Chapter 7: Conclusions and Recommendations

7.1 Conclusions

A summary of the results for the leaning arches tilted at 15° and 30° for fixed and pinned bases and for three load distributions is shown in table 7.1. In table 7.1 a first frequency of zero signifies that the arches buckled at the load specified by "final load." Positive sign conventions in table 7.1 are the same as those discussed in sections 5.1 and 6.1. In table 7.1, the deflections given are for the apex of the arches.

Figures 7.1 and 7.2 compare the load-vertical deflection curves and load-frequency curves for the full snow load acting on four pairs of arches. These pairs are arches with a 15° tilt angle with fixed bases (15-fix), 15° tilt angle with pinned bases (15-pin), 30° tilt angle with fixed bases (30-fix), and 30° tilt angle with pinned bases (30-pin). Figures 7.3 and 7.4 compare the load-vertical deflection and load-frequency curves for the half snow load on the four pairs of arches, and figures 7.5 and 7.6 compare the load-longitudinal deflection and load-frequency curves for the wind load on the four pairs of arches.

Some conclusions that can be drawn from the results are discussed below.

Buckling occurs for both full snow load and half snow load on the leaning arches with pinned bases tilted at both 15° and 30°; however, buckling only occurred for full snow load on the leaning arches with fixed bases tilted at 15°. For all other load cases, buckling did not occur in the range of loads considered. Each case of buckling observed was limit point buckling.

The boundary conditions of the arches have a significant impact on the behavior of the leaning arches. Fixed bases cause the structure to be much stiffer, stronger, and more stable. The vibration frequencies are higher for fixed bases when compared to the arches with pinned bases. The deflections are also smaller for the arches with fixed bases.

Table 7.1 Summary of results for leaning arches

Base	Load		Tilt Angle 15°	30°
Fixed	Internal Pressure	First Frequency (rad/sec)	13.1	13.7
		Vertical Deflection (cm)	6.11	6.70
	Full Snow	Final Load (kN)	253	204
		First Frequency (rad/sec)	0	9.98
		Vertical Deflection (cm)	45.5	48.0
	Half Snow	Final Load (kN)	199	173
		First Frequency (rad/sec)	8.07	10.4
		Longitudinal Deflection (cm)	40.5	32.6
		Vertical Deflection (cm)	36.8	40.7
	Wind	Final Pressure (kPa)	11.31	10.81
		First Frequency (rad/sec)	14	14.7
		Longitudinal Deflection (cm)	56	47.1
		Vertical Deflection (cm)	4.13	0
Pinned	Internal Pressure	First Frequency (rad/sec)	7.78	7.76
		Vertical Deflection (cm)	9.12	9.97
	Full Snow	Final Load (kN)	143	126
		First Frequency (rad/sec)	0	0
		Vertical Deflection (cm)	45.4	62.3
	Half Snow	Final Load (kN)	135	120
		First Frequency (rad/sec)	0	0
		Longitudinal Deflection (cm)	98.9	111.1
		Vertical Deflection (cm)	46.2	66.7
	Wind	Final Pressure (kPa)	9.04	10.21
		First Frequency (rad/sec)	9.07	9.6
		Longitudinal Deflection (cm)	107.6	96.2
		Vertical Deflection (cm)	24.1	23.5

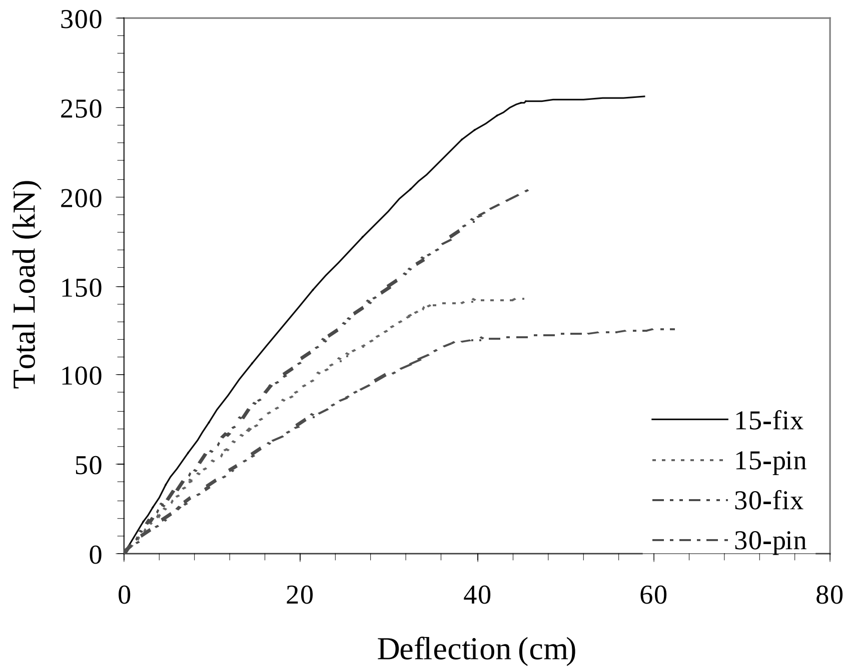

Figure 7.1 Total load vs. vertical deflection for leaning arches with full snow

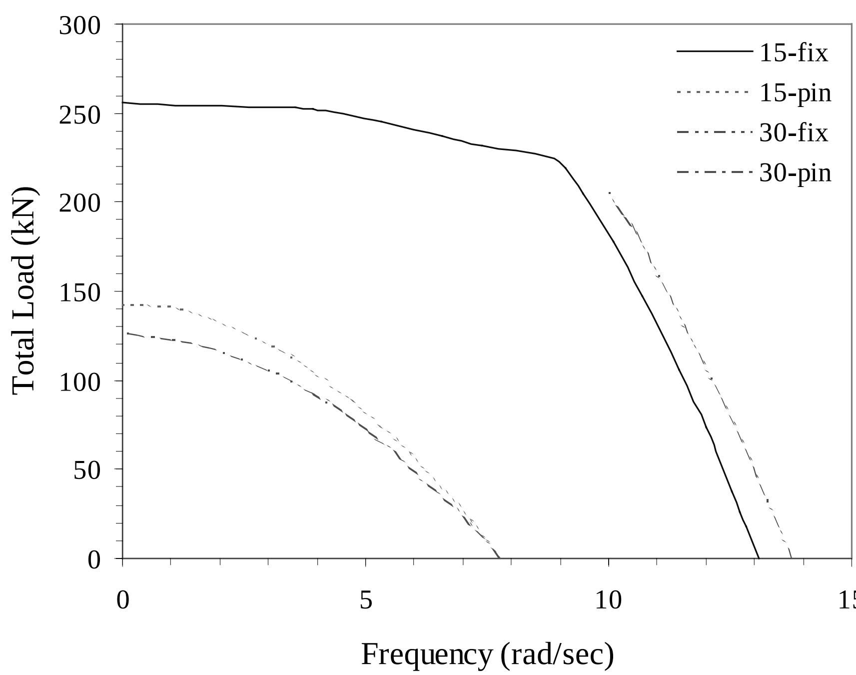

Figure 7.2 Total load vs. first frequency for leaning arches with full snow

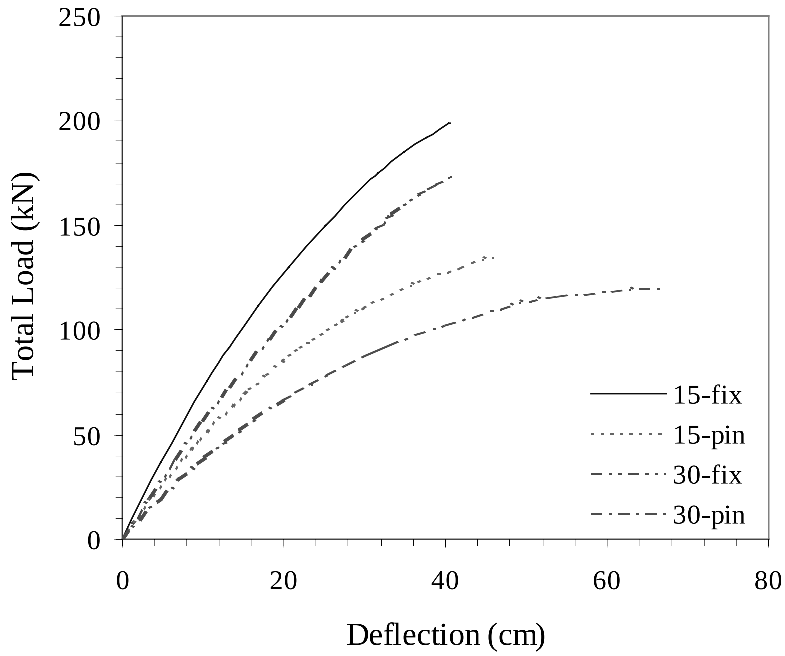

Figure 7.3 Total load vs. vertical deflection for leaning arches with half snow

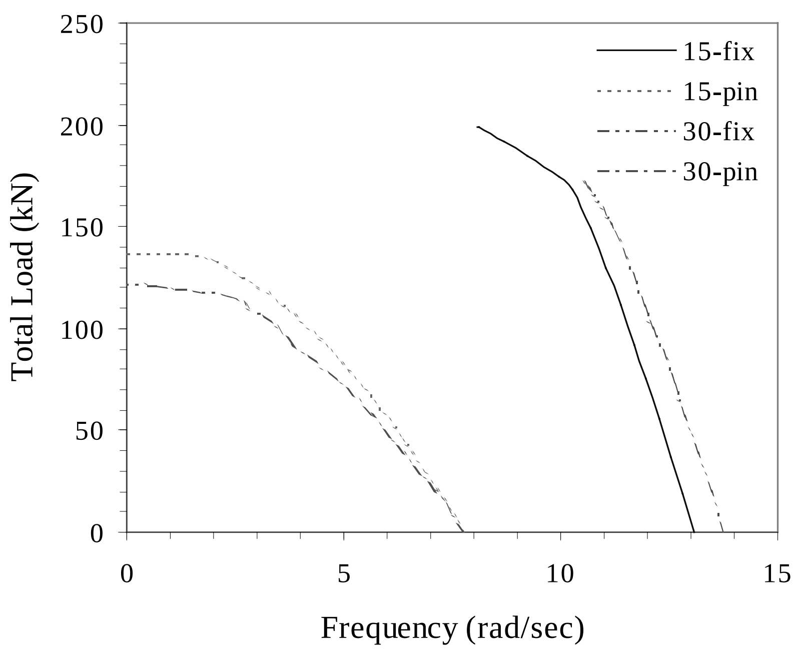

Figure 7.4 Total load vs. first frequency for leaning arches with half snow

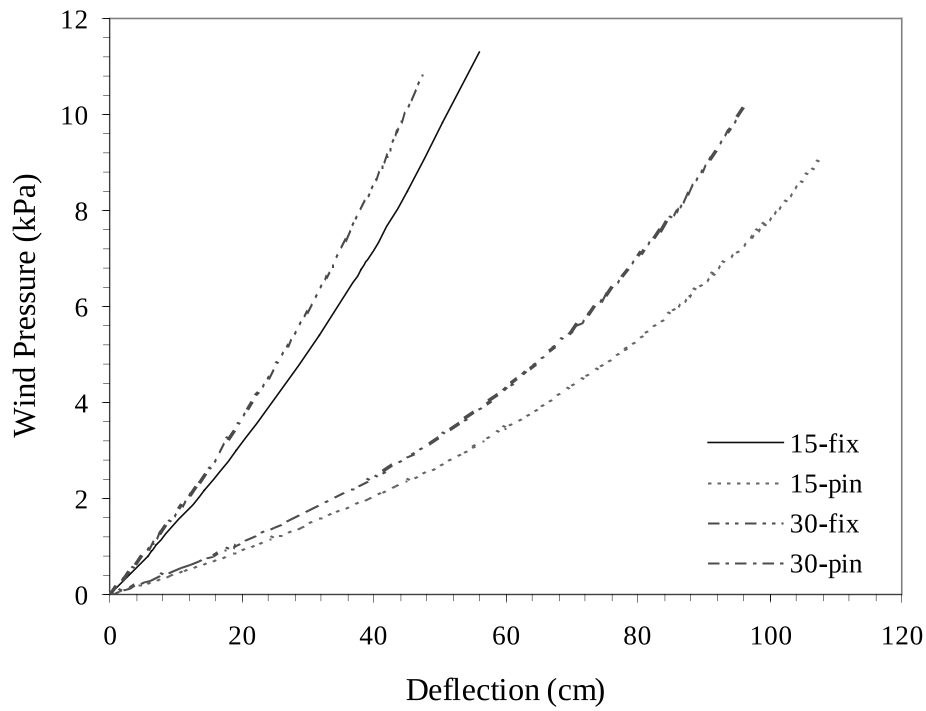

Figure 7.5 Wind pressure vs. longitudinal deflection for leaning arches with wind

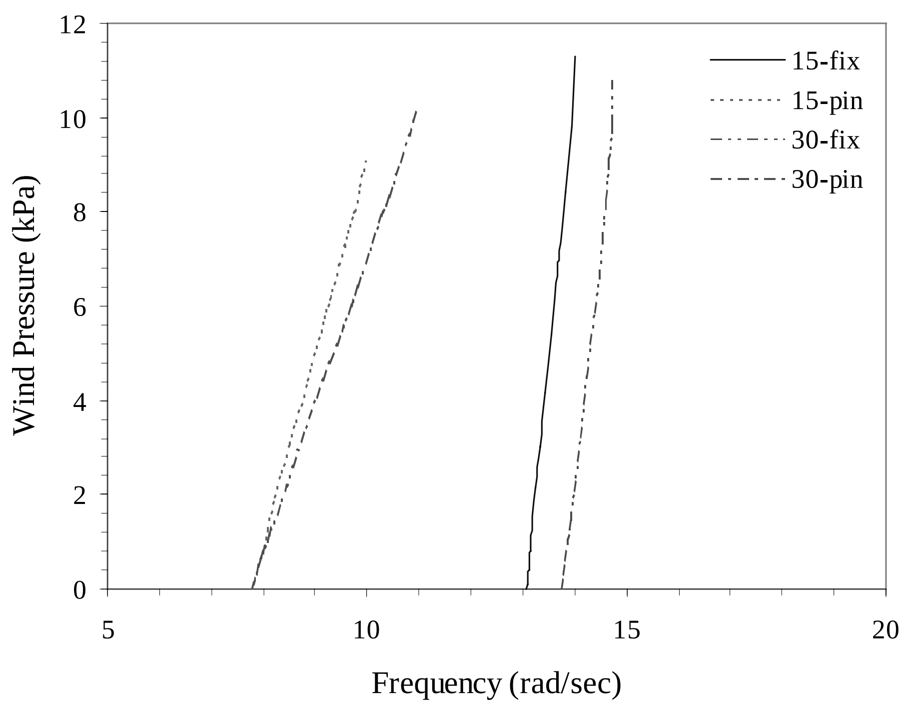

Figure 7.6   Wind pressure vs. first frequency for leaning arches with wind

The tilt angle has a less significant impact on the behavior of the leaning arches. For the full snow and half snow loads, the arches tilted at 30° have larger vertical deflections than the arches tilted at 15°; however, the arches with a 15° tilt angle have larger longitudinal deflections than the arches tilted at 30°.

From the vibration modes shown throughout chapters 5 and 6, it can be seen that the first vibration mode for the arches with pinned bases is often a twisting mode; however, the first vibration mode for the arches with fixed bases is a side sway mode. The buckling modes for all of the arches that buckle reflect this. This difference in vibration mode shows that the lack of restraint at the pinned bases causes the pinned arches to be much weaker in twisting than the fixed arches.

Wrinkling of the arches occurred near the final load for many of the load cases. This may suggest that the wrinkling load has been passed. The finite element model, however, did not develop fold lines like those that might be expected when a thin fabric loses its tensile prestress.

Cross-sectional deformations were taken into account during the analyses presented in this thesis. As expected, cross-sectional deformations were significant. Two typical displaced cross sections are shown in figures 7.7 and 7.8. Figure 7.7 shows the displaced cross section at the apex for arches under a full snow load of 143 kN, with pinned bases, and tilted at 15°. It can be seen that the arches come into further contact with each other, causing the once circular cross section to become oval-shaped. Figure 7.8 shows the displaced shape of the cross section at the apex for the side sway vibration mode. This figure is for leaning arches with pinned bases, tilted at 15°, and with only an internal pressure of 500 kPa. This figure shows how the cross section can change as the arches move. In both figures the blue solid line is the original shape and the green dashed line is the displaced shape.

The leaning arch module is a very efficient structure. A single arch with fixed bases buckles at a total load of 45 kN, but a pair of leaning arches tilted at 15° with fixed bases buckles at 253 kN. Adding a second arch increases the load carrying capacity of the structure by 550 %.

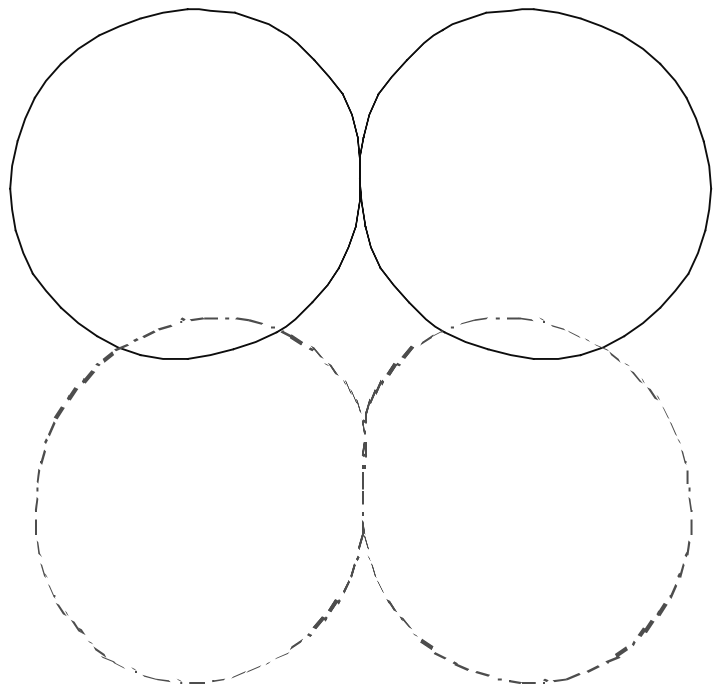

Figure 7.7 Displaced cross-section at apex under full snow load

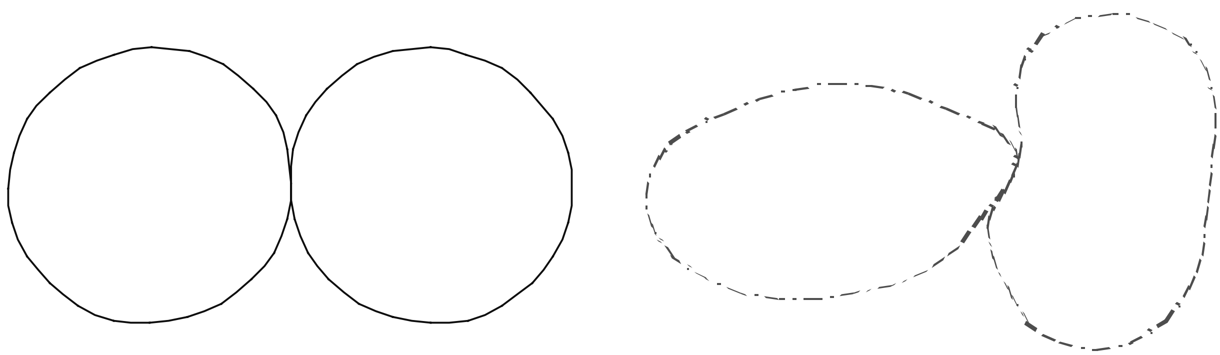

Figure 7.8 Displaced cross-section at apex during side sway vibration mode

7.2 Recommendations

This thesis leaves many areas open for further research. These areas where further research is justified are discussed below.

Only three types of loads have been considered to act on the structure. The three loads studied are the most common; however, other load types should be considered, such as loads perpendicular to the length of the arches, or loads which act at an oblique angle to the arches.

Finite element and scale models of the entire tent structure would be useful so that the behavior of a pair of leaning arches can be understood when it is part of a structural system. These models could then be compared to tent models using vertical arches.

The material used during this research was assumed to be linearly elastic, isotropic, and homogeneous; however, woven or braided fabrics may have different properties in various directions, which may significantly impact the behavior of the structure.

Finally, if tents are designed using leaning arches, the leaning arch structure should be optimized to obtain a shape, tilt angle, cross section, and internal pressure which has large critical loads, small deflections, and a low weight.