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Effect of support settlement on ultimate bearing capacity of Zhoukoudian steel structure

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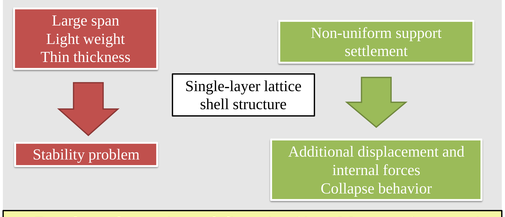
Introduction



Based on the project of first site (Ape Man cave) protective building in Zhoukoudian Ruins, consistent mode imperfection method and advanced consistent mode imperfection method are adopted to study the effect of non-uniform support settlement on the ultimate bearing capacity of the single-layer lattice shell structure by considering two kinds of global stability analysis: geometric nonlinear analysis (GNA) and double nonlinear analysis (i.e., geometric and material nonlinear analysis, GMNA).

Finite element model

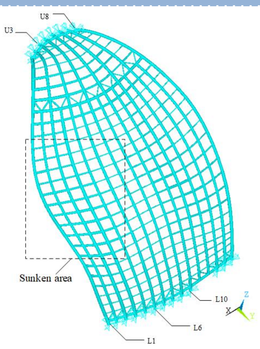


Figure 1. Finite element model of Zhoukoudian single-layer lattice shell.

Table 1. Support settlement cases.

Settlement case	SC1	SC2	SC3	SC4	SC5
L1 settlement/mm	-23.603	-59.008	-118.015	-177.023	-236.030
L6 settlement/mm	13.528	33.820	67.640	101.460	135.280
L10 settlement/mm	-33.288	-83.220	-166.440	-249.660	-332.880
U3 settlement/mm	-37.430	-93.575	-187.150	-280.725	-374.300
U8 settlement/mm	-2.678	-6.695	-13.390	-20.085	-26.780

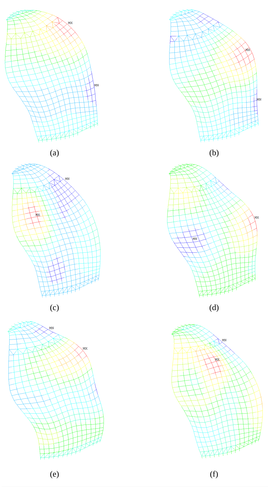


Figure 2. First six buckling modes.

Analysis results

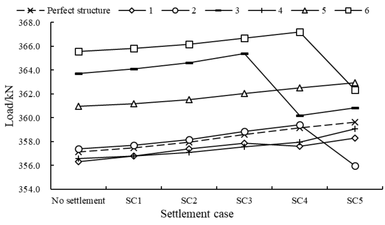


Figure 3. Diagram of changes in elastic global stability ultimate bearing capacity of lattice shells with each mode imperfection.

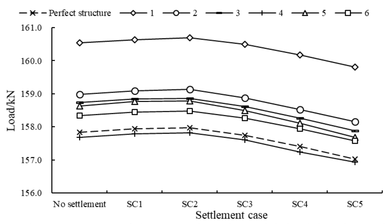


Figure 4. Diagram of changes in elastoplastic global stability ultimate bearing capacity of lattice shells with each mode imperfection.

Table 2. Mode imperfection combination coefficient.

Mode imperfection combination	1st mode imperfection	2nd mode imperfection	3rd mode imperfection	4th mode imperfection
C1	0.04	0.02	0.02	0.02
C2	0.02	0.04	0.02	0.02
C3	0.04	0.02	0.04	0.02
C4	0.04	0.02	0.02	0.04
C5	0.025	0.025	0.025	0.025

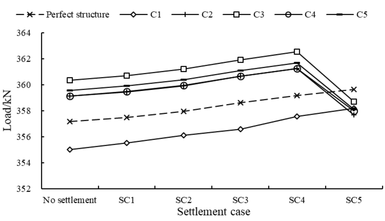


Figure 5. Diagram of changes in elastic global stability ultimate bearing capacity of lattice shells with combined mode imperfections.

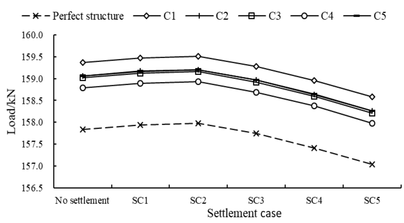


Figure 6. Diagram of changes in elastoplastic global stability ultimate bearing capacity of lattice shells with combined mode imperfections.

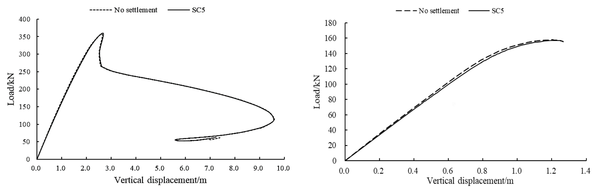


Figure 7. Load-displacement curve of the perfect structure by GNA and GMNA.

Conclusions

- Without considering material nonlinearity, the effect of non-uniform support settlement on the elastic ultimate bearing capacity of Zhoukoudian single-layer lattice shell is **within 1%**. Non-uniform settlement is beneficial to increase the elastic global stability ultimate bearing capacity of the perfect structure by a small margin, but excessive settlement may exert adverse effects on the bearing capacity of the structures with initial imperfections. The elastic global stability of the structure can be ensured by keeping the level **below 5-fold settlement**.
- When considering material nonlinearity, within 2.5-fold settlement, non-uniform support settlement is conducive to a slight increase in the elastoplastic global stability ultimate bearing capacity of the structure. After SC2, non-uniform support settlement has an adverse effect on the bearing capacity of the lattice shell with a decrease by **(0.508±0.09)%** under 10-fold settlement compared with that with no settlement. The elastoplastic global stability of the structure can be ensured by keeping the level **below 2.5-fold settlement**.
- Non-uniform support settlement will affect the value of elastic and elastoplastic global stability ultimate bearing capacity of the structure, but will not affect the instability path.