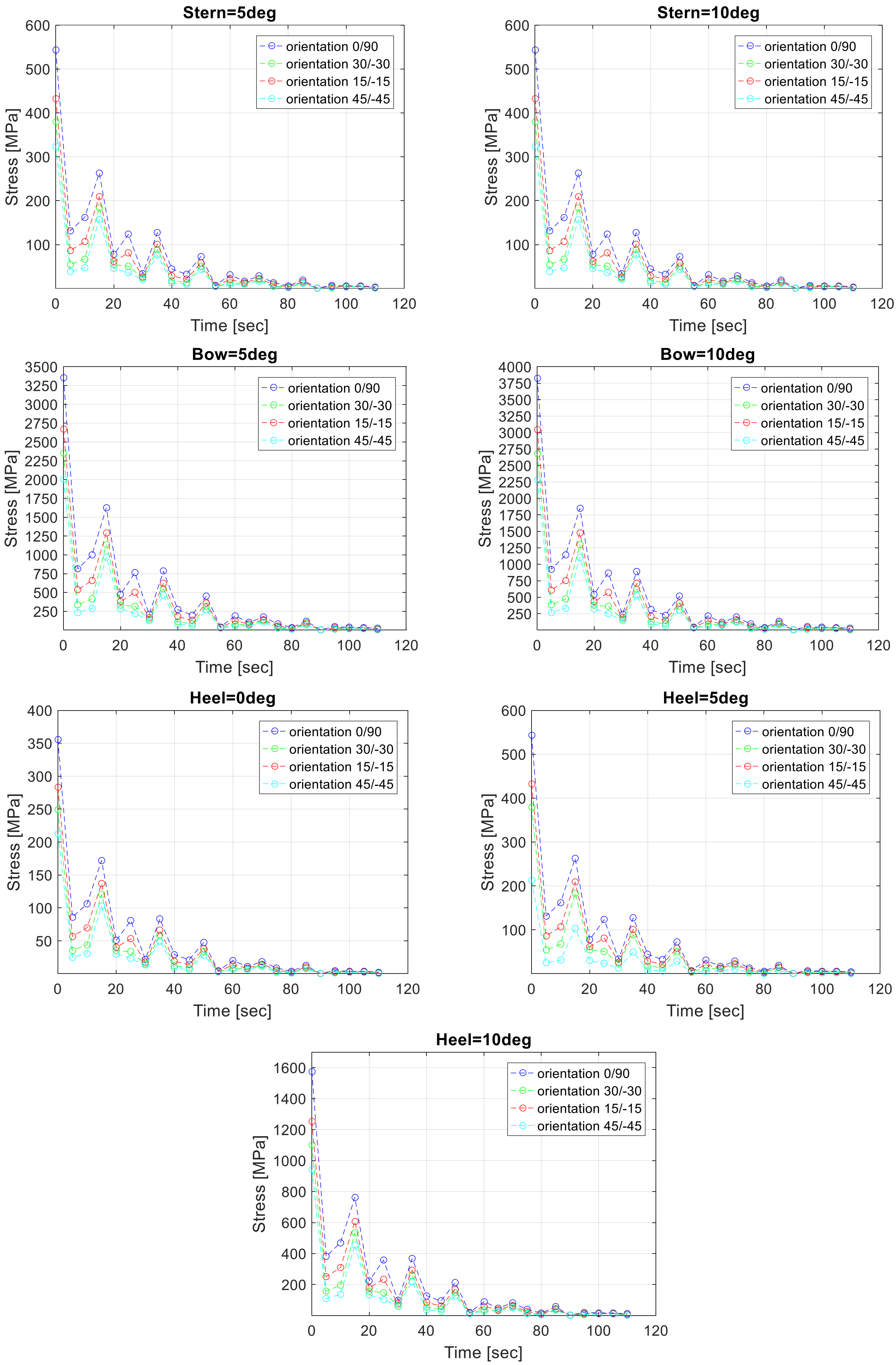


Figure. 11. Stress at keel thickness 20 mm

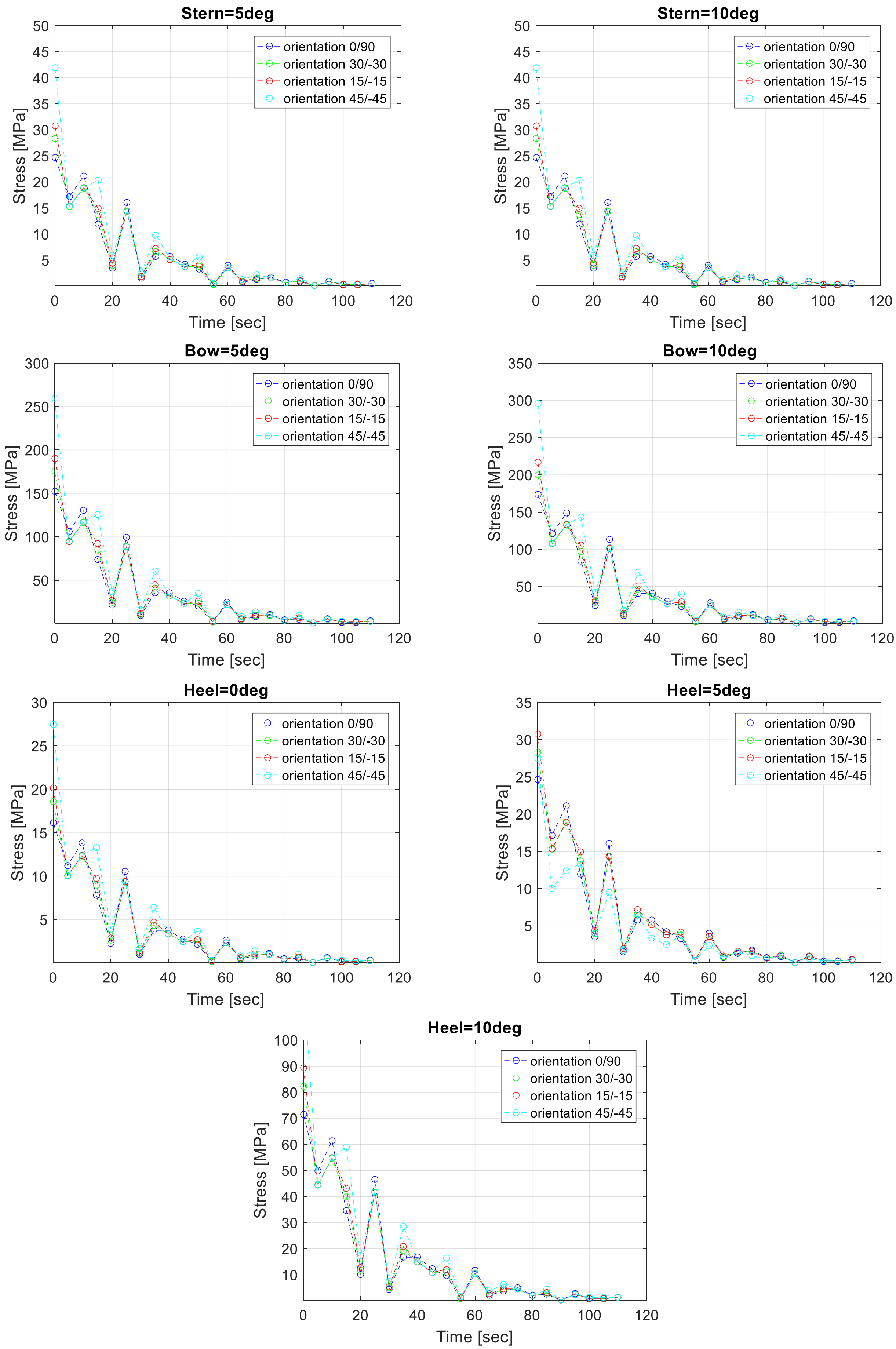


Figure. 12. Stress at frame thickness 20 mm

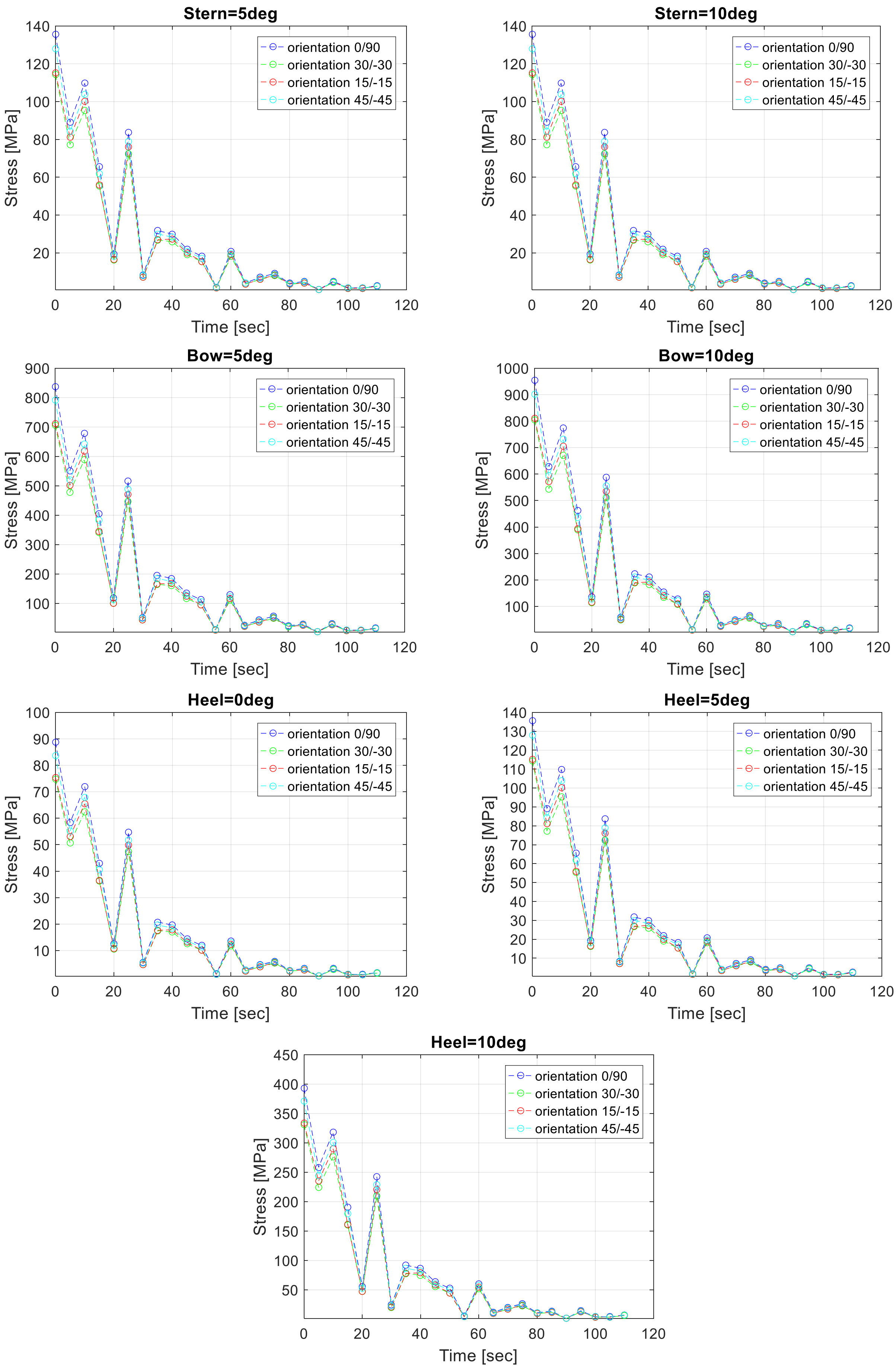


Figure. 13. Stress at base thickness 40 mm

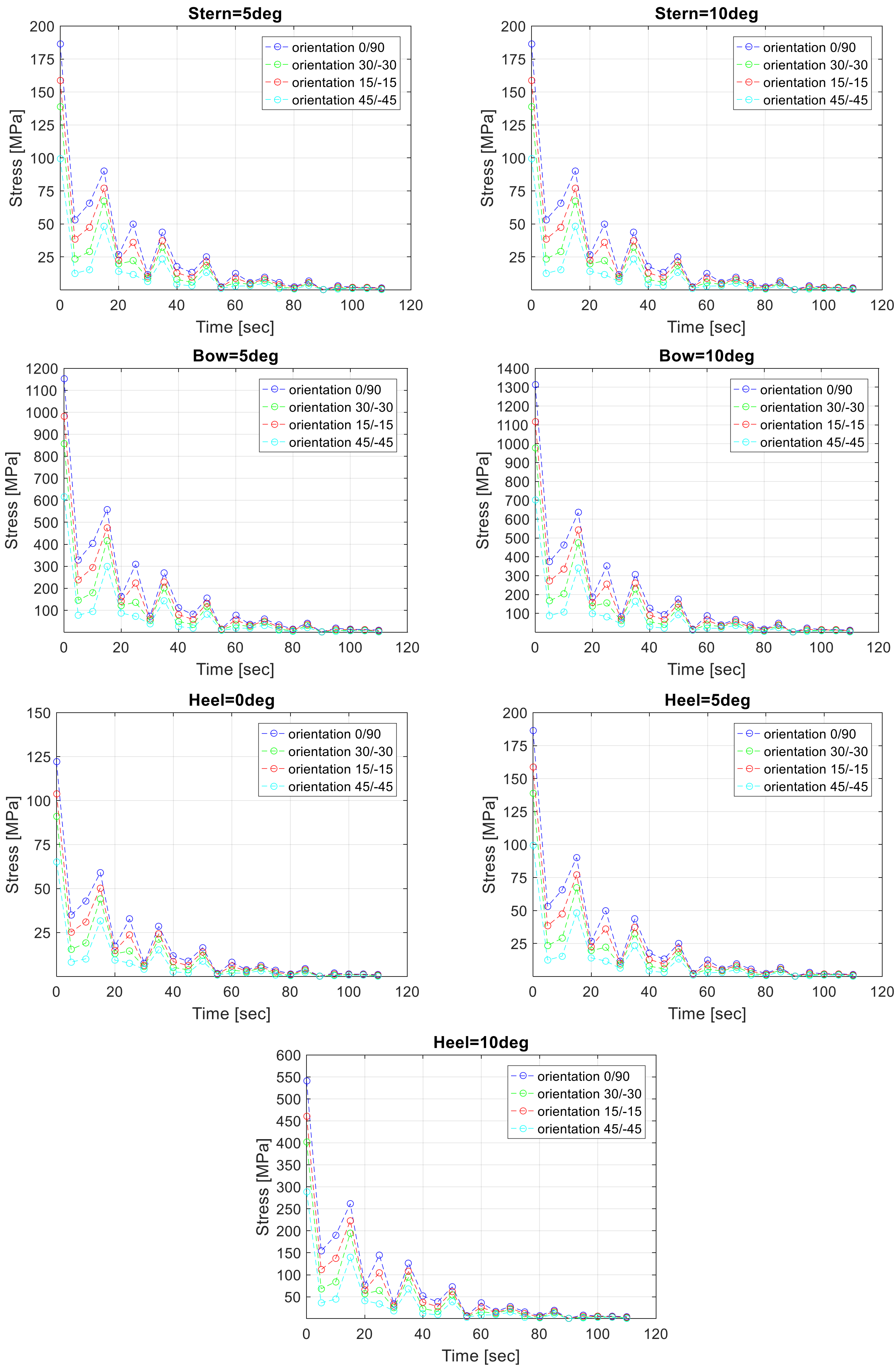


Figure. 14. Stress at keel thickness 40 mm

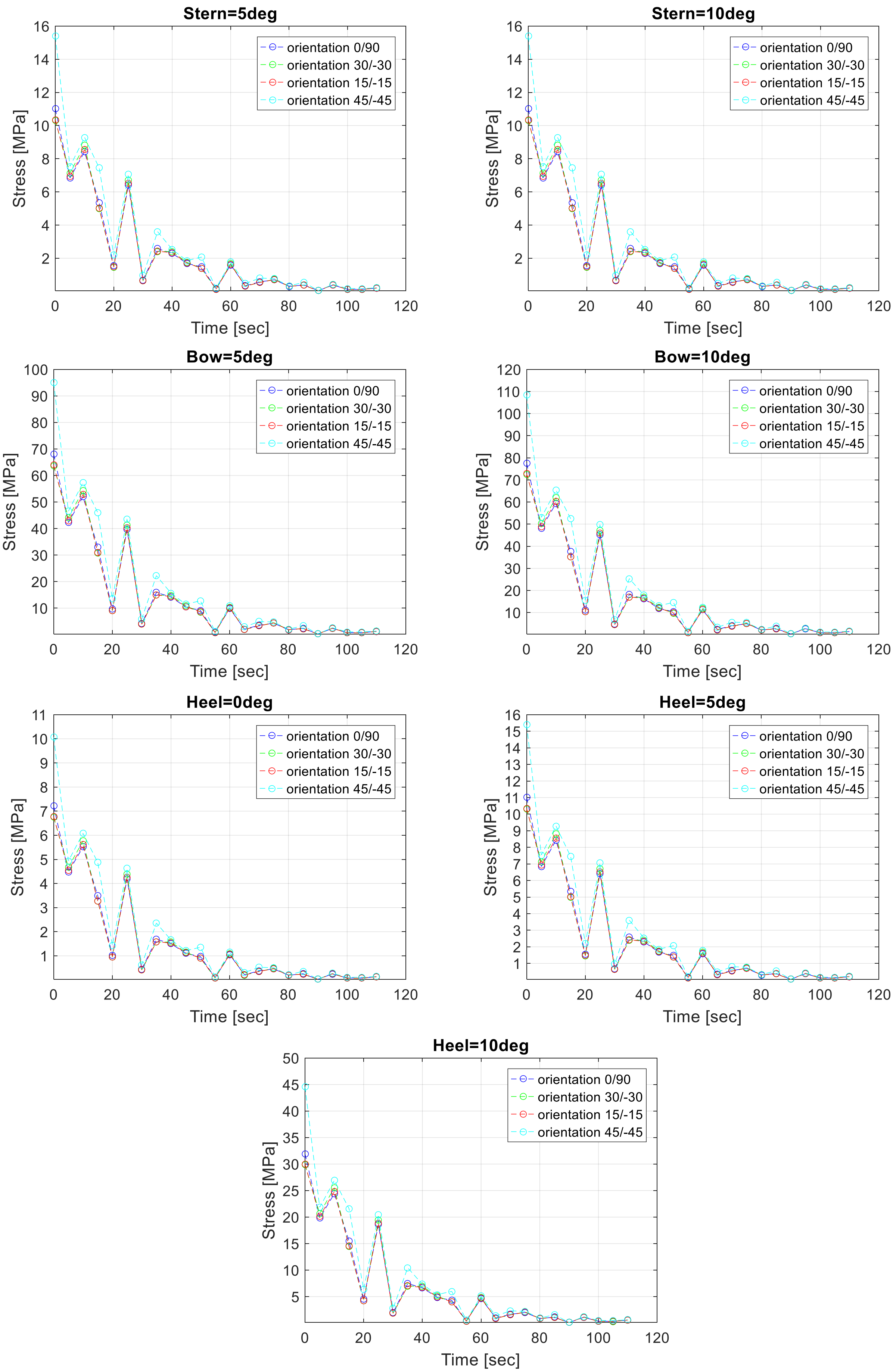


Figure. 15. Stress at frame thickness 40 mm

TABLE 3.
FATIGUE LIFE

Items	Thickness 20 mm				Thickness 40 mm			
	0/90	30/-30	15/-15	45/-45	0/90	30/-30	15/-15	45/-45
Fatigue life at base (year)								
Stern 5°	65,535	65,535	65,535	0.04812	65,535	65,535	65,535	65,535
Stern 10°	65,535	65,535	65,535	0.04812	65,535	65,535	65,535	65,535
Bow 5°	$5.09 x10^{-4}$	$7.53 x10^{-5}$	$6.44 x10^{-4}$	$2.43 x10^{-6}$	1.17775	0.02275	0.26859	0.00064
Bow 10°	$1.72 x10^{-4}$	$3.48 x10^{-5}$	$2.79 x10^{-4}$	$1.22 x10^{-6}$	0.39839	0.01042	0.11556	0.00032
Heel 0°	65,535	65,535	65,535	65,535	65,535	65,535	65,535	65,535
Heel 5°	65,535	65,535	65,535	0.04820	65,535	65,535	65,535	65,535
Heel 10°	0.26976	0.00656	0.08202	0.00013	765.757	65,535	65,535	0.05283
Fatigue life at keel (year)								
Stern 5°	52.15824	1.32111	10.35042	65,535	65,535	65,535	65,535	65,535
Stern 10°	52.15824	1.32111	10.35042	65,535	65,535	65,535	65,535	65,535
Bow 5°	$1.45 x10^{-5}$	$2.8 x10^{-5}$	$8.83 x10^{-5}$	$7.23 x10^{-6}$	0.10273	0.01073	0.05393	0.00368
Bow 10°	$4.89 x10^{-6}$	$1.29 x10^{-5}$	$3.82 x10^{-5}$	$3.63 x10^{-6}$	0.03475	0.00496	0.02335	0.00185
Heel 0°	1,745.301	65,535	65,535	65,535	65,535	65,535	65,535	65,535
Heel 5°	52.15824	1.32111	10.35042	65,535	65,535	65,535	65,535	65,535
Hell 10°	0.00767	0.00244	0.01124	0.00039	54.62453	0.94722	6.93033	65,535
Fatigue life at frame (year)								
Stern 5°	65,535	65,535	65,535	65,535	65,535	65,535	65,535	65,535
Stern 10°	65,535	65,535	65,535	65,535	65,535	65,535	65,535	65,535
Bow 5°	65,535	65,535	65,535	65,535	65,535	65,535	65,535	65,535
Bow 10°	65,535	65,535	65,535	65,535	65,535	65,535	65,535	65,535
Heel 0°	65,535	65,535	65,535	65,535	65,535	65,535	65,535	65,535
Heel 5°	65,535	65,535	65,535	65,535	65,535	65,535	65,535	65,535
Heel 10°	65,535	65,535	65,535	65,535	65,535	65,535	65,535	65,535

IV. CONCLUSION

From Table 3, it can be shown that the floater that uses CFRP layer with 20 and 40 mm thickness can have a longer fatigue life when landing on heel 0° position with 500 landing cycles. The fatigue life at the base, keel, and frame part shows the value over 1,745 years. However, when the floater lands with the angle of trim combination position (stern and bow 5-10°), both 20 and 40 mm thickness layer cannot withstand the load and only have fatigue life value of 1.2 years when landing at the bow angle of 10°. The layer with 20 and 40 mm thickness also cannot withstand the load for the angle of heel combination condition (heel 5-10°) with its fatigue life only 0.01 years. Therefore, it is required to add more thickness to the floater's CFRP layer with the minimum of 50 mm thickness. Subsequently, it is also urgently needed to run the stress simulation and fatigue life calculations, so that the minimum value of floater's layer thickness is obtained for the floater to be able to land on the water with angle of trim and angle of heel variation.

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