# A Comparative Structural Analysis of Shell-first and Frame-based Ship Hulls of the 1st Millennium AD

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## Introduction

The 1st millennium AD experienced a significant change in ship construction. A slow transition evolved where ships built 'shell-first' were ultimately supplanted by 'frame-based' ships. Shell-first ships were constructed with strakes edge-jointed using pegged and later unpegged mortise-and-tenons, dowels or coaks, and at times, sewing. Frame-based ships were characterized by transverse frames; most of the frames were fixed to the keel and reinforced by longitudinal components. The hull planks were later fastened to the pre-existing frames. The transition from shell-first to frame-based was completed as early as the 6th—7th centuries although the shell-first construction persisted for several centuries (Pomey et al., 2012, p. 308) (Fig. 1).

The objective of this work is to focus and examine whether mechanical factors contributed to the 'transition in ship construction'. The research employed Finite Element Analysis (FEA), a computerized numerical technique used for solving field problems in various engineering disciplines.

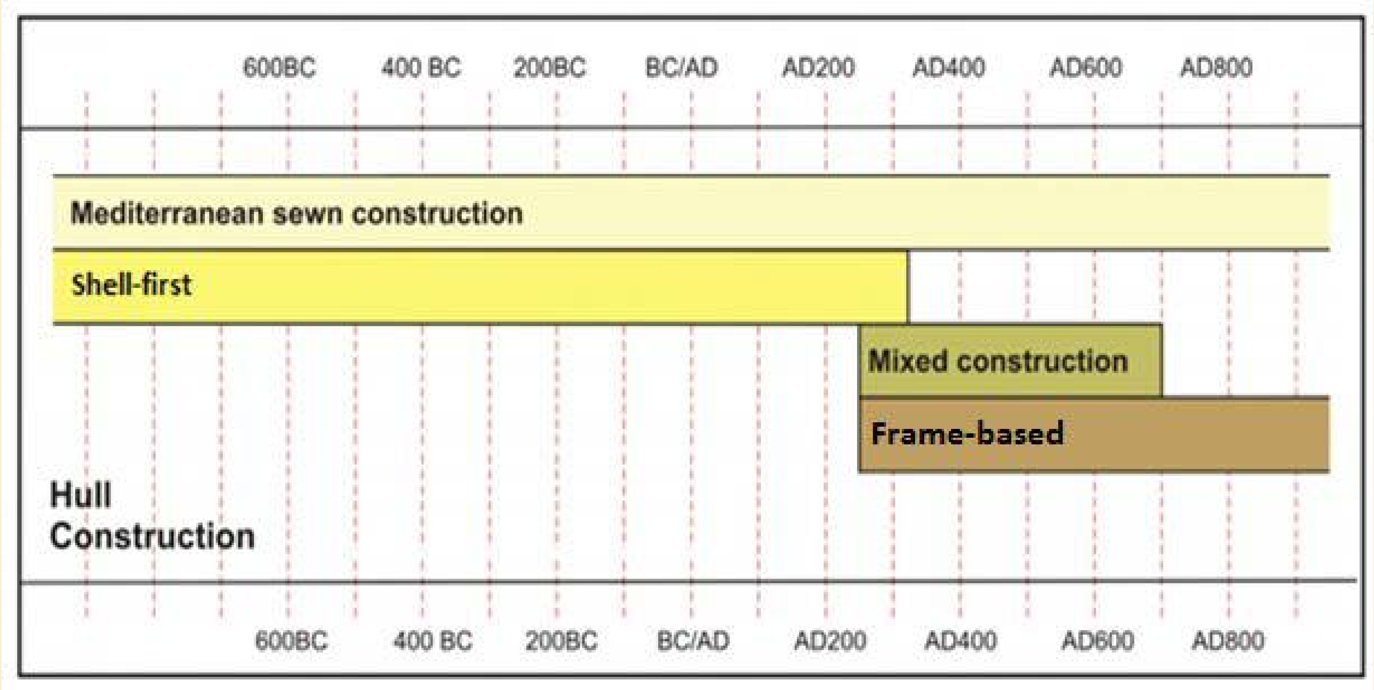


**Figure 1**: The relative time-lines of hull construction and features in the Mediterranean (Whitewright, 2008, p. 174).

## Research Methods

Determining the import of structural and mechanical factors contributing to the transition from shell-first to frame-based construction, a comparative global FEA structural analysis approach was adopted based on the guidelines of the DNV GL, an international certification body for yachts and boats (Lloyd, 2003),.

The global FEA simulations were conducted on CAD models of the Ma'agan Mikhael ship dated to 400 BC and the Dor 2001/1 shipwreck dated to 6th C. AD. Multiple external loads were applied which included gravity, hydrostatic hull pressure, cargo, wind pressure and longitudinal axial torsion (Figs. 2, 3). Stillwater hogging and sagging simulations were also performed.

In order to study the transition in a controlled environment, architype of shell-first and frame-based models were devised where loads and load directions were varied. In addition, the number of frames were varied. Materials and mesh levels remained constant (Fig.4).

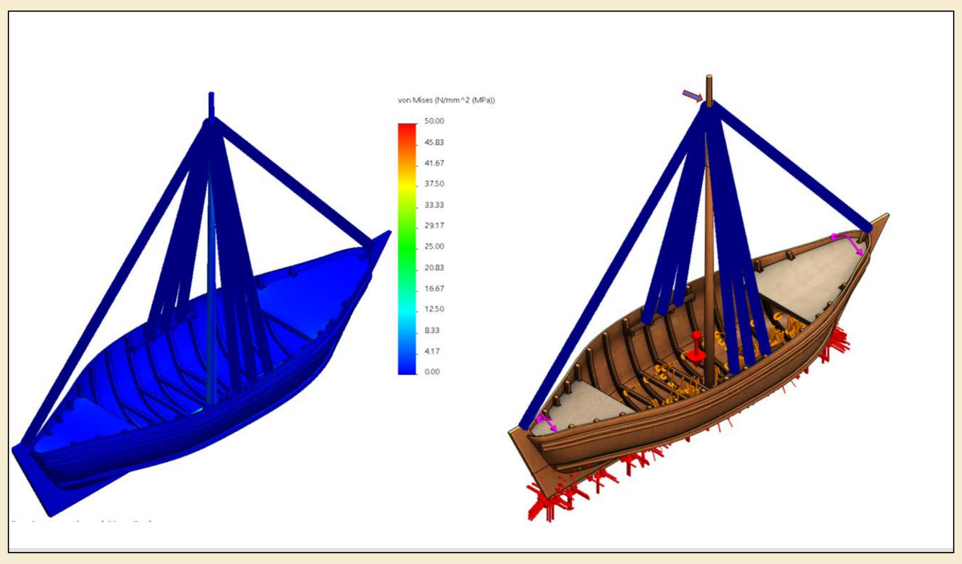

**Figure 2**: Ma'agan Mikhael ship—loads and FEA analysis.

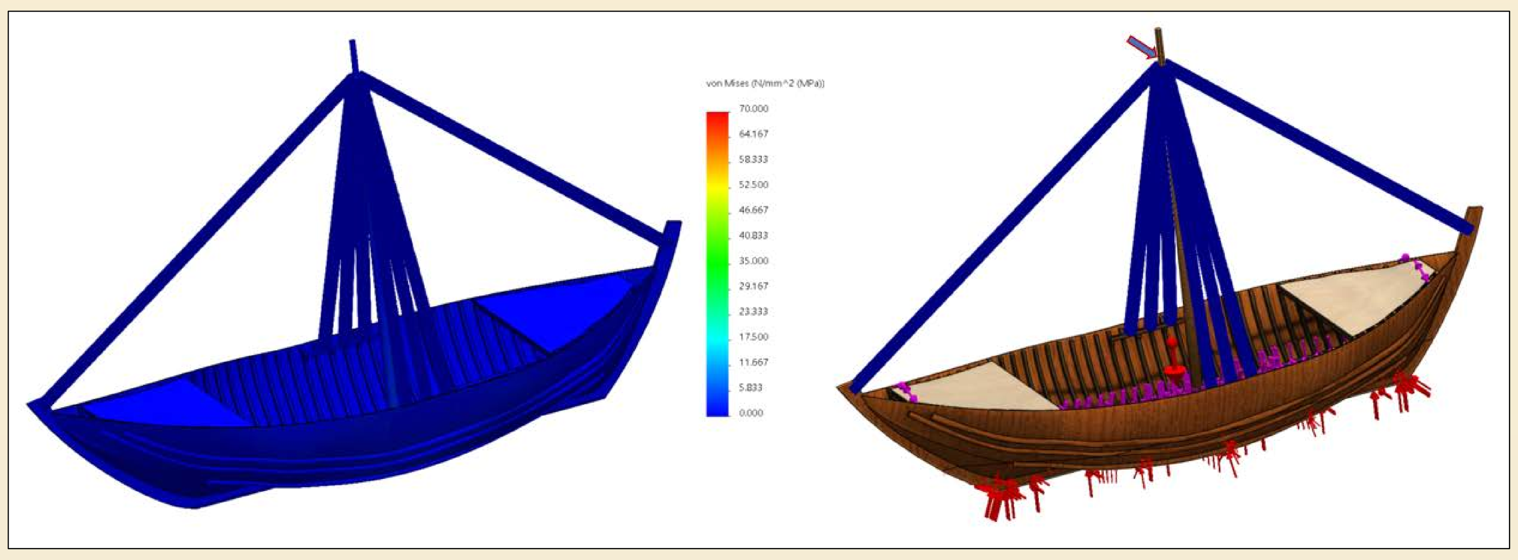

**Figure 3**: Dor 2001/1 shipwreck—loads and FEA analysis.

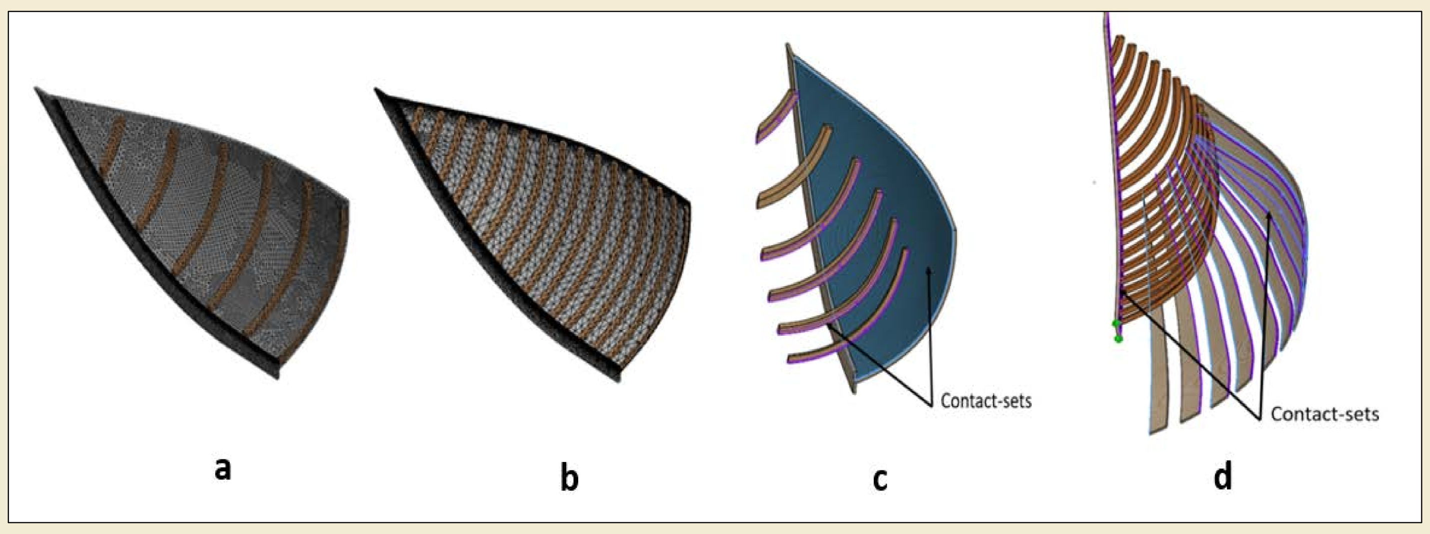


**Figure 4:** Archetype models of shell-first and frame-based: a) shell-first meshed; b) frame-based meshed; c) exploded shell-first model; d) exploded frame-based model.

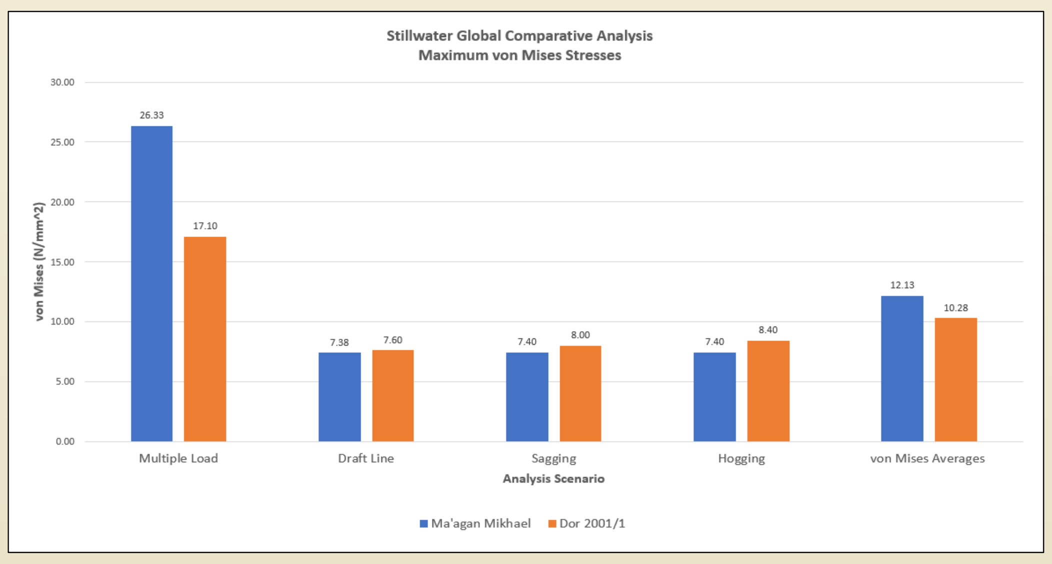


**Figure 5**: Global and stillwater von Mises stress results.

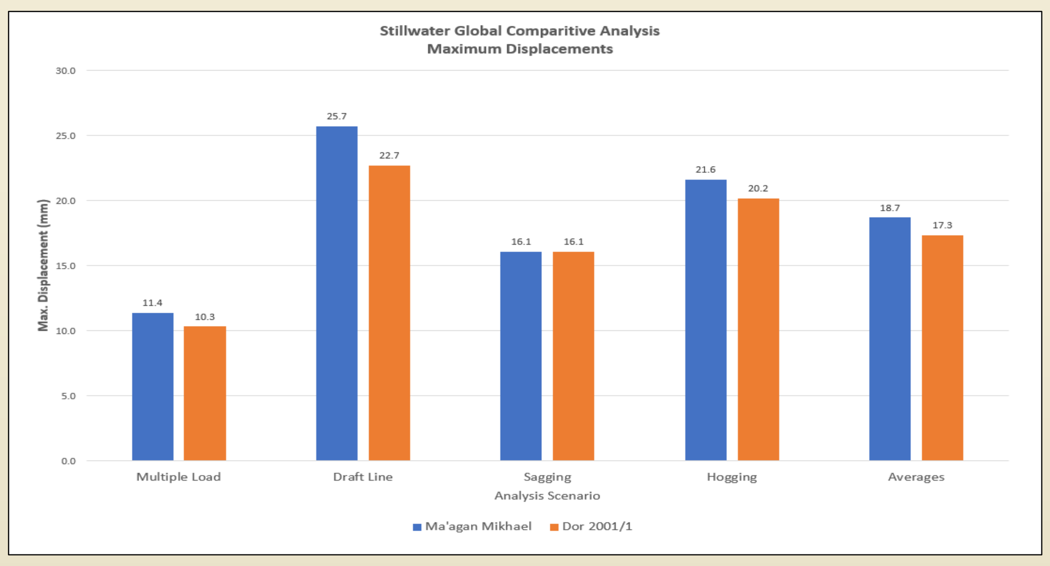


**Figure 6**: Global maximum displacement results.

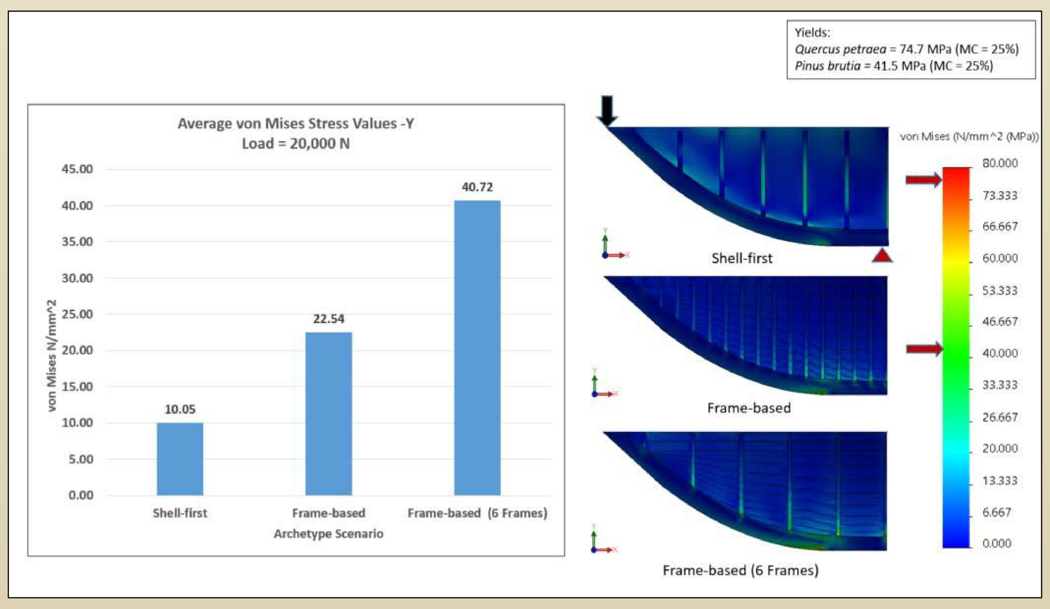

**Figure 7**: Archetypal von Mises stress results.

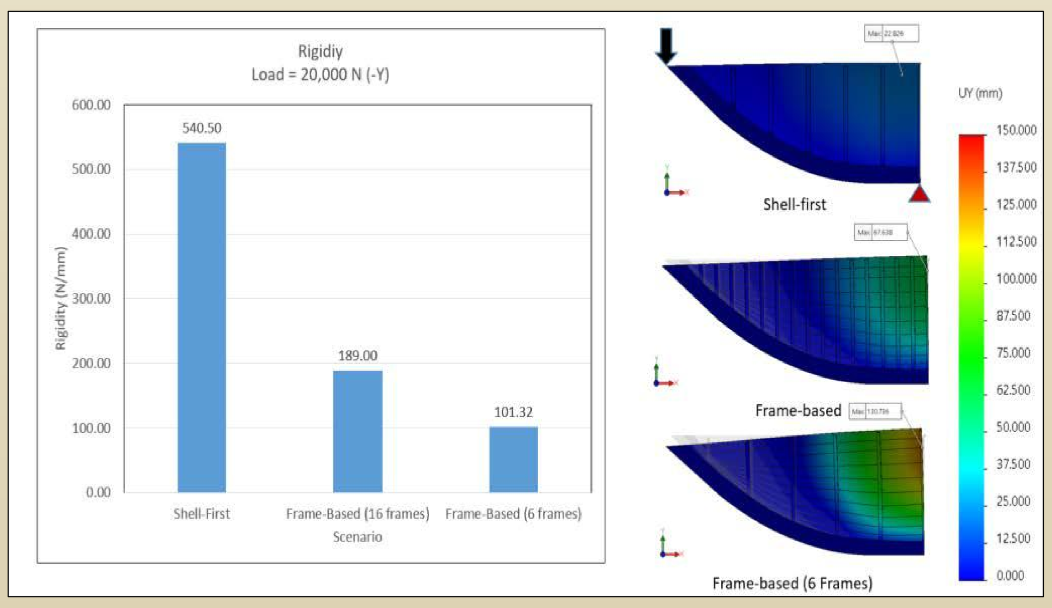

**Figure 8**: Archetypal rigidity results.

## Results

The simulations were designed to test to what extent the two types of structures met the factor of safety ($n$) conditions as per the equation:

$$n = \frac{\text{Allowable stess (strength)}}{\text{Calculated stress}} = \frac{S}{\sigma}$$

The stress criteria utilized the distortion energy theory known as von Mises-Hanky, stated simply as:

$$\sigma_{VM} \geq \sigma_y$$

such that if the von Mises ($\sigma_{VM}$) stress is equal to or greater that the yield stress ($\sigma_y$), failure occurs.

Rigidity was also calculated based on the ratio of the force directionally applied (vector) to an elastic member and the displacement produced.

The global results of the Ma'agan Mikhael ship and the Dor 2001/1 shipwreck revealed that both ships were on a par and exhibited high degrees of structural integrity based on the von Mises allowable stress criteria (Figs. 5, 6). Their displacement levels were also remarkably similar (Figs. 5, 6).

The archetypal results revealed significant stress and rigidity differences between the shell-first and frame-based construction. With the increased number of frames, the frame-based showed improved structural integrity (Figs. 7, 8).

## Conclusions

The transition from shell-first to frame-based was not due to an inherent structural advantage of the frame-based system. The archetypal simulations emphasized that the process of adopting the frame-based system required the improvement of a structurally inferior design. It could be posited, therefore, that the transition from shell-first to frame-first involved improving the construction methods of frame-based vessels to achieve a satisfactory end-product.

## Acknowledgements

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