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## EVALUATION OF THE NOAH'S ARK: WOOD MECHANICAL PROPERTIES AFFECTED BY WATER IMMERSION

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**KEYWORDS:** ark, wood, mechanical properties, elastic modulus, tensile strength, compressive strength, water

### ABSTRACT

This study focuses on the mechanical properties of different wood types related to Noah's Ark and their degradation over time as the ark experienced over a year in water. The objective of this research was to evaluate the wood mechanical properties affected by water immersion as a function of time to see if the strength and stiffness would be diminished. Wood specimens from white oak, teak, and pitch-coated and non-coated southern yellow pine were chosen, because they represent upper and lower bounds of the elastic moduli and strengths of different wood types found around the world. Teak is thought to best represent gopher (term used in the bible) wood, since it was prevalently used as a structural material in the Middle East. The different wood types were soaked in fresh water and salt water for one year (the total time of the flood event). The tensile, compressive and flexural properties of the wood specimens were tested every two months, and the results were statistically analyzed. Since all of the wood types gave similar degradation trends in their mechanical properties over time, one would expect that the mechanical behaviors of gopher wood would exhibit the same trends. Even pitch was used to coat some wood specimens for comparison to provide understanding of the corrosion protection by water-proofing. The bottom line is that the mechanical properties and consequential dimensional stability of gopher wood would not have changed significantly by water immersion (30% maximum), even if it was in salt water and even if there were no pitch to cover the wood. This 30% reduction is not enough to diminish the structural integrity of the ark.

### INTRODUCTION

Noah's ark was built in accordance with God's commands, which was recorded in Genesis, Chapter 6. <sup>14</sup>"Make thee an ark of gopher wood; rooms shalt thou make in the ark, and shalt pitch it within and without with pitch. <sup>15</sup>And this is the fashion which thou shalt make it of: The length of the ark shall be three hundred cubits, the breadth of it fifty cubits, and the height of it

thirty cubits. <sup>16</sup>A window shalt thou make to the ark, and in a cubit shalt thou finish it above; and the door of the ark shalt thou set in the side thereof; with lower, second, and third stories shalt thou make it."

In the days of Noah, the whole earth experienced a world-wide catastrophic flood (Whitcomb and Morris, 1961). The ark was immersed in water since the day it began to rain until the day the ground was dried. When reading the hints from Genesis 7:11, 7:17, 8:3, and 8:13, one can surmise that the ark was immersed in water for a total of 375 days. One can imagine that the first experience of the gopher wood would be with fresh water but once the "foundations of the deep" started to move and the major preflood oceans starting to move, the ark may have experienced salt water or brackish water (mixture of fresh water and salt water) as well.

Before one can quantify the effects of the fresh water, salt water, or brackish water, one must address other factors related to the ark such as the following: (1) What species of wood was the gopher wood mentioned in the bible? (2) What were the specifications of the pitch? (3) How thick was the pitch coating on the ark? (4) Did the pitch completely protect the wood components from water and moisture? (5) What were the effects of water immersion on the wood properties if the pitch did not completely proof the wood components from water absorption and moisture absorption? (6) What kinds of stress did the wood components bear during the days of the Flood? (7) How did Noah arrange the wood directions including radial, tangential and longitudinal directions when he made the Ark? All of these factors have to be taken into consideration when studying the rationality of the scriptures on Noah's Ark.

Others have studied various aspects of Noah's ark. Besides Whitcomb and Morris' (1961) excellent overview on all-things Genesis Flood, Morris (1975) later showed that the geometric design of the ark was dynamically stable up to 90 degrees using energy methods. Horstemeyer *et al.* (2008) validated the Morris (1975) analysis with experiments. Hong *et al.* (1994) performed the first finite element analysis to study the stresses in the ark using a fairly coarse mesh and linear elasticity. Woodmorappe (1996) further studied many aspects of the ark but did not use computational methods to study the stresses or strengths of the gopher wood. Horstemeyer *et al.* (2008) used a more complex finite element analysis with greater resolution to show the stresses in different wood types, the associated modal frequencies and mode shapes, and determined that the resonant frequencies would not cause harm to humans or animals.

In this study, we investigate the effects of two month intervals up to one year in water (fresh and saltwater) immersion on wood mechanical properties. Three wood types (pine, oak, and teak) were studied, which had upper and lower bounds on the mechanical properties that were garnered from the literature. Pitch was used to coat the wood specimens to investigate the effects the water-proofing characteristics.

## **MATERIALS**

As recorded in Genesis 6:14, Noah's ark was made from gopher wood; however, it is still unknown what wood species the gopher is although Woodmorappe (1996) has argued for teak. Three wood species including teak (*Tectona grandis*), southern yellow pine (*Pinus ponderosa*) and white oak (*Quercus alba*), were used to investigate the changes of wood properties resulted

from water absorption. The results can be the representative of gopher wood, because all wood types have the similar cell structures, chemical compositions, and relationship with water. The lumbers of white oak, southern yellow pine and teak were purchased from Swedenburg's Specialty Lumber Co., Columbus, MS, East Mississippi Lumber Co., Starkville, MS and Buck Woodcraft Inc., respectively. The dimensions of the specimens are 25 mm × 25 mm × 100 mm (radial × tangential × longitudinal) for the compressive testing, and 25 mm × 25 mm × 410 mm (radial × tangential × longitudinal) for the flexural testing. The specimens for tensile testing were dog-bone shape following American Standard Testing Methods (ASTM) 143-94 except that the thickness was 5 mm. The moisture content of the control specimens was 7.4% when they were used for mechanical testing and immersed in water.

As described in Genesis 6:14, the ark was coated with pitch. However, the specifications and the thickness of the pitch were unknown. In this study, commercial pitch (Genuine Wood Tar 850, 100% wood tar, Auson AB) was used. Southern yellow pine wood specimens were coated with the pitch twice and air-dried after each coating. The final thickness of the pitch layer was  $92 \pm 35 \mu\text{m}$ .

Although the ark probably experienced being in fresh water, salt water, brackish water, we only used fresh water and salt water to bound our study. Seawater typically has a NaCl content of 2.7% (weight percentage). Therefore, salt water with 2.7% NaCl was prepared with tap water and commercial salt to simulate the real seawater. Both the salt water and regular tap water were used to immerse the wood specimens.

## **METHODS**

The dimensions and weights of the wood specimens were measured. Then they were immersed in both fresh water and salt water for 2 months, 4 months, 6 months, 8 months, 10 months and 12 months, respectively. Five specimens for flexural, tensile, and compressive testing were taken out from the water tanks every two months. After the superfluous water was wiped from wood surface, the dimensions and weights of the specimens were measured. Flexural and tensile tests were conducted using an Instron 5566. In the flexural testing, a center point load with a span of 360 mm was applied along the radial direction of the wood specimens. In the tensile testing, the load was applied parallel to the longitudinal direction of the wood specimens. The compressive testing was conducted with an Instron 5500. The compression load was parallel to the longitudinal direction of the wood specimens. The testing procedures were in accordance with ASTM 143-94. The flexural and tensile loads were not released until the wood specimens were broken. The flexural moduli and strengths were obtained from the flexural testing. The tensile moduli and strengths were obtained from the tensile testing. The compressive loads were not released until the stress saturated upon continued deformation. The two ends of the wood specimens were crushed during the compressive testing for all of the wood types. The compressive moduli and compressive strengths were obtained from the compressive testing. The images of the tensile fracture surfaces were captured with a scanning electron microscope (SEM, Zeiss Supra TM 40). The specimens were coated with gold/palladium to provide electrical conductivity before being observed under SEM. A multiple comparison with Fisher's least significance difference (LSD) method at  $\alpha = 0.05$  was carried out with SAS 9.2 software (SAS Institute Inc. NC, USA).

The water content and volume swelling percentages of the wood specimens were calculated using the Equations 1 and 2.

$$W_c = \frac{W_w - W_d}{W_d} \times 100\% \quad (1)$$

where,  $W_c$  is water content.  $W_w$  is the weight of the wood specimens after water immersion.  $W_d$  is the oven-dry weight of a wood specimen.

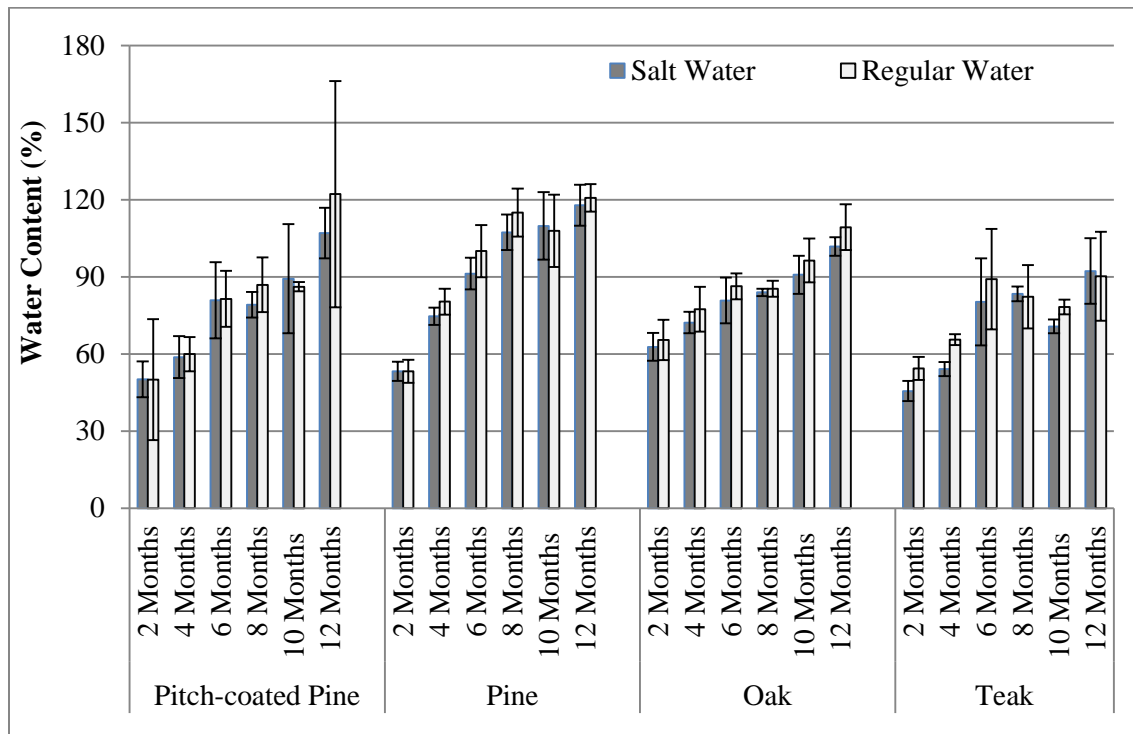
$$VSP = \frac{V_s - V_d}{V_d} \times 100\% \quad (2)$$

where, VSP is volume swelling percentage of a wood specimen.  $V_s$  is the volume of a specimen after water immersion.  $V_d$  is the volume of a wood specimen before water immersion.

## RESULTS AND DISCUSSION

### Water absorption and volume swelling

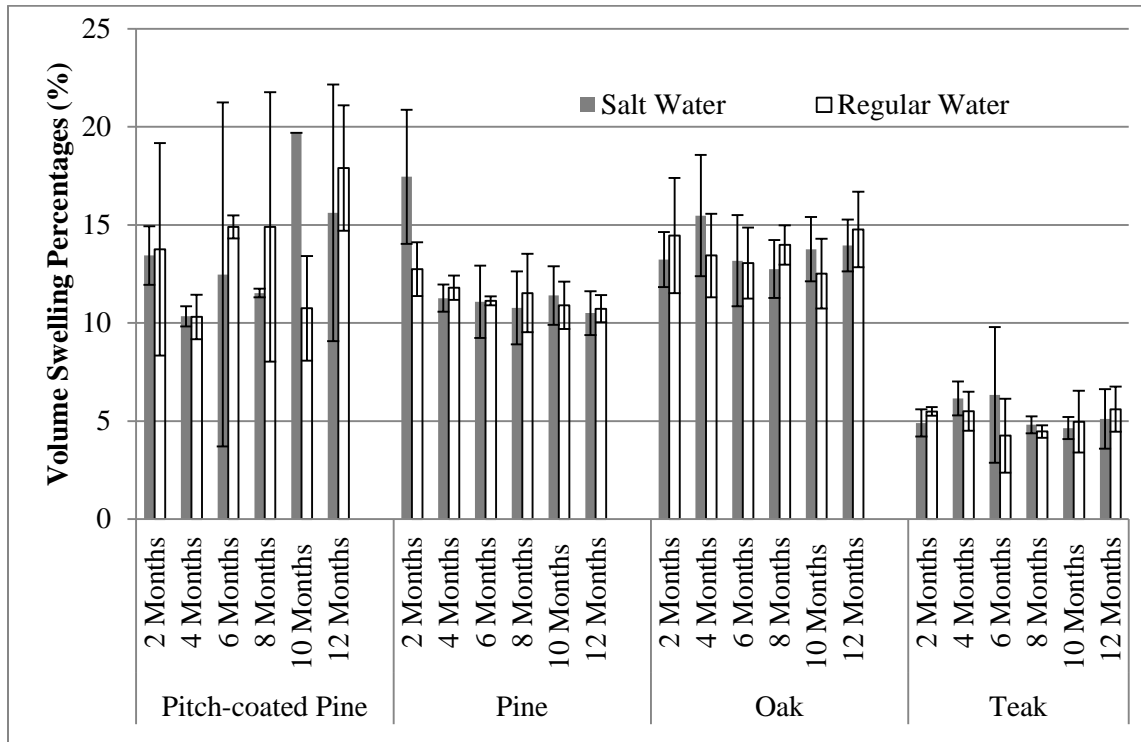
The water contents and volume swelling percentages of the wood specimens are shown in Figure 1 and 2. Figure 3 shows the wood cell wall thicknesses.



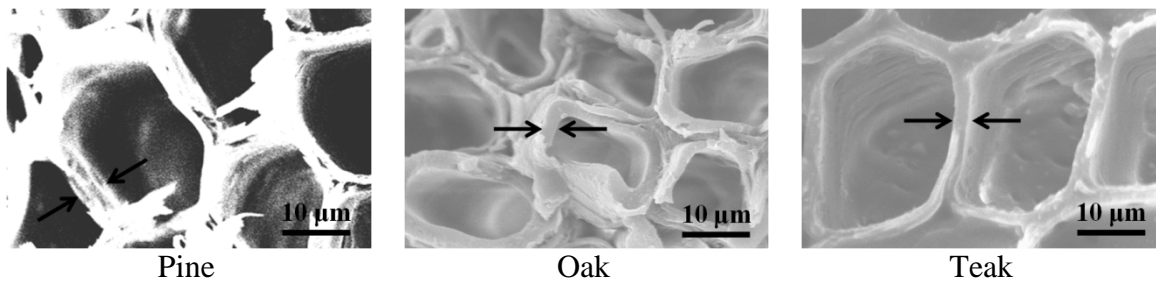
**Figure 1.** Water content of the wood specimens after water immersion in salt water and fresh (regular) water.

Figure 1 clearly shows that water absorption continued throughout the year in all of the wood materials. Even with this water absorption increase, the total volumetric expansion was dominated by an increase in the first two months after which saturation occurred. These two observations are general trends since the error bands do not conflict. This indicates that the

water absorption early on was involved in creating volumetric strains, but the later increases did not increase the volumetric stains as much indicating a nonlinear expansion rate overall. At the microscale the water content of the wood specimens reached the fiber saturation points in the first two months and additional water uptake did not result in further volume swelling. The fiber saturation point is the moisture content (expressed as a percentage of the weight of the oven-dry wood) at which the cell walls are saturated and the cell cavities are free from water. Figure 3 shows a Scanning Electron Microscope (SEM) image of the wood cells. The water molecules penetrate the cell wall and become bound to cell wall components through hydrogen bonding. With addition of water to the cell wall, wood volume increases nearly proportionally to the volume of water added (FPL, 1944).



**Figure 2.** Volume swelling percentages of the wood specimens after water immersion in salt water and fresh (regular) water.



**Figure 3.** Scanning Electron Microscope (SEM) images of the wood cross sections showing a close microstructural similarity with very different wood types suggesting that gopher wood would be similar.

Volume swelling does not increase until the fiber saturation point has been reached. Water absorbed beyond this point remains as free water in the lumen and does not cause further swelling (Rowell and Youngs, 1981). In this study, water penetrated in the wood cell wall and cell lumen simultaneously as long as the wood specimens were immersed in the salt water or fresh water. Water in wood cell wall is usually referred to as “bound water” or “adsorbed water” and results in the swelling of cell wall. Water in cell lumen is usually referred to as “free water” or “absorbed water” and does not cause the change of cell lumen’s size.

The fiber saturation levels for most wood species including southern yellow pine, white oak and teak range from 20% to 35% (Smith 1986). In this study, the water content of the wood specimens were above 40% after the first two months water immersion (Figure 1), which was obviously higher than the fiber saturation point. Water absorption below the fiber saturation point results in the swelling of wood cell walls. After the water content in the cell walls reaches the saturation point, water absorption continues. But the absorbed water is held in cell lumens and does not cause volume swelling. Therefore, although the water content gradually increased as water immersion prolonged, the volume of the wood specimens did not changed significantly.

One other point related to Figures 1-3 is that the Teak specimens obtained significantly lower volume swelling than oak, pine and coated pine specimens. It may be because teak has thinner cell wall than oak and pine (Figure 3) although they were fairly similar in structure. If the modern day Teak is indeed the biblical gopher wood, then the effect of the water (fresh or salt) would affect it much less than the other types of wood.

One final point related to Figures 1-3 is related to the pitch. The pitch-coated pine specimens did not show significant difference in water absorption and volume swelling compared with the pine specimens without the pitch coating. Our suspicion is that our pitch layer ( $92 \mu\text{m} \pm 35 \mu\text{m}$ ) was not sufficiently thick enough to completely cover the wood surfaces. The real Noah’s ark should be coated with thick enough pitch for water-proof. A further study is being proposed to analyze this effect.

## **Mechanical Properties**

Figure 4 shows the flexural strength of the different wood types under fresh (regular) water, salt water, and with no water (control). Since the water absorption into the cell walls affected the volumetric strains in the first two months, this in turn reduced the flexural strength on the order of 60% for pine, 50% for oak, and 30% for teak with no changes occurring after the first two months.

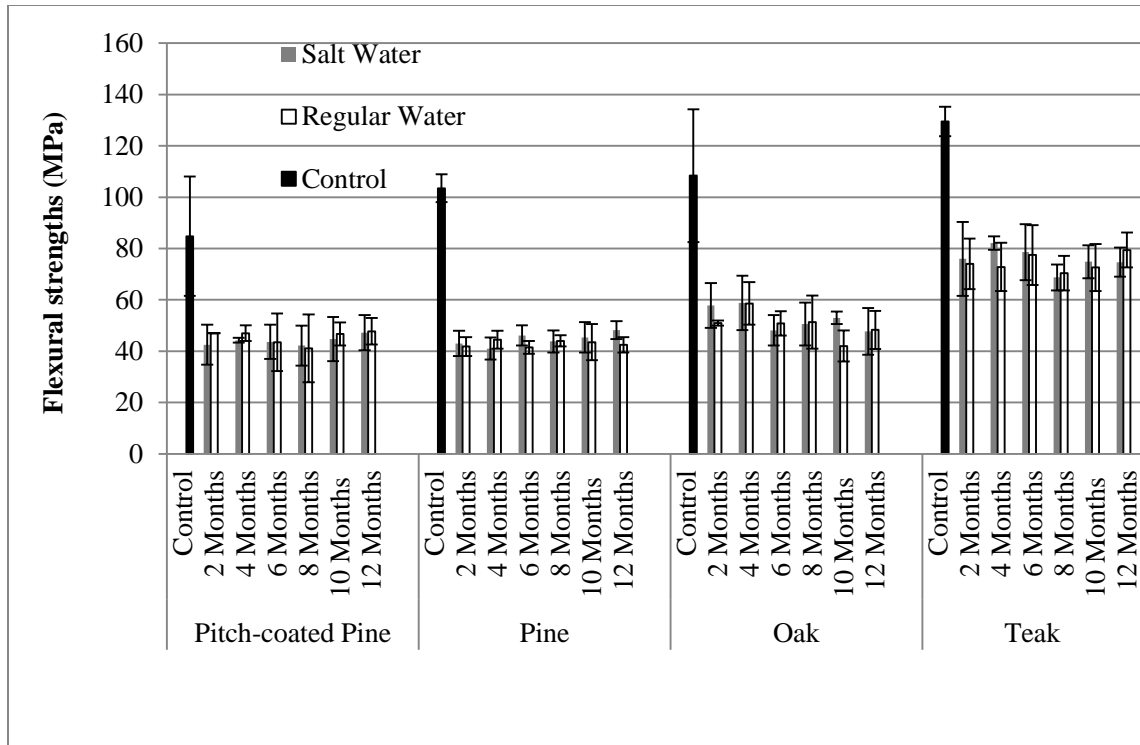
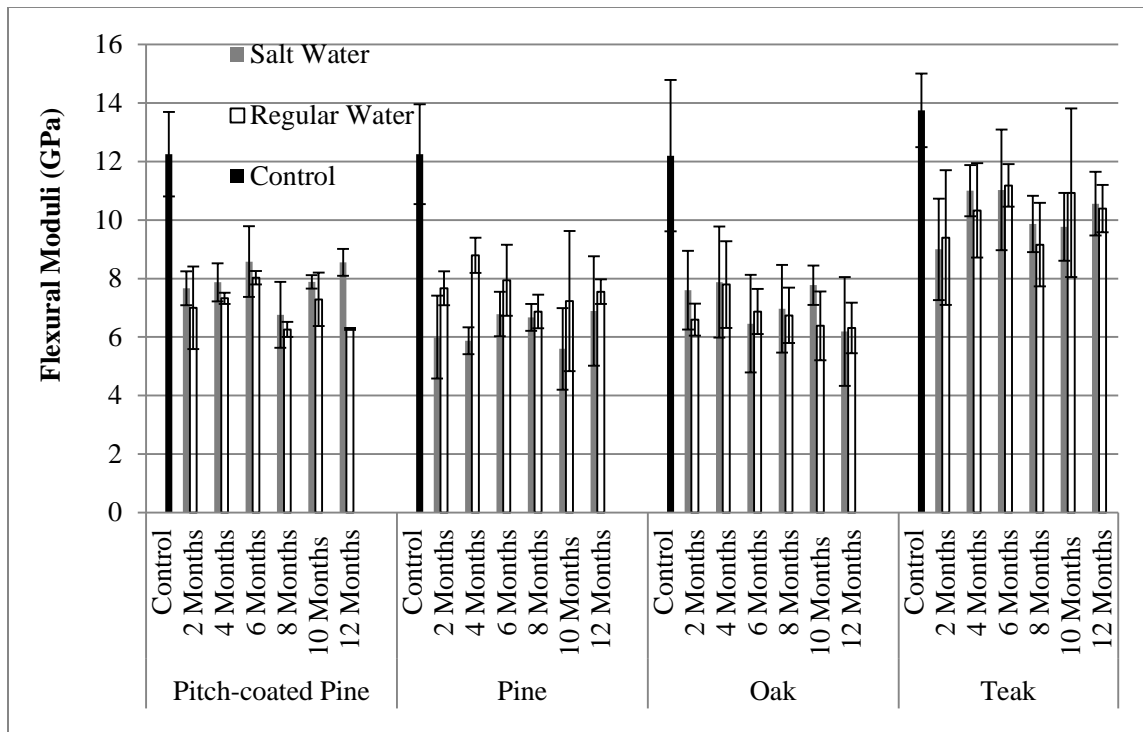


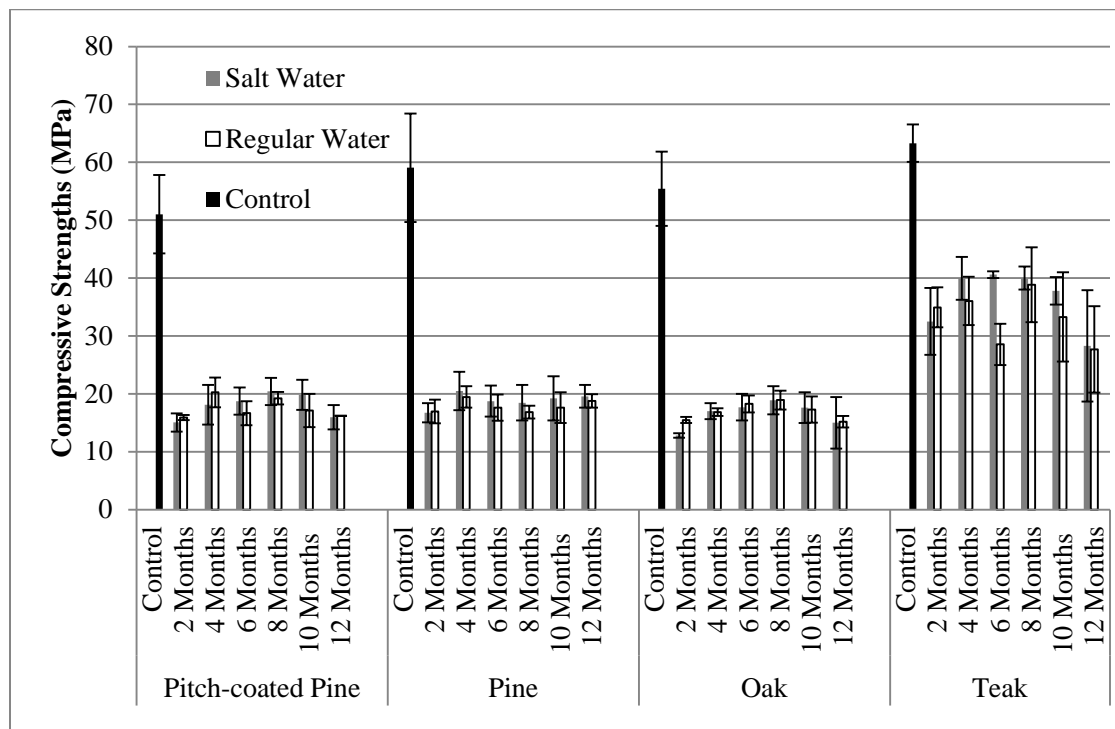
Figure 4. Flexural strengths of the wood specimens under fresh (regular) water, salt water, and no water (control).

As with the flexural strength degradation as a function of time, all of the other mechanical properties obtained significant reductions after the first two months in the water immersion compared with the control specimens, which were tested with no water. Also, with the flexural strength trend, the properties did not decrease as the water immersion prolonged after two months in indicating the absorption into the cell walls affected the mechanical properties and not the absorption into the free volume within the cells. This occurs because the wood specimens reached their fiber saturation points in the first two months, beyond which the mechanical properties of the wood specimens were not affected by the increase of free water. By examining Figures 5, 6, 7, 8, and 9, one can observe the aforementioned points. Other trends that are similar between the different mechanical properties are that the water salinity and the pitch coating did not impact on the changes of the wood mechanical properties.

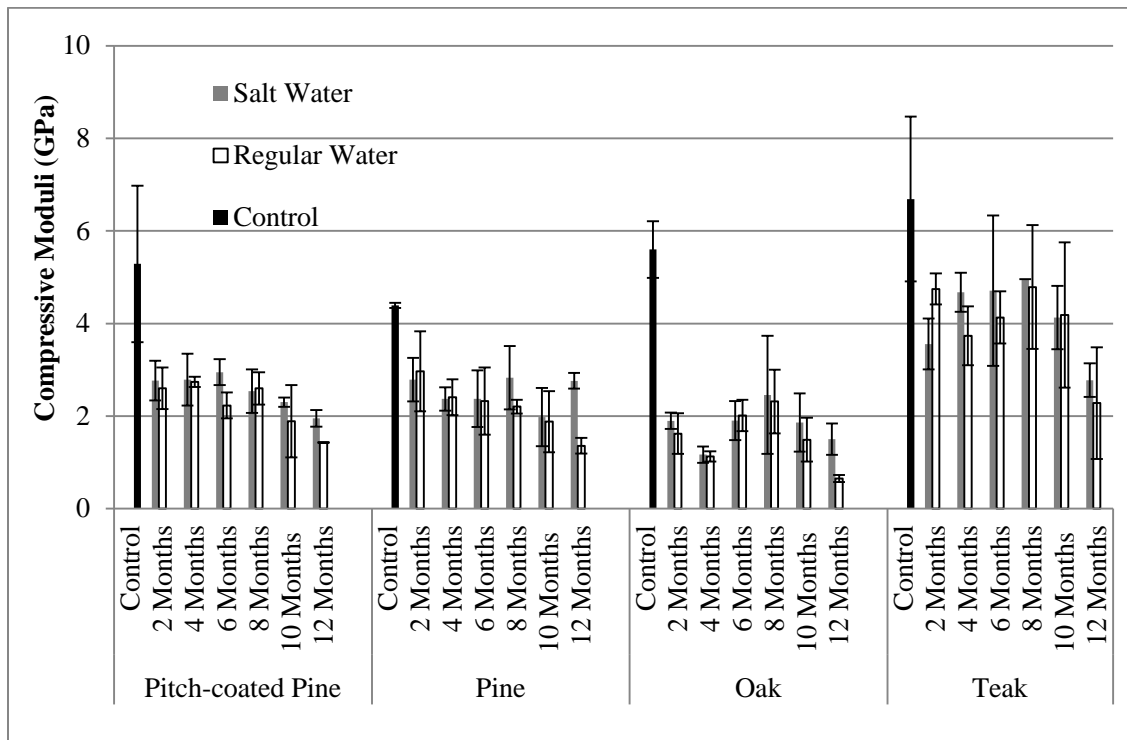




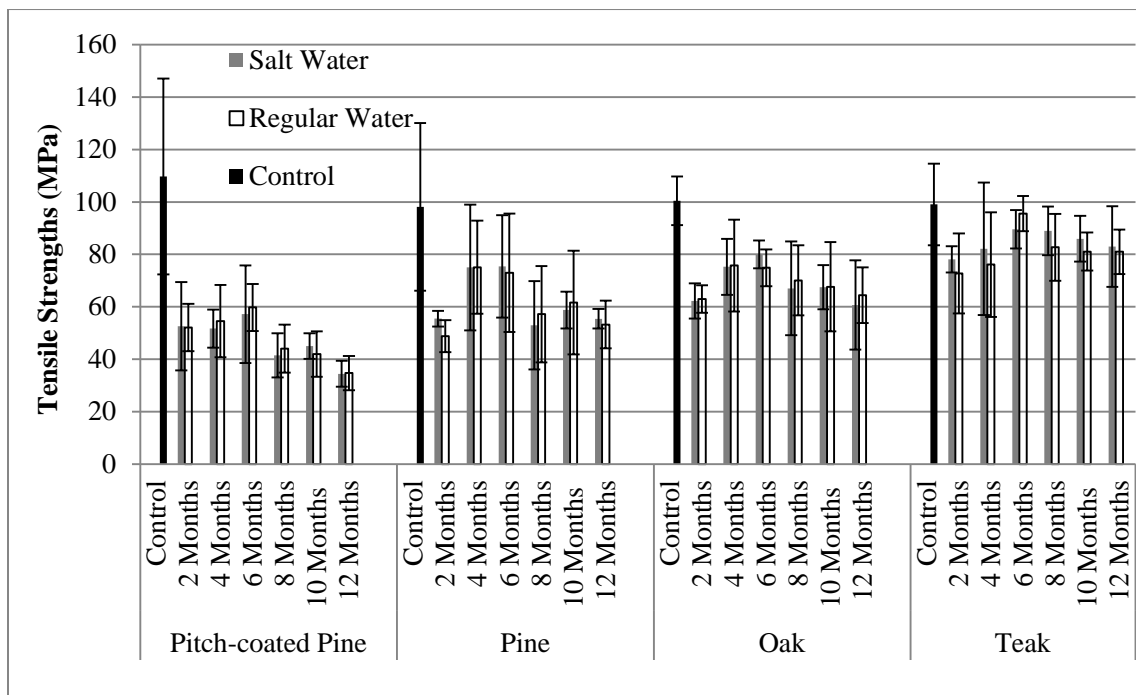
**Figure 5.** Flexural moduli of the wood specimens under fresh (regular) water, salt water, and no water (control).



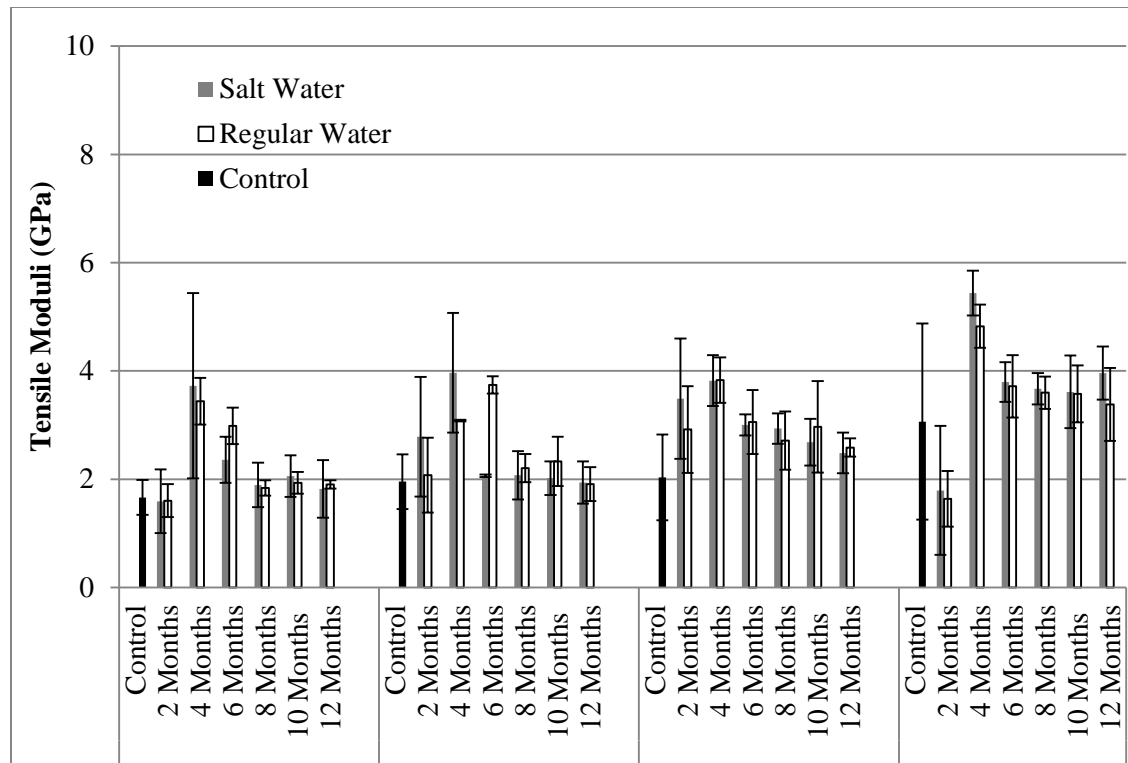
**Figure 6.** Compressive strengths of the wood specimens under fresh (regular) water, salt water, and no water (control).



**Figure 7.** Compressive moduli of the wood specimens under fresh (regular) water, salt water, and no water (control).



**Figure 8.** Tensile strengths of the wood specimens under fresh (regular) water, salt water, and no water (control).



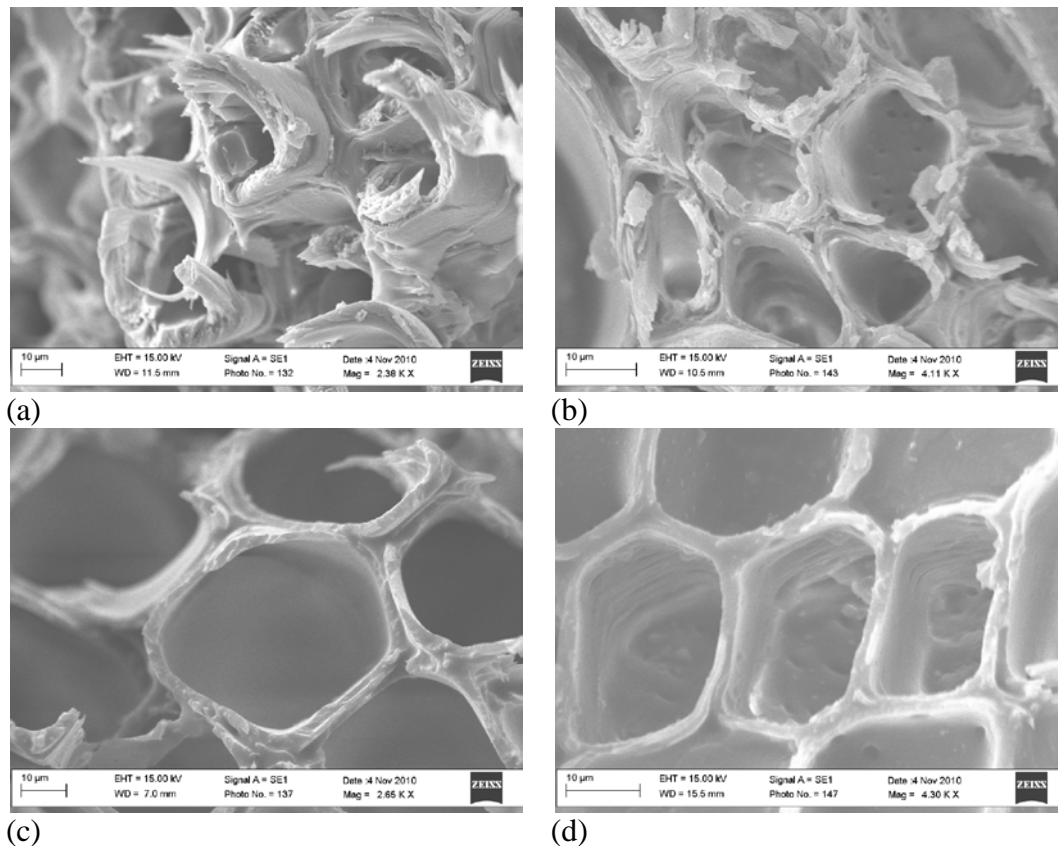
**Figure 9.** Tensile Moduli of the wood specimens under fresh (regular) water, salt water, and no water (control).

The reduction percentages of the mechanical properties shown in Figures 4-9 are summarized in Table 1. The reduction percentages are the ratios of the minimum and maximum properties of the water immersed wood specimens compared to the properties values of control wood specimens. Teak obtained the lowest mechanical properties reductions. It may be due to the density of teak wood cell walls. Teak, oak, and pine have the densities of  $0.63 \text{ g/cm}^3$ ,  $0.68 \text{ g/cm}^3$ , and  $0.58 \text{ g/cm}^3$ , respectively. These densities describe the compaction of the wood bulk including wood mass and cavities. The wood mechanical properties are mainly attributed to wood mass containing in cell walls. Recall that Figure 3 shows that the teak wood cell walls are slightly thinner than those of pine and oak indicating that the mass including cellulose, hemicelluloses, and lignin in the teak wood cell wall is more compact than that in oak and pine. After wood absorption, the teak obtained smaller volume swelling than oak and pine. Therefore, water molecules resulted in less swelling between the microfibrils in teak than in oak and pine. Stress is more easily transferred between the microfibrils in teak than in oak and pine. Therefore, teak has the lowest mechanical properties reductions caused by water absorption.

**Table 1.** Reduction percentages of the wood mechanical properties upon water immersion

	Coated Pine	Pine	Oak	Teak
Tensile Moduli	No Significant Difference			
Tensile Strengths	45.54-68.60%	23.18-50.28%	20.35-39.60%	3.53-26.62%
Compressive Strengths	59.98-70.51%	65.31-71.67%	65.87-76.91%	35.84-56.23%
Compressive Moduli	44.23-72.97%	32.35-69.02%	56.07-88.32%	25.86-65.92%
Flexural Strengths	41.12-43.69%	53.43-60.39%	45.80-61.24%	36.58-46.91%
Flexural Moduli	35.59-48.90%	28.16-54.29%	35.41-48.28%	18.69-34.55%

The SEM images of the tensile fracture surfaces for each wood species are shown in Figure 10. The fracture of the wood cell walls in pine and oak occurred in a tortuous path reminiscent of ductile tearing in rubber materials although the tensile elongation to failure was approximately 3% strain. The fracture surface of teak wood cell walls was relatively smooth compared to pine and oak giving more cleavage look with a tensile elongation to failure of 2% strain. The smoother fracture surface of teak could possibly also arise, because the cell walls have a more uniform strength. Recall that the wood mass was denser in teak wood cell wall than for the oak and pine thus minimizing the strength variation throughout the wood cell walls.



**Figure 10.** Scanning Electron Microscope (SEM) images of the tensile fracture surfaces: (a) pine, (b) oak, (c) pitch-coated pine, and (d) teak.

### Relation to Stiffness and Resonant Frequencies

Now that we have discussed the strength issues with the water absorption effects on the different wood types, we can now turn our attention to the stiffness and associated vibrational frequencies. The analytical function for the first fundamental natural frequency (resonance) of a beam is given by the following:

$$\omega_1 = \sqrt{\frac{12EI}{mL^3}} = \left(\frac{1}{L^2}\right) \sqrt{\left(\frac{E}{\rho}\right) \frac{12I}{A}} \quad (3)$$

where  $E$  is the elastic modulus of the material,  $m$  is the mass of the material, and  $\rho$  is the density of the material; the ratio  $E/\rho$  is given in many handbooks for various wood types.  $I$  is the cross-sectional moment of inertia and has to do with the resistance to bending, and  $L$  is the length of the beam, and  $A$  is the cross-sectional area. Horstemeyer *et al.* (2008) showed from Equation (3) that the first fundamental frequency from Noah's ark geometry is the following:

$$\omega_1 = 0.84 \left(\frac{E}{\rho}\right)^{0.5}. \quad (4)$$

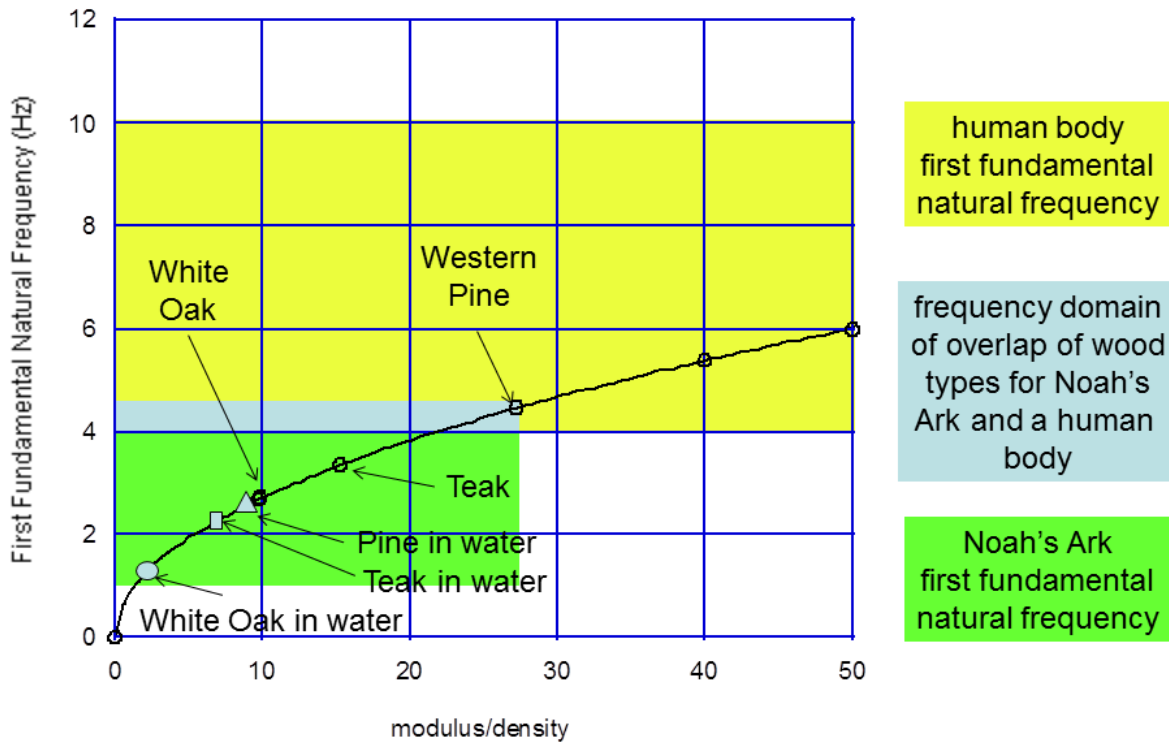
Hence, the difference in materials is related to the ratio of  $E/\rho$ . Table 2 summarizes the values of the elastic modulus and density with the addition of the water garnered from our study.

**Table 2.** Stiffness and resonant frequency effects of the water absorption within the wood.

Wood	Dry Wood				Wet Wood			
	Modulus (MPa)	Density (kg/m <sup>3</sup> )	Modulus/Density	full scale ark (Hz)	Modulus (MPa)	Density (kg/m <sup>3</sup> )	Modulus/Density	full scale ark (Hz)
White Oak, Bur	7100	716.9	9.90	2.7	3600	958	3.8	1.6
White Oak, Pitch	7100	716.9	9.90	2.7	3600	958	3.8	1.6
Teak	9400	616.0	15.26	3.3	6100	880	6.9	2.2
Pine	11900	477.9	24.90	4.2	5900	638	9.2	2.5

Horstemeyer *et al.* (2008) discussed that the natural frequencies of the human (and animal) body and associated organs (cf., Brownjohn and Zheng, 2001) ranges from 6-10 Hz. If the resonant frequency of Noah's ark was within the range of the human resonant frequencies and the flood waters induced such frequencies, then all of the living creatures on the ark would get sick. Horstemeyer *et al.* (2008) noted that the finite element simulations of the Noah's ark gave the first fundamental frequencies ranging from 2.7-4.5 Hz as illustrated in Table 2, below that of the human levels. That was with no water absorption. The question here is what happens to the first fundamental frequency when water is present. Since water absorption decreased the  $E/\rho$  ratio, the first fundamental frequency for the water saturated ark wood would even be lower. Table 2 shows the calculations based upon the water saturated levels were lower ranging from 1.6-2.5 Hz,

and Figure 11 shows the comparison. As such, the wood in the water absorbed, would not affect the stiffness or frequency issues in a deleterious manner for Noah, his family, and the animals.



**Figure 11.** A comparison of the first fundamental natural frequency with the modulus/density ratio of various wood types showing the relationship of Noah’s ark potential frequency range and the human body frequency range. This suggests that the modulus/density ratio of gopher wood was probably below 21 MPa·m<sup>3</sup>/kg. This also shows that the water absorption helps move the resonance frequency away from the human domain.

## CONCLUSIONS

Three different wood types (high modulus/density ratio, low modulus/density ratio, and best possible guess for “gopher” wood) were examined to study the possible deleterious effects that water could have on Noah’s ark. The high modulus/density ratio wood used in the study was pine; the low modulus/density ratio wood was oak; and the best possible guess for gopher wood was teak. The definitive conclusion is that **any** type of wood **would not** have given problems in terms of strength and stiffness, which are the common characteristics used in the mechanical design of structures.

All of the wood specimens used in this study gave similar trends when completely saturated by water. All the wood specimens reached their fiber saturation points in two months. The tensile

strengths, flexural moduli and strengths, and compressive moduli and strengths obtained reductions after the first two months water immersion compared with the control specimens (tested specimens in no water) indicating that the ark would withstand the year long flood event. Essentially no changes occurred after two months. Teak had the lowest reductions in its mechanical properties.

Although the tensile, flexural and compressive properties of gopher wood were not reduced significantly after the wood obtained a water content higher than its fiber saturation point, if the wood was completely proofed from water and moisture with pitch, the pitch must be thick enough to guarantee the water/moisture proof efficiency. This study provides further experimental evidence demonstrating the authenticity of the scriptural account of the Genesis Flood and the constructional feasibility of Noah's Ark.

## **ACKNOWLEDGEMENTS**

This study was birthed from two conversations with Russ Humphreys and John Woodmorappe. Russ Humphreys encouraged MFH to use his talents and abilities for the Lord and pray about how they could be used in relation to items mentioned in the bible. John Woodmorappe had been studying Noah's ark and suggested that since MFH's background was that of mechanical engineering that MFH should study the engineering design aspects of the ark. Hence, the authors would like to recognize those two individuals for their thought-provoking encouragement.

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