An efficient numerical shape analysis for light weight membrane structures

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Main goal of this paper

A recently-developed numerical method for the efficient shape analysis of lightweight membrane structures is proposed.

Major aspects involved in the method

- Construct a 3-node triangular (T3) membrane element based on the general structural analysis framework of the finite particle method (FPM), including the discrete model, the motion equation and the internal force formulations of membranes involving large rigid body motion.

- An integral-form explicit time integration scheme is applied to solve the motion equation and achieve the equilibrium shape in a short time.

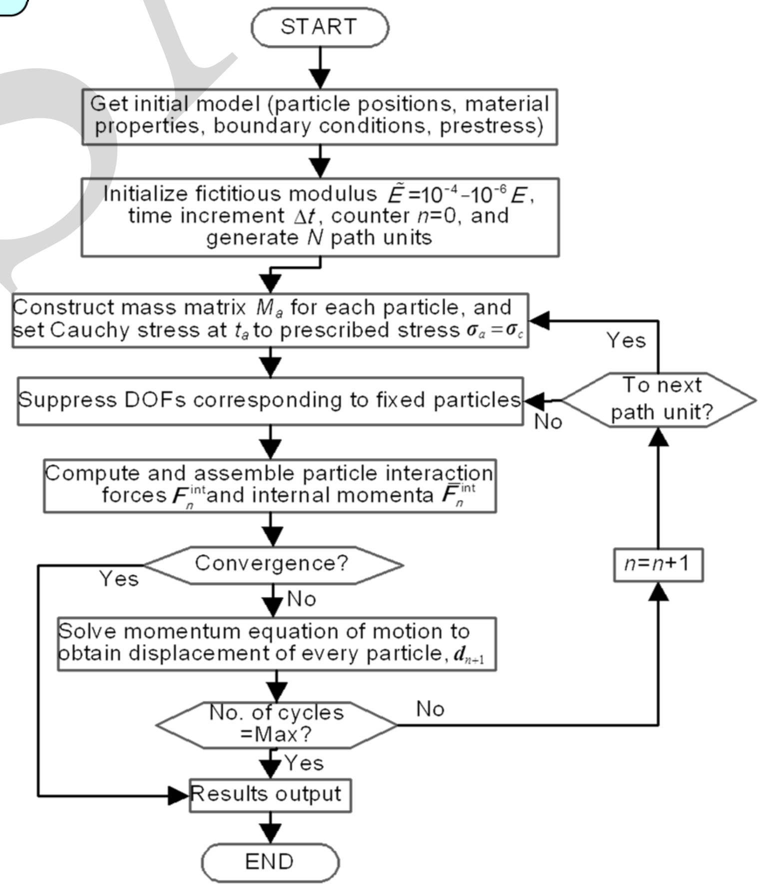

Fig. 9 Procedure of shape analysis performed by the FPM

Computational models and results

Model 1: Catenoid

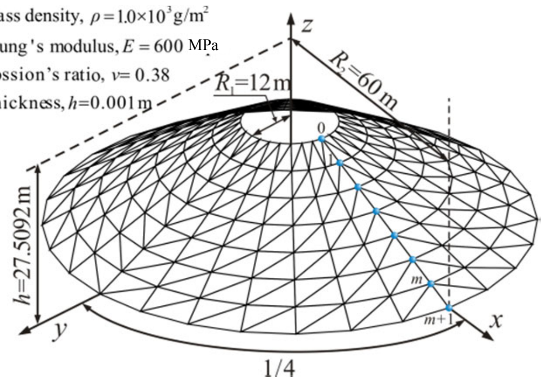

Fig. 11 Catenoid: initially assumed analysis model

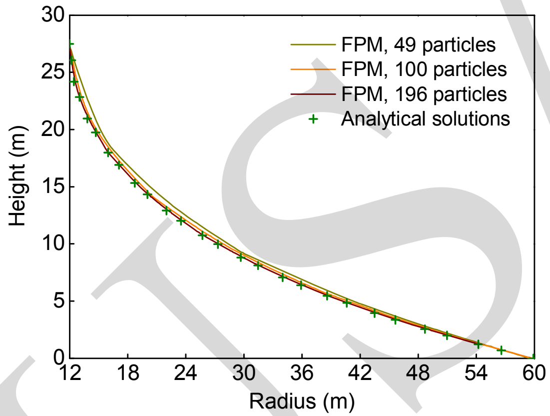

Fig. 13 Profiles of the form-found shapes in comparison with the theoretical solution

The discrepancy is small even in the case of a coarse arrangement of particles, and the convergence trend is apparent as the surface discretization is refined.

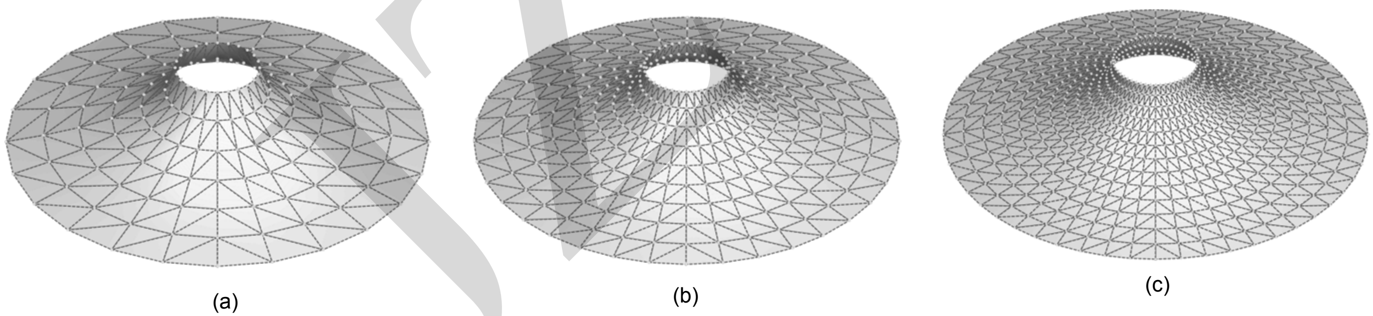

Fig. 12 Form-found shapes of tension membranes in the form of catenoid

(a) Model 1 with 49 particles; (b) Model 2 with 100 particles; (c) Model 3 with 196 particles

Computational models and results

Model 2: Scherk-like surface

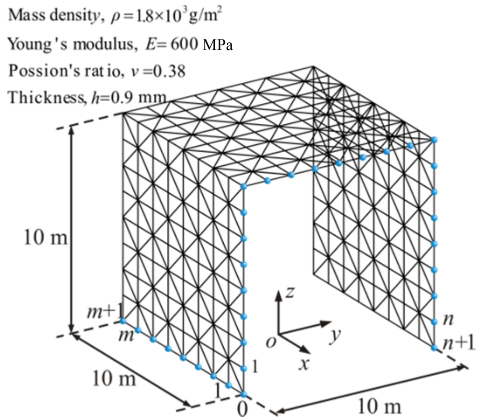

Fig. 14 Scherk-like surface: initially assumed analysis model

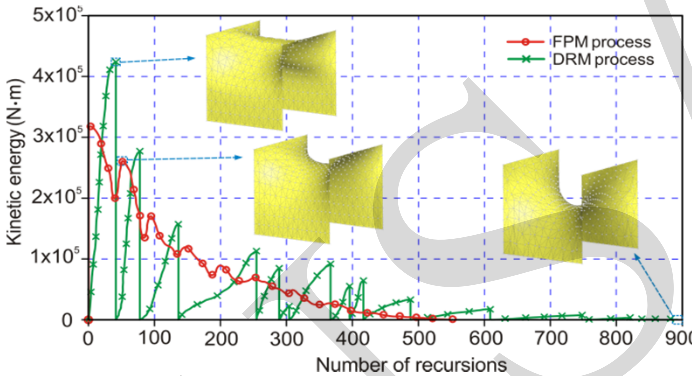

Fig. 17 Convergence process for kinetic energy (KE) of the entire system

A much smoother convergence process can be achieved within a shorter iteration history, when compared with the DRM with kinetic damping.

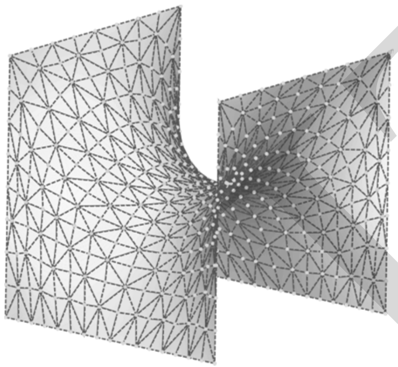

Fig. 15 Form-found shape of tension membrane in the form of Scherk-like minimal surface

Table 2 Comparison of the efficiency between FPM and DRM

No. of DOFs	DRM			FPM			Improvement, (DRM − FPM)/DRM (%)	RMS deviation in z-direction (m)
	No. of iterations	Average runtime per iteration (s)	Total runtime (s)	No. of iterations	Average runtime per iteration (s)	Total runtime (s)		
288	592	0.0042	2.483	447	0.0046	2.051	17.4	3.46×10^{-1}
399	648	0.0063	4.075	481	0.0068	3.270	19.8	1.82×10^{-1}
528	697	0.0089	6.204	503	0.0097	4.894	21.1	1.09×10^{-1}
675	745	0.0122	9.079	524	0.0133	6.988	23.0	6.81×10^{-2}
1023	887	0.0203	18.029	554	0.0218	12.098	32.9	3.95×10^{-2}
1275	993	0.0264	26.215	561	0.0281	15.792	39.8	2.73×10^{-2}

The FPM is much more efficient, in terms of the total CPU time required for convergence, than the DRM.