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Structural Properties of Tensioning Air Beam System (TABS)

Ki-Youl BEAK*, Jong-Soo KIM

*Senior Researcher, Dr. Eng., CS Structural Engineering Inc., #413-4 Togok2-dong,
Kangnam-gu, Seoul 135-854, South Korea , cutty9@csse.kr

P.E., President of CS Structural Engineering Inc., jskim@csse.kr

Abstract

Light weight structures have much structural merits than ordinary building element in roof structure. Tensioning Air Beam System (TABS) which consists of air beam and cable strut is a light weight structure system and hybrid system. Several researches which concerned to tensioning pneumatic structure reported in recent year, especially *Tensairity* is representative of tensioning pneumatic structure. In *Tensairity*, compression and tension are physically separated. Low pressure compressed air is used for pre-tensioning the tension element and for stabilizing the compression element against buckling. Previous researches of *Tensairity* show structural ability of a typical air pressure beam. Therefore, there is necessary to make an interrelation between air pressure and structural abilities of tensioning air beam qualitatively. In this study, a number of specimens were tested with different air pressure condition.

Keywords: Tensairity, Tensioning Air Beam System

1. Introduction

Tensioning air beam system (TABS) is a hybrid system which consists of air beam, cable and frame, and this system is a combination of air beam structure and tensioning structure. This system is a light weight system as well as a system which can improve supplied ability of air beam structure, and excellent constructability is also its advantage. This system can be considered as a very effective system in both structural and economical side to maximize individual ability of basic elements constituting this system including air beam and frame. TABS was first suggested by Swiss EMPA under the name of *Tensairity*, and various research results on design equation and structural ability have been presented, but the interrelation between important variables for design including pressure, cable tension and system structural ability was not clear, so there are not sufficient quantitative and qualitative data for actually applying *Tensairity* to a structure.

TABS structural test was carried out in this study under various pressure conditions as variables in order to understand TABS structural ability according to the pressure of air beam. Slenderness ratio, air pressure, cable tension, membrane intensity, sectional ability of tube used as compression element, and displacement of air beam itself due to interaction between membrane and cable suggested in design equation can be used selectively for actual test variables, but the pressure of air beam was used basically as test variable in this study. The test was carried out by dividing it into pressure test of air beam itself and TABS structural ability test. Variation of air beam according to change in air tightness and pressure of beam was determined through the pressure test to calculate the length of cable which is used in TABS. 10m span actual size test was carried out based on the pressure of air beam as a variable for structural ability test to determine structural advantage of TABS through qualitative and quantitative ability of TABS. The results obtained from the test were compared with the result of the initial rigidity on load-displacement relations obtained from theoretical equation

2. Basic concept of TABS

2.1 Composition of TABS

TABS is composed of air beam, square steel tube member described as compression element and cable which wraps air beam as shown in Figure 1. Cable is an element for combining square steel tube with air beam, and it is connected to both ends and the center part of square steel tube. Basic mechanism of TABS is as follows.

1) Moment is created on beam of air beam by applying load on beam.

2) Tensile force is applied on the cable due to applied moment

3) Tensile force of cable is delivered to the joint.

Figure 1 Composition of TABS

2.2 Basic equations for TABS

According to reference on *Tensairity* (R.H. Luchsinger, 2004),normal force of membrane and load and pressure relations cab be obtained as follows by limiting displacement against the radius of air beam to 0.2.

$$T_{\max} = p \cdot R^{2}{}_{0} \cdot \frac{\gamma^{2}}{\pi^{2}}\ Tensairity^{R} \tag{1}$$

$$p = \frac{\pi^2}{2} \cdot q \tag{2}$$

Table 1 is the arrangement of equations on normal force (f), cable force (T) and the pressure according to *R/d* value.

From the equations above, *R* is the radius of air beam, δ (delta) is vertical displacement of membrane, *p* is the pressure and *q* is uniform load.

Table 1. Design equation of TABS

δ / R_0	f_max	T	pressure
0.1	$0.283 \cdot p \cdot R_0$	$0.566 \cdot p \cdot R_0{}^2 \cdot \frac{\gamma^2}{\pi}$	$p = \frac{1}{2.24} \cdot \frac{\pi^2}{R_0} \cdot q$
0.2	$0.5 \cdot p \cdot R_0$	$p \cdot R_0{}^2 \cdot \frac{\gamma^2}{\pi}$	$p = \frac{1}{4} \cdot \frac{\pi^2}{R_0} \cdot q$
0.3	$0.66 \cdot p \cdot R_0$	$1.32 \cdot p \cdot R_0{}^2 \cdot \frac{\gamma^2}{\pi}$	$p = \frac{1}{5.28} \cdot \frac{\pi^2}{R_0} \cdot q$

3. TABS Structural ability test

3.1 TABS structural test

In order to find out TABS structural ability, structural test on 10m span was carried out. Test variable is beam pressure of air beam, and the test was conducted under the pressure of 100, 200, 400 and 600mbar. Table 2 shows the specifications of cable and square steel tube used in TABS. 2-point loading was applied on 2.5m location from both ends as Figure 2 so that moment of center could be identical to distributed loading load. 4 cables were used as the pictures below. Each loading point and Joule displacement meter as the center part was used for the location of displacement measurement. Monotonic loading is used for loading method, and cylinder type oil jack was used for loading device. And also, plate boundary condition of specimen was designed at the pin point of both ends by considering actual constructability. Figure 3 shows the joint location of TABS, and cable and square steel tube are connected using bolts by swaging the cable as Figure 4. This is for adjusting the length of cable flexibly on beam volume change of air beam according to change in the pressure and installing load cell on the joint for the measurement of cable tensile force at the same time.

Table 2. Property unit of material

Cable				Compression element			
$\Phi 10(1\times7)$				$125\times75\times2.3(SS400)$			
Diameter	Sectional area	Fracture load	Unit weight	E	ν	Fy	Fu
10	61.3	84.7	0.49	210	0.3	0.24	0.41

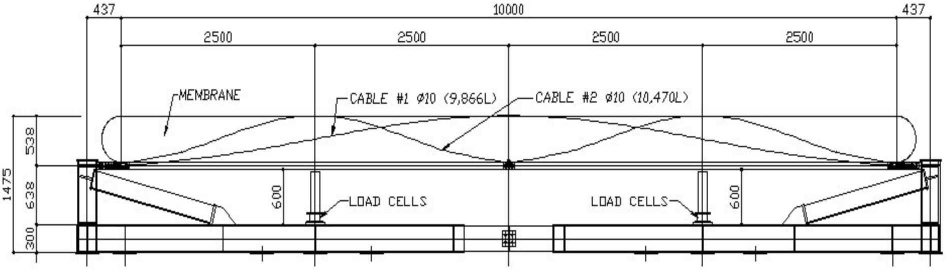

Figure 2 Specimen detail

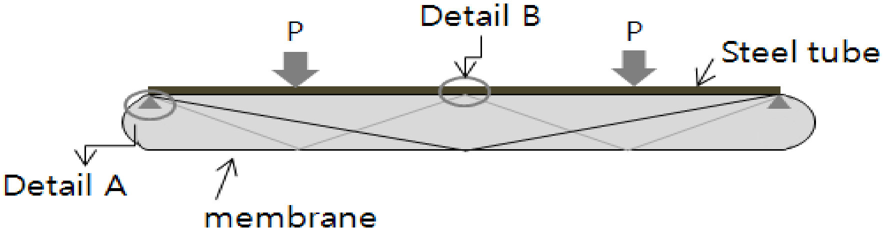

Figure 3 Location of joint

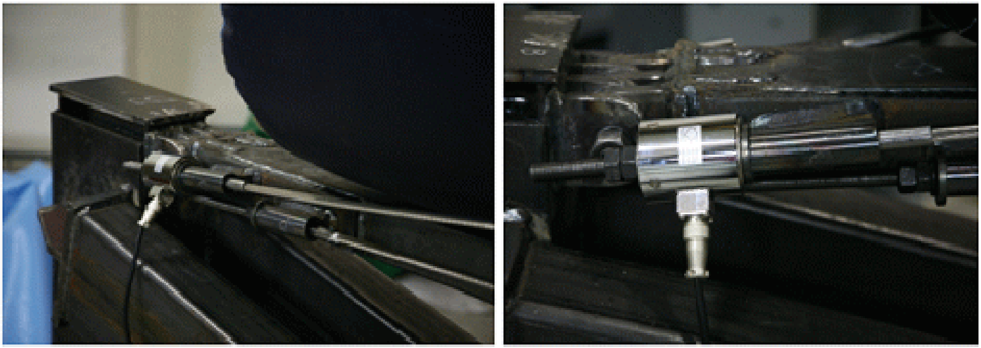

Figure 4 Connection detail A

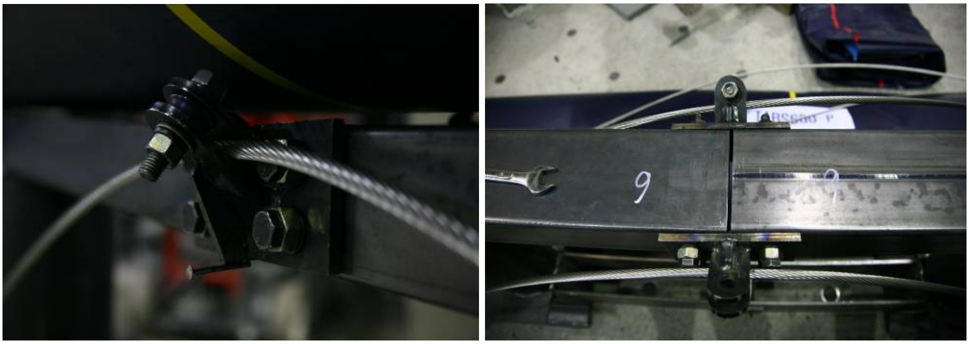

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Figure 5 Connection detail B

Figure 5 shows center joint of beam among TABS structure, and it is connection detail B for connecting the center part of the beam to a cable wrapping the beam of air beam. In case TABS structure is used on a long span and the length of compression element becomes longer, compression element must be sliced and delivered for the convenience of delivery and installation. In this case, connection of center part is required in order to maintain continuance of compression element, and detail B can be considered as an effective joint detail for solving the connection of element and the connection between square steel tube and cable simply by using bolts.

3. 4 Result of structural test and consideration

TABS is a ductile structure, and all specimens showed variation ability over 250mm which is the maximum stroke of the cylinder. Therefore, the maximum load and tension described in this study mean test value in the maximum displacement of 250mm, not final state of specimen. In specimen design, grade of load displacement relations is expected to be decreased at center load point the due to local buckling of square steel tube, but as a result of test, load is continuously increased because air beam provides elastic support to square steel tube regardless of local damage of square steel tube. Local variation of square steel tube is determined by stain gauge value, and actual point where load-displacement grade of specimen is actually changed can be considered as the maximum internal force point of square steel tube.

Table 3 shows the result of TABS structural test according to change in the pressure, indicating the maximum load, the maximum displacement and cable tension of loading point. This result is for a case of connecting a cable by considering volume change after air beam expansion at each pressure state, and a case of setting initial form of beam of air beam to post-variation. That is, no tension on cable is assumed before external force is applied. Average 15kN tension was occurred at the time of connecting a cable to plate joint of square steel tube actually, but this value is disregarded in this study.

P_{u_cal} of Table 3 is load calculated by Equation (2), and the value inside of the table is a value of replacing uniform load with center load. The maximum load of all specimens was higher than design equation value. TABS ability is improved as pressure increased, but it performs relatively higher structural ability in low air pressure (100, 200mbar) in comparison to calculation value. Especially, 100mbar specimen showed 3 times higher structural ability than calculation load Tension created on the cable is increased as pressure of air beam is increased, and the value of average 15% is measured in comparison of design equation value.

This is because ductile variation of air beam is not considered and the value calculated from the maximum moment of beam is applied in case of design equation. And also, it is because a case of cable being attached closely along the curvature shape of air beam is considered theoretically. Figure 5 shows a view of TABS structural ability test and loading status. As seen in Figure 5, a local variation of square steel tube could be confirmed on loading point, and also variation of air beam due to cable in the maximum stroke could be confirmed.

Table 3 The result of structural test

Unit : kN, mm

Pressure (mbar)	Maximum load		$P_{u\text{-}exp}/P_{u\text{-}cal}$	Maximum uniform load	Maximum center displacement	Maximum cable tension		T_{exp}/T_{cal}
	$P_{u\text{-}exp}$	$P_{u\text{-}cal}$				T_{exp}	T_{cal}	
100	16	5.0	3.2	3.0	245	-	-	-
200	19.3	10.1	1.9	3.8	232.4	13	96	0.13
400	23.1	20.2	1.1	4.6	222.6	20	115	0.17
600	30.3	30.3	1.0	5.7	223	27	151	0.17

Figure 6 shows load-displacement relations of loading point and Figure 7 show reaction moment-cable force relations. The picture shows that initial rigidity and the maximum load are increased in proportion to the increase in beam pressure of air beam. In case the pressure is high in uniform load-displacement relations, displacement at the maximum point is displayed smaller than low air pressure. This is because beam rigidity of air beam is increased in case of high air pressure specimen so that reaction force at the center part is relatively increased. Cable tension also is in proportion to increase in moment due to pressure increase.

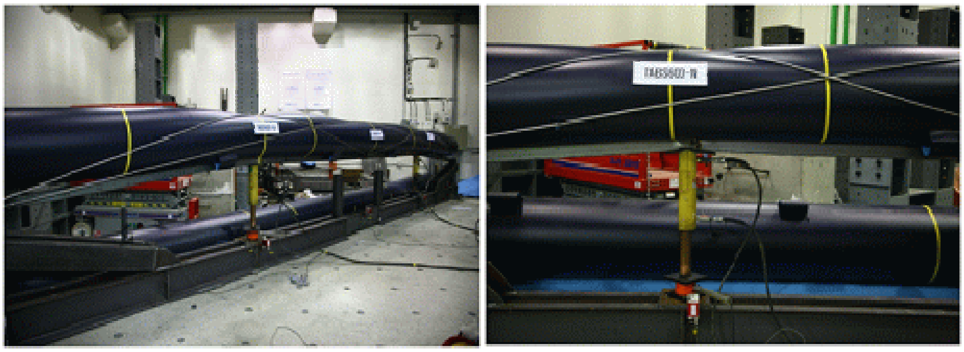

Figure 5 view of specimen and loading status

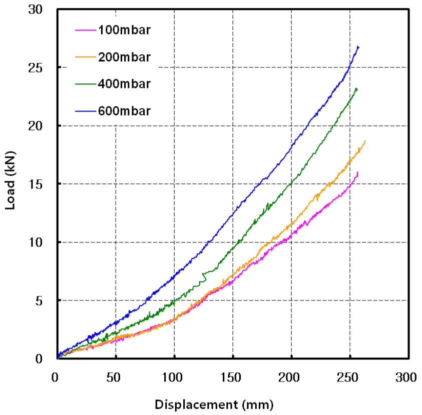

Figure 6 Load-displacement relations

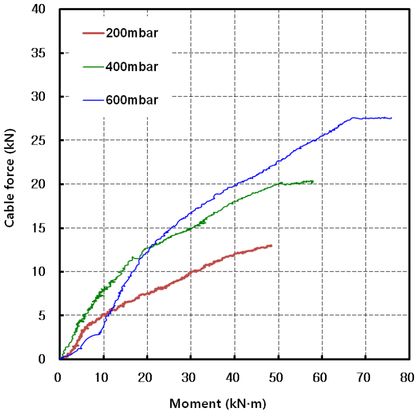

Figure 7 Moment-cable force relations

4. Conclusion

In order to understand TABS structural ability according to the air beam pressure, TABS structural test was carried out under various pressure conditions as variables, and induction and structural analysis of design equation on initial rigidity was carried out through the test result. The result obtained through the study is as follows.

1) As a result of TABS structural ability test, the structural ability is improved in proportion to increase in beam pressure of air beam, but relative structural ability is greatly improved in low pressure (100, 200mbar).

2) As a result of the test, TABS behavior is very ductile, and the examination of its usability on load-displacement relations will be required for its actual application, and its application on roof structure of large space structure will be very effective.

3) Behavior of TABS is nonlinear, and in case of applying it to an actual structure, structural analysis with the consideration of boundary condition will be required.

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