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Monitoring of full-scale tensegrity skeletons under temperature change

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Abstract

Strain change in the members of full-scale tensegrity skeletons has been monitored for eight years. The one-day data of one of the tensegrity frame on the hottest and the coldest day in the record are reported and discussed.

Keywords: tension structures, tensegrity, thermal deformation, temperature, monitoring.

1. Introduction

A pair of tensegrity frames supporting a membrane roof was constructed at Chiba in Japan in 2001. After their construction the strain levels of all of their members have been recorded every ten minutes for about eight years until now.

In this paper, from these monitored and recorded data, one-day data of one of the skeletons, on the hottest day and the coldest day, are reported.

Figure 1: Interior view of the building

2. The tensegrity skeletons

In the two tensegrity skeletons, one is about ten-meter high and called frame A, while the other is lower, about seven-meter high, called frame B. Either frame is a variation of so-called "simplex" tensegrity, having three compressive struts and nine tendons, with three additional sub side tendons. Each frame further has an extra set of three suspension tendons supporting an isolated post member that is pushing up the membrane roof and transmitting the external force on the roof to the tensegrity frame. At the lower end of the isolated post it is connected to the suspended tendons with a connection where the post can rotate in a certain range so that it can accommodate large deformation of the membrane roof.

Figure 2. Frame A under construction

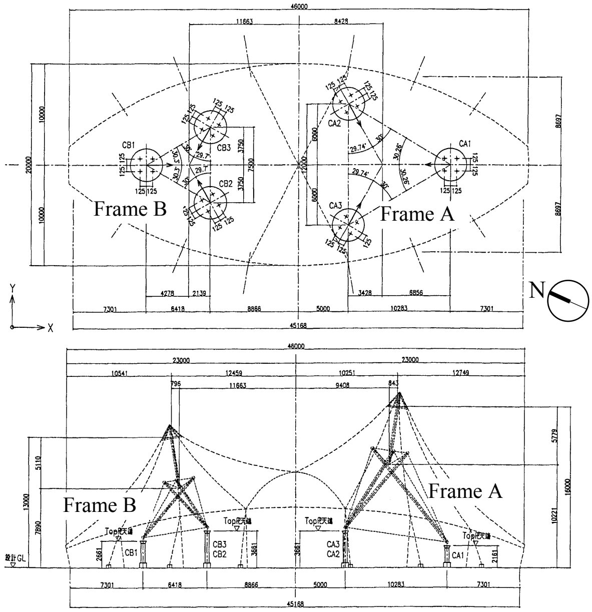


Figure 3: Plan and section view of the building

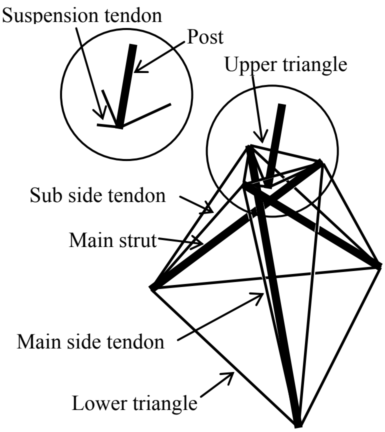


Figure 4: Schematic view of the frame

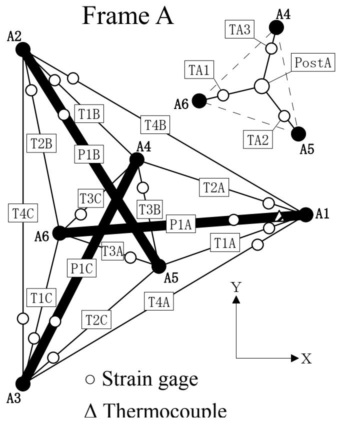


Figure 5: Members and sensor locations

3. Measures

For the construction of the two tensegrity skeletons real time monitoring of the stress in the members was essential (*Kawaguchi et al.* [1]). This was main reason why we had prepared strain gage sets on each member. However in the design stage we have already decided to continue the monitoring after the completion, considering the importance of the structure as the world first typical tensegrity frame applied to the building skeleton. Therefore we prepared the gage sets also to the suspension tendons and posts although we did not need them during the construction.

A pair of strain gages was attached to every member of the frames so that bending deformation can be detected, if any. The strain gages were attached on every member of two frames and initialized before the construction when the members were released horizontally on the ground in their natural lengths. Each strain gage was attached in a way that the deformation due to temperature change was canceled off and the reading gave pure strain due to the axial force.

The main concern of the monitoring was to know the real behavior of the full-scale tensegrity frames under temperature change. Its behavior under heavy wind load was also in the scope of the observation.

The room temperature at the height of 1m from the floor level is also being recorded. Thermocouple is attached to the foot of one of the main struts of each tensegrity frame and records temperature of it directly. This temperature data is thought to represent the temperature of the frame itself.

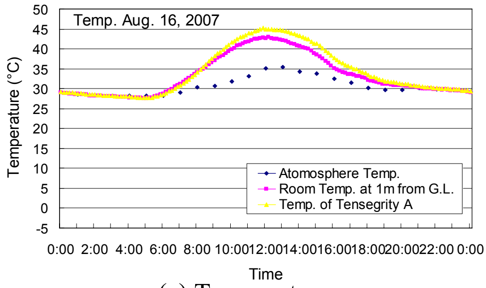
All these monitored readings have been recorded every ten minutes, constantly, since the completion of the building.

4. One-day data of the frame A

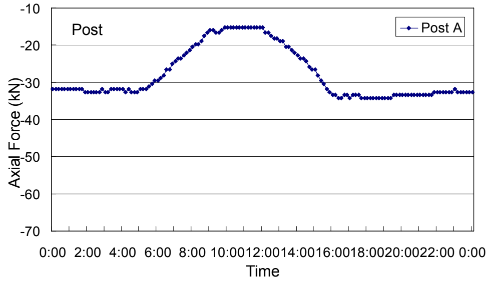
The completion of the building was June 2001. Since then the strain of each member has been recorded as well as the room temperature and the member temperature. In this section the one-day data of the hottest day and the coldest day, after the monitoring has started, is reported. Since the behavior of the two tensegrity skeletons, frame A and frame B, are rather similar here, thus, we report just about the data of frame A.

The hottest day was June 16th, 2007. The atmosphere temperature, the room temperature reached 35.4°C and 42.9°C, respectively, and the frame temperature became 45.2°C. The lowest frame temperature was 27.7°C. The range of the temperature change of the tensegrity frame was 15.2°C. The changes of the axial force of each member, calculated from the recorded strain, are shown in Figure 6.

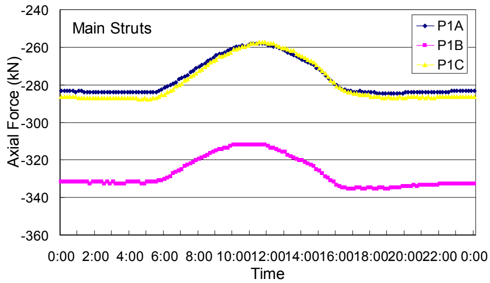
The coldest day was January 16th, 2003. The atmosphere temperature and the room temperature dropped to –1.6°C and –3.5°C, respectively, and the frame temperature became –3.4°C. The highest frame temperature was 10.2°C. The range of the temperature change of the tensegrity frame was 13.6°C. The changes of the axial force of each member, calculated from the recorded strain, are shown in Figure 7.



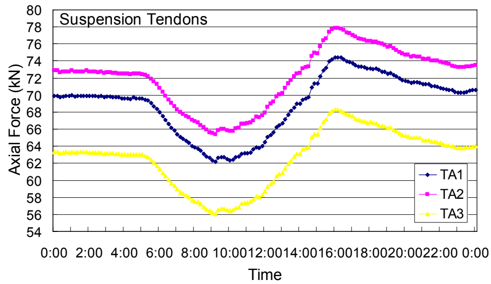
(a) Temperature



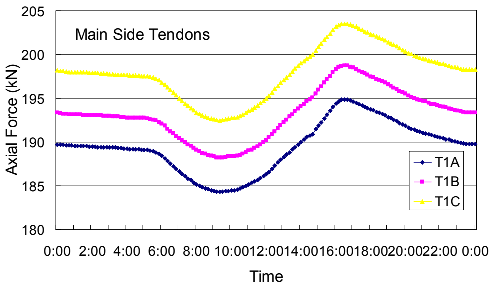
(e) Post A



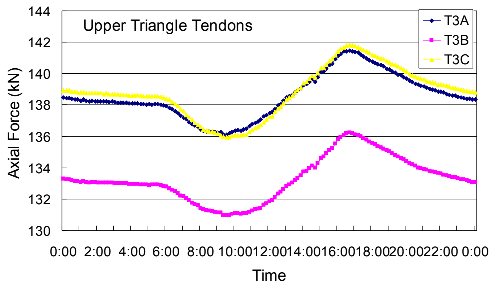
(b) Main struts



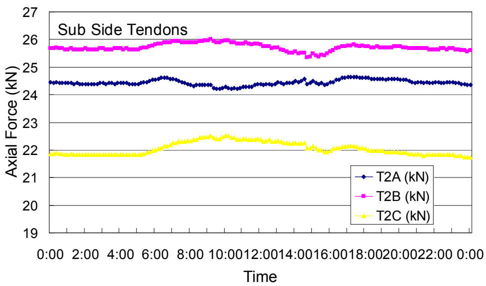
(f) Suspension tendons



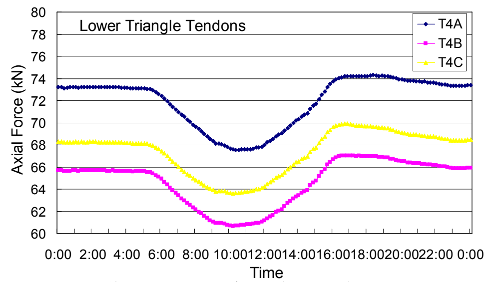
(c) Main side tendons



(g) Upper triangle tendons

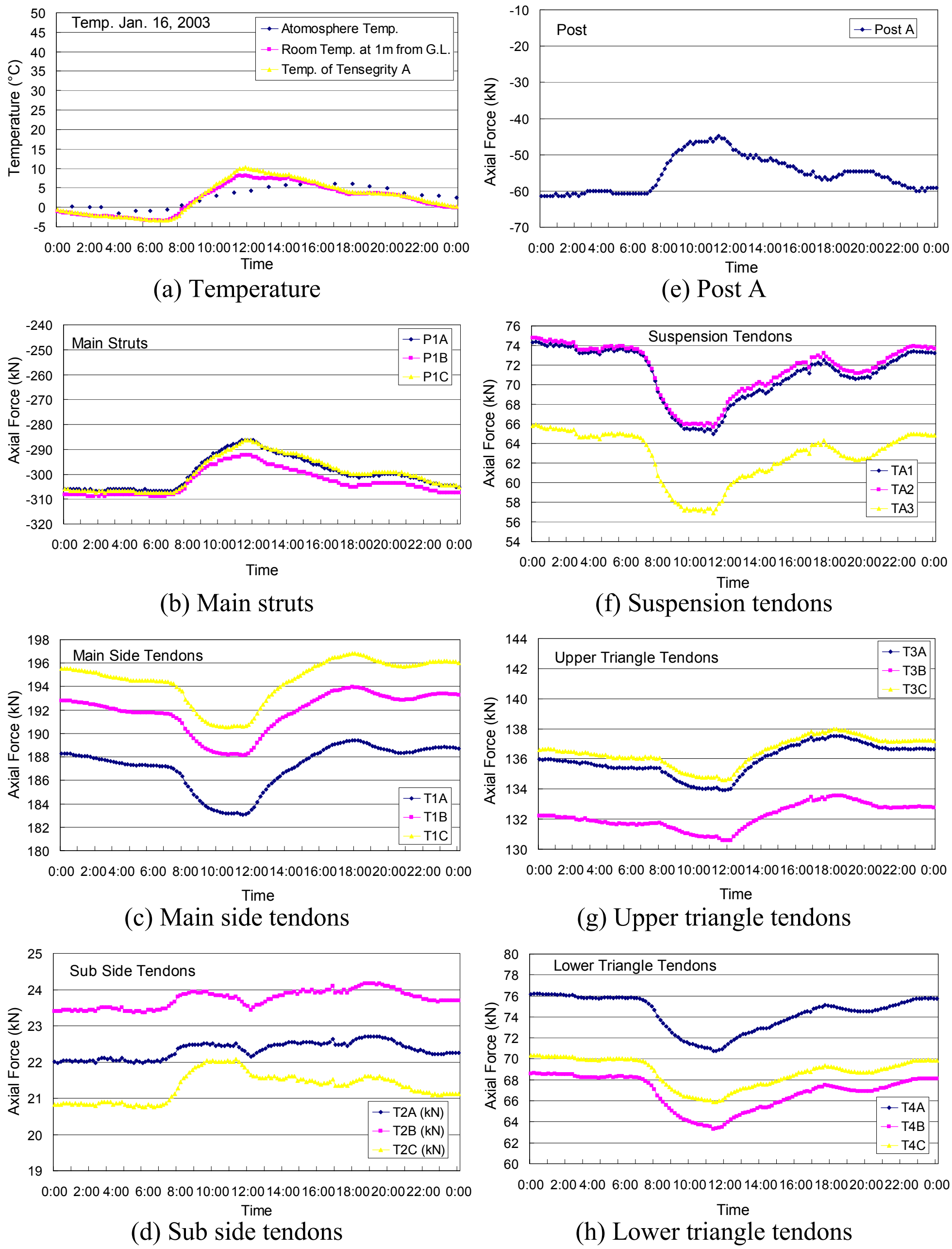


(d) Sub side tendons



(h) Lower triangle tendons

Figure 6: Axial force in frame A on Aug.16, 2008



(a) Temperature

(b) Main struts

(c) Main side tendons

(d) Sub side tendons

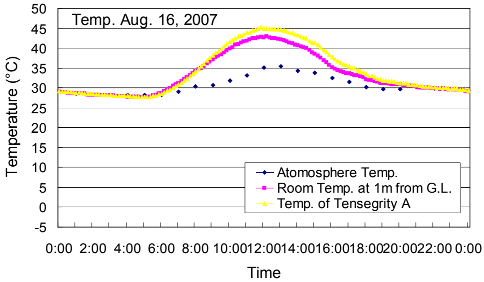
(e) Post A

(f) Suspension tendons

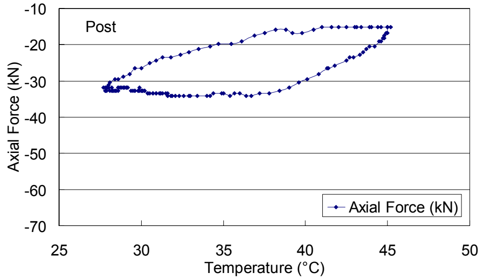
(g) Upper triangle tendons

(h) Lower triangle tendons

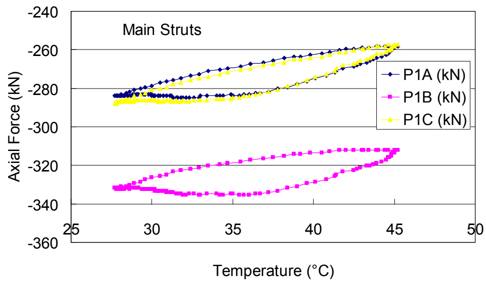
Figure 7: Axial force in frame A on Jan.16, 2003



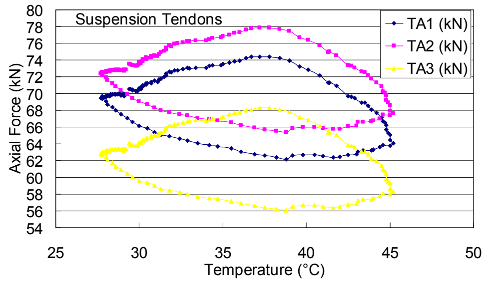
(a) Temperature



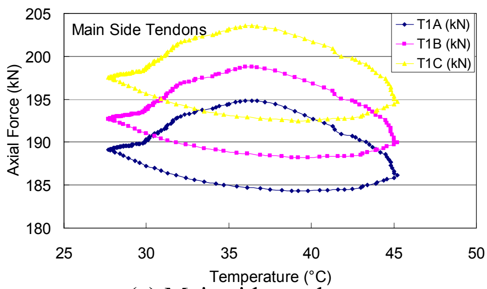
(e) Post A



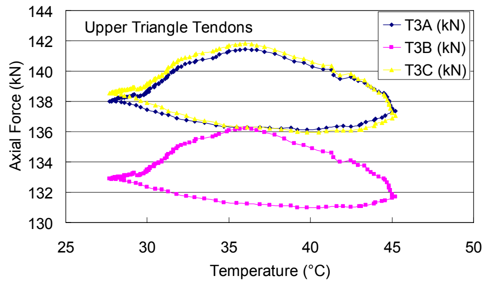
(b) Main struts



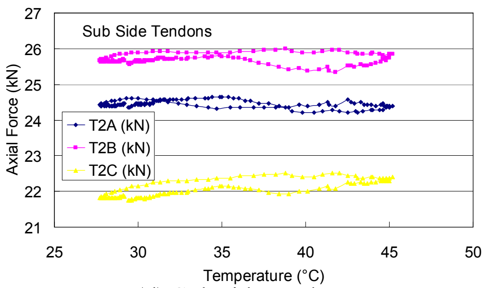
(f) Suspension tendons



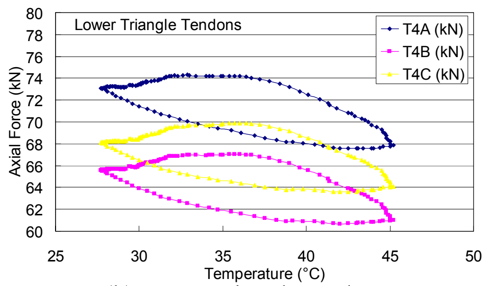
(c) Main side tendons



(g) Upper triangle tendons



(d) Sub side tendons



(h) Lower triangle tendons

Figure 8: Temperature vs. axial force in frame A on Aug.16, 2007

5. Axial force change of the members

As was explained earlier the expansion due to temperature change is cancelled off. However the strain change and, namely, axial force change in each member can be clearly observed.

Comparisons of the axial force changes in the corresponding members in figures 6 and 7 show that the change of the axial forces in one day seems almost similar even in the hottest day and in the coldest day. From figures 6 and 7, it can be seen that increase of temperature generally reduces the self-stress level of the tensegrity frames. Range of the change of the main struts are about 20kN and the main side tendons are about 5kN in either day. Axial force change in the sub side tendons is always comparatively small since they are rather insensitive to the change of the skeleton.

It seems that there are direct and indirect sources of the axial force change. The direct source is the change of the temperature. Every curve in the figures 6 and 7 seems to follow the temperature change indicated by the curves in the figure (a) in figures 6 and 7. The indirect source is the tension change in the membrane roof. This tension pulls down the post at its top and usually induces the vertical load to the tensegrity skeleton through suspension tendons.

The membrane roof covers the outside of the building and gets heat a little earlier than the interior space. This is, probably, why the upper members, especially the post member, seem to reduce their axial force a little earlier than the temperature change and reach their peak also a little earlier than the temperature change. The responses of members seem to follow this change as the change of the vertical load transmitted from the post. As is can be seen from the (e)'s in figures 6 and 7, the tension in membrane recovers quickly around 18:00 and this produces another small peak in each curve. For example the maximum tensile force in the main side tendons can be observed at this peak. Since the temperature of the interior space goes back slowly then the axial forces gradually come down.

Relationships between the temperature and axial forces, in the hottest day, are indicated in figure 8. As is can be seen in the figure their relationships draw loops. Loops for compressive members progress in clockwise while that for tensile members go anti-clock wise.

6. Conclusions

One-day data showing axial force change of one of the full-scale tensegrity frames under temperature change were reported. The increase of the temperature generally reduces the self-stress level of the tensegrity frames. The axial force change seemed to be influenced by two conditions, the temperature change and the behavior of the membrane roof that the skeletons are supporting.

References

[1] K.Kawaguchi K. and Lu Z-Y, Construction of three-strut tension systems, in *Proceedings of 5th International Conference on Space Structures*, Parke G & Disney P (ed.), 2002; Vol.1; 1-10

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[2] K.Kawaguchi K. and Ohya S., Preliminary Report of Observation of Real Scale Tensegrity Skeletons under Temperature Change, in *IASS 2004 Symposium, Shell and Spatial Structures from Models to Realization, Montpellier*, Motro R (ed.), 2004, TP149.pdf.