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A structural reliability-based sensitivity analysis method using particles swarm optimization: relative convergence rate

Key words:
Sensitivity analysis, Optimization, Structural reliability, Random variable

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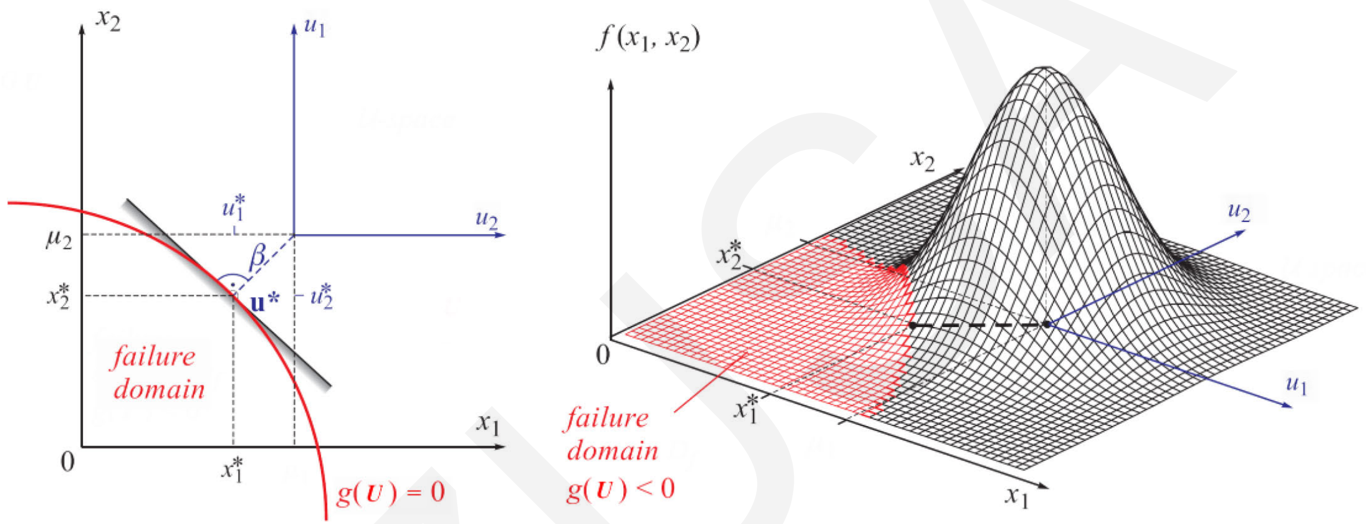
Background

Reliability



Geometrical meaning of structural reliability index

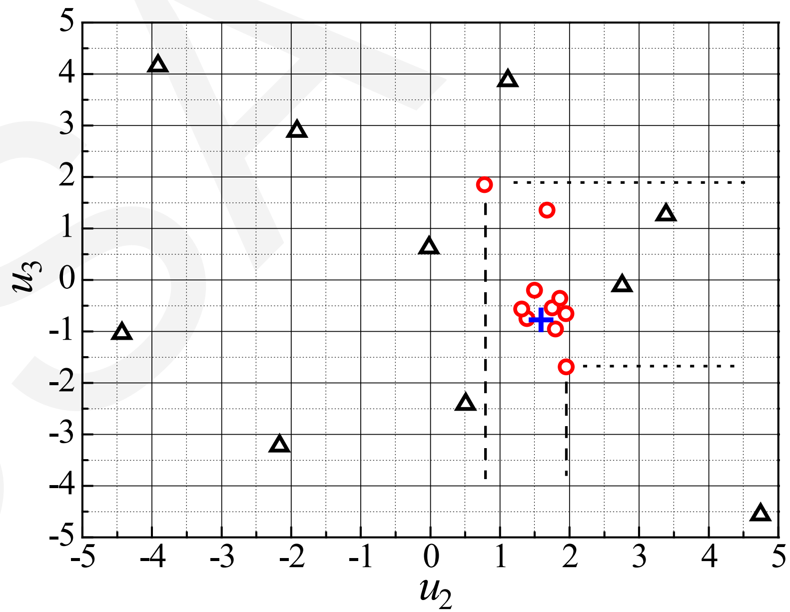
Sensitivity analysis (SA)

- SA is generally useful to know which variables mostly contribute to output variability.
- SA has played a key role in structural reliability design.
- Reduction of the insignificant random variables and improvement of computational efficiency are the important issues in the SA of structural reliability.

Method

Relative convergence rate using PSO

- The convergence rates of various random variables are different.
- The smaller the COV for the candidate particles of a variable is, the more sensitive the fitness function with respect to this variable is.



Diagrammatic sketch of relative positions of all particles in the u_2-u_3 plane

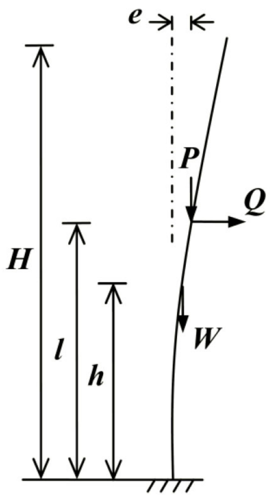
Question:

- PSO is a stochastic optimization algorithm, the convergence rate of various variables may fluctuate during optimization process.

Solutions:

- The COVs for the candidate particles of the random variables in PSO solution space are obtained in an optimized group, rather than in each population.
- An optimized group is a set of particles with relatively better fitness values, and these particles are selected from successive *S* generations.

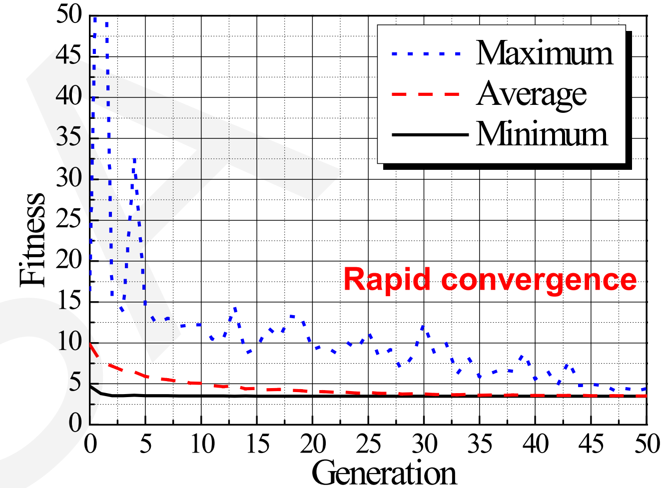
Simulations for bridge tower



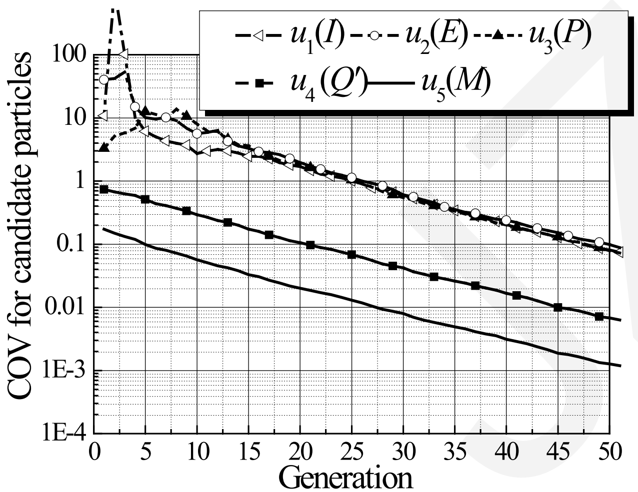
Schematic model of the tower of a cable-stayed bridge along longitudinal direction

The limit-state function:

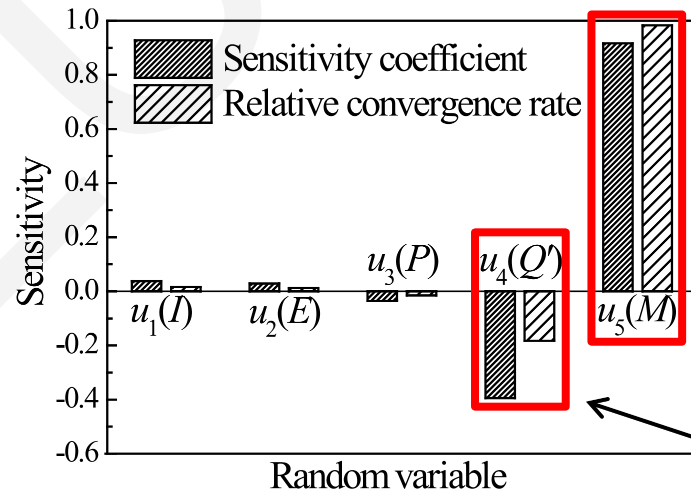
$$g = M - \frac{PQ'l^3}{3EI\left(1 - \frac{2}{5}\frac{Pl^2}{EI}\right)} - \frac{WQ'lh^2}{3EI\left(1 - \frac{2}{5}\frac{Pl^2}{EI}\right)} - Q'l$$



Convergence history of minimum, average and maximum fitness



Convergence curves of COV for candidate particles of random variables



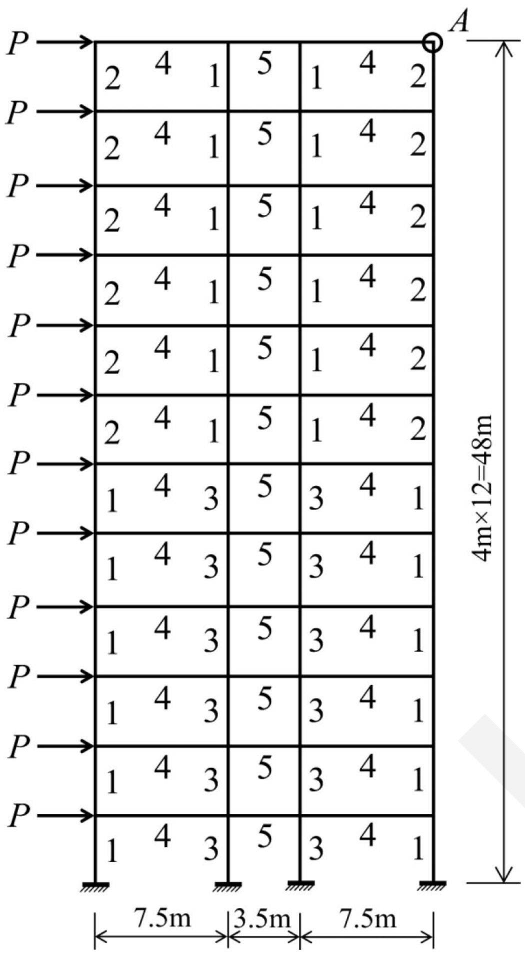
Sensitive variables:

The moment resistance of a section at the bridge tower foot

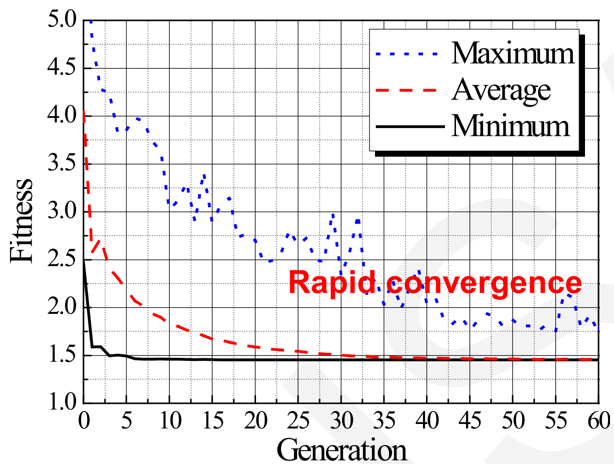
The additive horizontal force

SA based on the PSO and the gradient of limit-state function

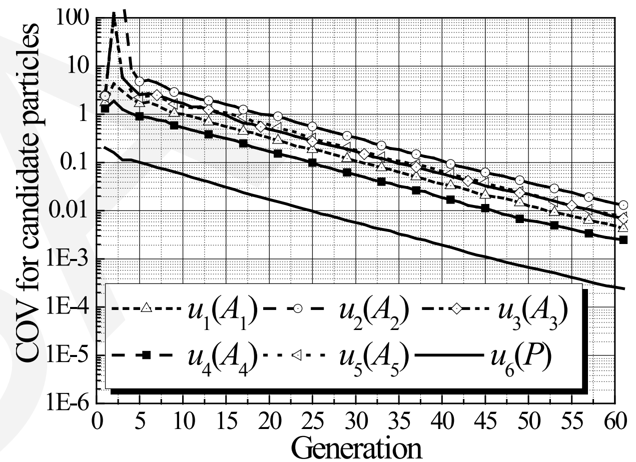
Simulations for frame structure



Schematic model of 12-storey frame structure



Convergence history of minimum, average and maximum fitness



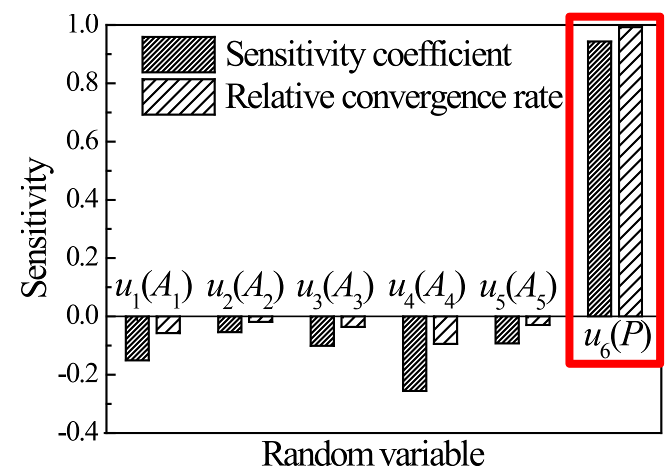
Convergence curves of COV for candidate particles of random variables

The implicit limit-state function:

$$g(X_1, X_2, X_3, X_4, X_5, X_6) = 0.096 - u_A(X_1, X_2, X_3, X_4, X_5, X_6)$$

Sensitive variables:

The load variable *P*



SA based on the PSO and the gradient of limit-state function

Conclusions

- A novel reliability-based SA method using PSO, namely the relative convergence rate is proposed. The relative convergence rate of the random variable during an evolution optimization process is related to the sensitivity of the objective function with respect to the random variable.
- To avoid fluctuation of the convergence rate, an optimized group strategy is proposed to ensure that the COV curve for candidate particles converges consistently in the solution hyperspace. The convergence rate of a random variable is replaced by the COV for candidate particles.
- The COV for candidate particles of a variable is statistically operated on the selected optimized group for several generations and is regarded as the measurement of sensitivity of the variable. The smaller the COV for the candidate particles of a variable, the more sensitive the objective function with respect to that variable.
- Numerical studies indicate that PSO is more efficient for reliability index calculation and SA, particularly in solving complicated problems.