Soap Film of Tensioned Fabric Structure in the Form of Handkerchief Surface

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ABSTRACT

Form-finding has to be carried out for tensioned fabric structure in order to determine the initial equilibrium shape under prescribed support condition and pre-stress pattern. Tensioned fabric structures are normally designed to be in the form of equal tensioned surface. Tensioned fabric structure is highly suited to be used for realizing the surfaces of complex or new forms. However, the research study on a new form as a tensioned fabric structure has not attracted much attention. Alternative source of inspiration of minimal surface which could be adopted as form for tensioned fabric structure is very crucial. The aim of this study is to investigate initial equilibrium shape of tensioned fabric structures in the form of Handkerchief surface, u=v=0.2 and u=v=1.2. Experimental form-finding using soap film model is frequently used to develop the possible form of uniformly stressed surfaces. Apart from that, soap film model also provides a means for checking the accuracy of computational form-finding results. In this study, soap film model is used to investigate surface form corresponding to boundary shape defined by mathematical equation for minimal surface. Computational form-finding using nonlinear analysis method has been used in this study. The study proposes an alternative architectural surface for architect and structural engineer to consider Handkerchief surface, u=v=0.2 and u=v=1.2 applied in tensioned fabric structure. The results on factors affecting initial equilibrium shape can serve as a reference

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for proper selection of surface parameter for achieving a structurally viable surface. Such in-sight will lead the improvement of rural basic infrastructure, economic gains, sustainability of built environment and green technology initiative.

Keywords: *Soap film model, tensioned fabric structure, Handkerchief surface, minimal surface, nonlinear analysis method.*

Introduction

Tensioned Fabric Structure (TFS) is the structure composes of fabric structural as structural members which acting in tension direction. This structure used fabric as main material in TFS. Structure of TFS is suitable to be used for long span application. The structures are built to last a long time as mentioned from [1]. Actually, TFS has been used over the past 50 years ago. Figure 1 shows an example of Tensioned Fabric Structure. The structure of TFS can be composed of fabric structural as structural members. The material is usually used is fabric, fabric is used to join together with the structure. Fabric is tensioned through with the cable to a rigid supporting system to typically and to provide a roofing structure.

Figure 1: Tensioned Fabric Structure

Some researcher found that there is some particular information about the development of a new sort of a temporary modular steel footbridge for pedestrians and cyclist, which was designed as a truss system with the deck below the supports and with the closed cross-section [2]. Other researchers have stated that this research in the course of development in the field of protection of new and existing structures subject to dynamic events [3].

The surface type structure used in this study is Handkerchief surface. Handkerchief surface is suitable used for TFS. Handkerchief surface is a form of minimal surface. Minimal surface is surface structures were very minimal and it is normally designed to be in the form of equal tensions surface. [4] presented for the initial shape finding of fabric structures. From this study, minimal surface for this structure can be achieved through a succession of equilibrated configurations. The characteristic of minimal surface is the surface of a minimal area within a given boundary.

The process of this study began with structural analysis in TFS is form-finding. Form-finding is to determine the initial equilibrium shape under pre-stress pattern and boundary condition. The proposed method used is nonlinear analysis method for form-finding of tensioned fabric structures [5]. Applicability of the computational strategies proposed has been verified by form-finding carried out models of tensioned fabric structures by [5,6]. A few researchers have carried out form-finding using nonlinear analysis method known as Catenoid, Helicoid, Scherk, Enneper, Oval, Costa, Moebius Strip, Monkey Saddle and Chen-Gackstatter TFS models, respectively [7-19]. In this study, only form-finding using nonlinear analysis method of Handkerchief surface, u=v=0.2 and u=v=1.2 has been carried out.

The form of TFS is highly suited to be used for realizing surfaces of complex or new forms. However, none of the new examples mentioned present any results on the Handkerchief surface, u=v=0.2 and u=v=1.2 as load carrying members. The understanding of the possible Handkerchief surface, u=v=0.2 and u=v=1.2 initial equilibrium shapes to be obtained will provide alternative shapes for designers to considerations.

Generation of Handkerchief Surface

Figure 2 shows the form of Handkerchief surface [20,21]. Equation (1) is used to determine the shape of Handkerchief Surface.

$$X = u\,,\ Y = v\,,\ Z = \frac{1}{3}u^3 + uv^2 + 2(u^2 - v^2) \qquad (1)$$

Where X, Y and Z are the coordinates in X, Y and Z directions, respectively. u and v are variable, the change shape of Handkerchief surface using on the variable and each side are equal to constant value.

From this study, the program of ADINA system has been used as the finite element method (FEM) software for the purpose of model generation [22]. Aspect of modeling for Handkerchief surface and form as well pre-stress pattern of the resulting TFS through form-finding using nonlinear analysis method proposed [5].

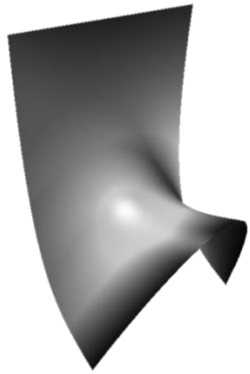

Figure 2: Model of Handkerchief Surface

Computational Method using Nonlinear Analysis Method

The principle of nonlinear analysis method is based on work had done by Yee [5]. The large displacement finite element formulation had used for analysis of structural behaviour under external loads. Since the method can be used for both the initial equilibrium problem and load analysis, the approach using nonlinear analysis is quite common. The basic Equation (2) is used to express the shape of Handkerchief surfaces as follows:

$$({}_0^t\boldsymbol{K}_L + {}_0^t\boldsymbol{K}_G)\boldsymbol{u} = {}^{t+\Delta t}\boldsymbol{F} - {}_0^t\boldsymbol{f} \tag{2}$$

Where ${}_0^t\boldsymbol{K}_L$ is linear strain incremental stiffness matrix, ${}_0^t\boldsymbol{K}_G$ is nonlinear strain incremental stiffness matrix, ${}_0^t\boldsymbol{f}$ is vector internal forces, ${}^{t+\Delta t}\boldsymbol{F}$ is load vector and $\boldsymbol{u}$ is vector of increment in displacement.

The nonlinear analysis method used in the study and this method are proposed from the analysis of tensioned fabric structures [5]. The procedure adopted is based on the work as specified in [5]. 3-node plane stress element has been used as element to model the surface of TFS. All the x, y and z translation of nodes lying along the boundary edge of the Handkerchief surface have been restrained. The member pretension in warp and fill direction is 2000N/m, respectively. The shear stress is zero, at this plane.

Two stages of analysis were involved in the procedures of form-finding in one cycle proposed [5]. First stage (denoted as SF1) is analysis which starts with an initial assumed shape in order to obtain an updated shape for initial equilibrium surface. The initial assumed shape can be obtained from any pre-processing software and reference [5] is chosen for this study. This is then followed by the second stage of analysis (SS1) aiming at checking the convergence of updated shape obtained at the end of stage (SF1). During stage

(SF1), artificial tensioned fabric properties, E with very small values are used. Both warp and fill tensioned fabric stresses are kept constant. In the second stage of (SS1), the actual values of tensioned fabric properties are used. Resulting warp and fill tensioned fabric stresses are checked at the end of the analysis against prescribed tensioned fabric stresses. Then, iterative calculation has to be carried out in order to achieve convergence where the criteria adopted is that the average of warp and fill stress deviation should be < 0.01. The resultant shape at the end of iterative step n (SSn) is considered to be in the state of initial equilibrium under the prescribed warp and fill stresses and boundary condition if difference between the obtained and the prescribed membrane stresses relative to the prescribed stress is negligibly small. Such checking of difference is obtained and prescribed stresses has been presented in the form of total stress deviation in warp and fill direction versus analysis step. As a first shape for the start of form-finding procedure adopted in this study, initial assumed shape is needed. For the generation of such initial assumed shape, knowledge of the requirement of anti-clastic nature of TFS is used. The incorporation of anti-clastic feature into the model will help to produce a better initial assumed shape.

Experimental Method using Soap Film Model

The soap film model is shown in Figure 3. The experimental method using soap film is based on work done by Yee [5]. The material and equipment have been used in the project is steel, aluminum wires, plywood, super glue, rubber band, wire, glycerin, concentrated car detergent, distilled water, theodolite, plumb bob and camera.

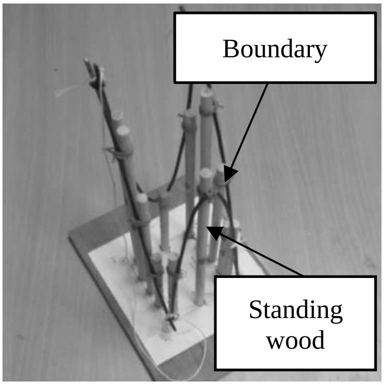

Figure 3: Soap Film Model with standing wood and boundary.

The boundary frame on the surface has been built based on the coordinate. The coordinates have been calculated using Equations (1).

Plywood has been used as x-coordinate and y-coordinate of the boundary, standing steel rods has been used to support the wire frame at the desired height corresponding to z coordinate of the wire frame. Aluminum wires have been used to build the boundary of models. Super glue has been used to fix the steel and plywood. The rubber band has been used to secure the wire to steel rods. The wire has been tied to the steel rod at specified coordinates with rubber bands in order to produce the desired boundary defined by equations of Handkerchief surface. Then, glycerin, concentrated car detergent and distilled water used to prepare a soap solution. The preparation of soap solution has been contained the composition of water, detergent and glycerin. The composition used is 25.7% of glycerin, 22.8% of concentrated car detergent and 51.1% of distilled water.

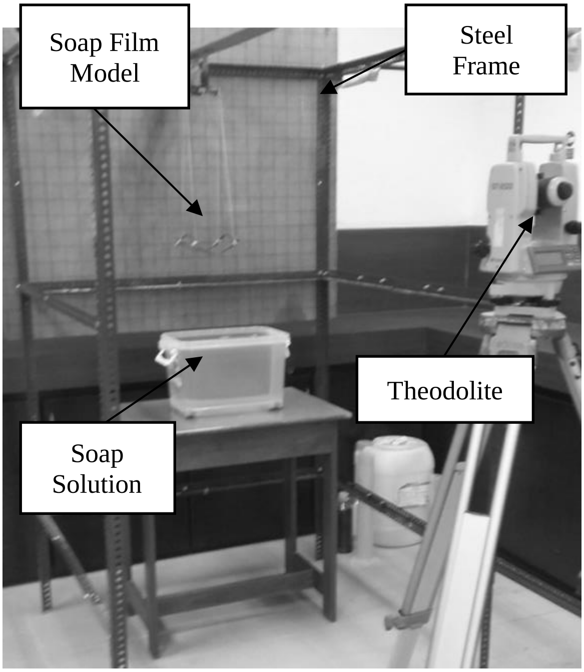

Figure 4: Experiment setup for soap film model.

Experimental setup form-finding using soap film model has been carried out as shown in Figure 4. In this experimental setup include theodolite, the container with soap solution, steel frame and physical model. Theodolite has been used to check the horizontal alignment and plan position alignment. In order to developed soap film model, the container is lift to dip soap solution to the model and it developed soap film model. Soap film model has been used to determine the surface form corresponding to the boundary shape defined by mathematical equations for Handkerchief surface in detail.

Comparison between Computational and Experimental Results

Handkerchief Surface, $u=v=0.2$

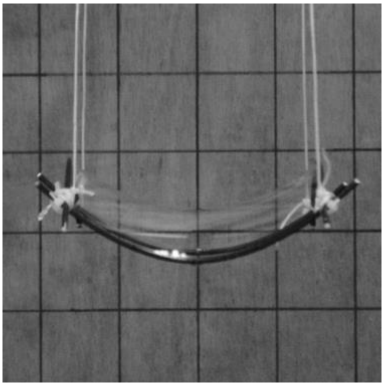

Figure 5 : Soap film model of Handkerchief Surface, $u=v=0.2$

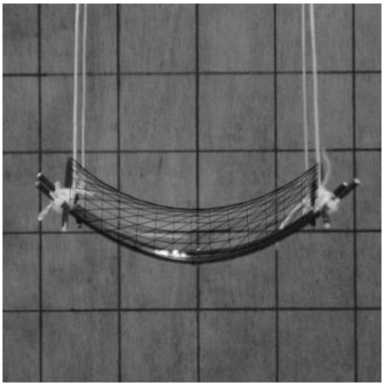

Figure 6 : Comparison of experimental and computational results of Handkerchief Surface, $u=v=0.2$

Figure 5 shows the soap film model for Handkerchief surface in view with parameters of $u=v=0.2$. From the computational result, the model of Handkerchief surface, $u=v=0.2$ has been superimposed with experimental soap film model, $u=v=0.2$. Meanwhile, Figure 6 shows the comparison of experimental and computational results of Handkerchief surface with parameter surface of $u=v=0.2$. The result is found to be in close agreement between them. The geometry between experimental and computational result has been found to match very closely.

Handkerchief Surface, $u=v=1.2$

Figure 7 shows soap film model for Handkerchief surface in front view with parameters of $u=v=1.2$. From the computational result for Handkerchief surface, $u=v=1.2$ has been superimposed with experimental soap film model, $u=v=1.2$ as shown in Figure 8. The result is found to be in close agreement. The geometry between experimental and computational result has been found to match very closely.

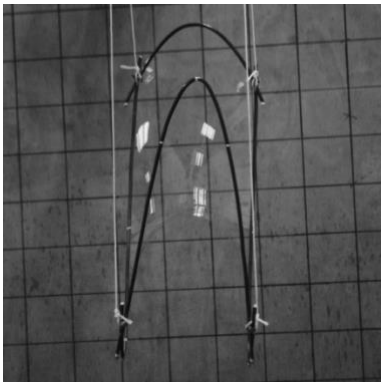

Figure 7 : Soap film model of Handkerchief Surface, *u*=*v*=1.2

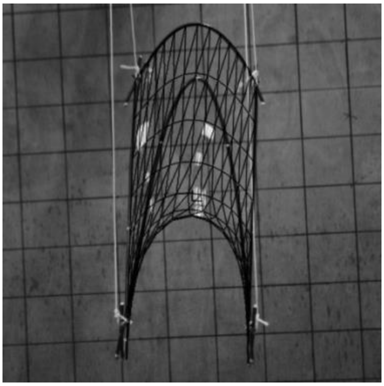

Figure 8 : Comparison of experimental and computational results of Handkerchief Surface, *u*=*v*=1.2

Conclusions

Soap film models with surface shape in close agreement with computational results with Handkerchief surface, *u*=*v*=0.2 and *u*=*v*=1.2 have been produced. Handkerchief surface, *u*=*v*=0.2 and *u*=*v*=1.2 provide an alternative architectural surface for architect and structural engineer to consider the tensioned fabric green structure in the form of Handkerchief surface. The Handkerchief surface, *u*=*v*=0.2 and *u*=*v*=1.2 would enhance the understanding on the suitable choice of Handkerchief surface for TFS among structural designer.

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