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The Implementation of Adaptive Parallel Arc-Length Method (APALM)

Motivation

To effectively capture the complete geometrically non-linear response of a structure, it is essential to maintain sufficiently small arc-length for ALM*, resulting in more calculation time.

Inspired by parareal algorithm and combined with parallel computing, APALM* is implemented to enhance computational perfomance by simultanaeously refining multiple coarse intervals from reference solution derived by ALM and finding finer solutions using Matlab.

*ALM: Arc-Length Method *APALM: Adaptive Parallel Arc-Length Method

Methodology

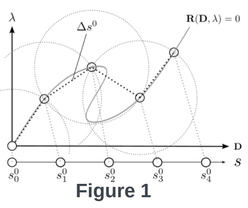


Figure 1

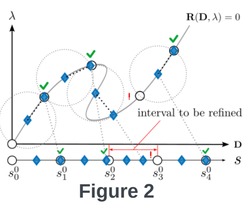


Figure 2

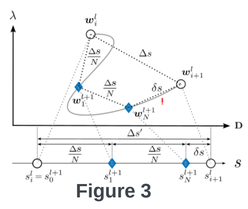


Figure 3

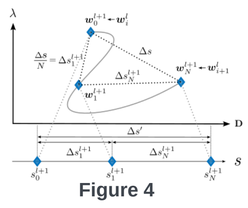


Figure 4

Reference solution(Figure 1)

- Starting with reference solution using ALM

Refined solution(Figure 2~4)

- New solutions derived at intervals in parallel
- Validate intervals by error calculation

$$\delta s = \sqrt{\left|\mathbf{d}_{i+1}^{l} - \mathbf{d}_{N}^{l+1}\right|^2 + \psi^2 \times (\lambda_{i+1}^{l} - \lambda_{N}^{l+1})^2}$$

$$\epsilon = \frac{\Delta s' - \Delta s}{\Delta s} = \frac{\delta s}{\Delta s}$$

- Update solution and arc-length

$$\Delta s_N^{l+1} = \frac{\Delta s}{N} + \delta s, \qquad \begin{matrix} \boldsymbol{w}_N^{l+1} \longleftarrow \boldsymbol{w}_{i+1}^{l} \\ [\, \boldsymbol{w}_0^{l+1}, \boldsymbol{w}_1^{l+1}, \boldsymbol{w}_N^{l+1} \,] \longleftarrow [\, \boldsymbol{w}_i^{l}, \boldsymbol{w}_{i+1}^{l} \,] \end{matrix}$$

Implementation

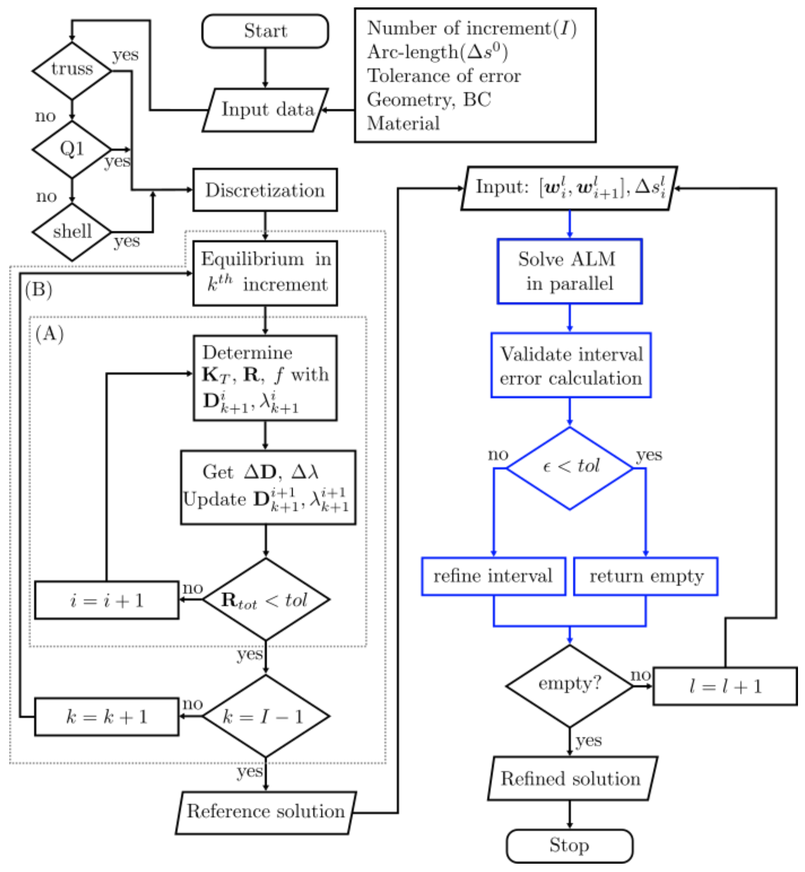
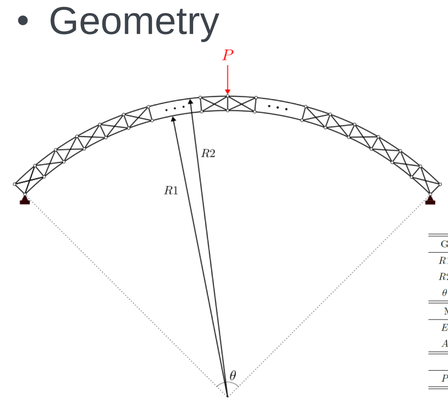


Figure 5: Algorithm of APALM. Left side is an algorithm for reference solution, right side is deriving refined solution. (A) is Newton Raphson method and (B) is ALM. Blue line is representing parallel processing. Initially, reference solution is prepared by ALM. Reference solution is reshaped into interval form and intervals are processed in parallel. At each calculation of intervals, the validation for refinement is excuted, including error calculation. Following solutions are collected, the next level computation is excuted if there is a returned interval. If not, refined solutions in all refinement level are derived, and APALM stops.

Numerical Examples

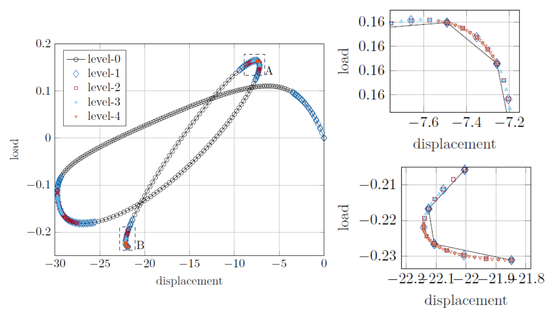
1. Crisfield's arch

- Geometry



Geometry parameter		
$R1$	48	$[m]$
$R2$	50	$[m]$
θ	90	$[°]$
Material parameter		
E	10^6	$[N/m^2]$
A	10	$[m^2]$
Load		
P	10^6	$[N]$

- Load-displacement curve

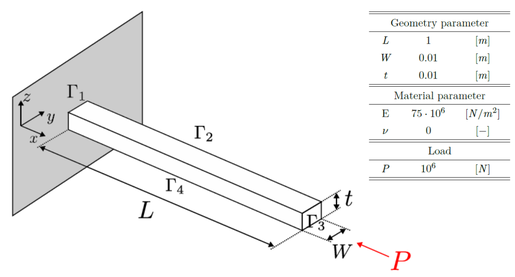


- Calculation time

*AALM: Adaptive Arc-Length Method

2. Strip buckling

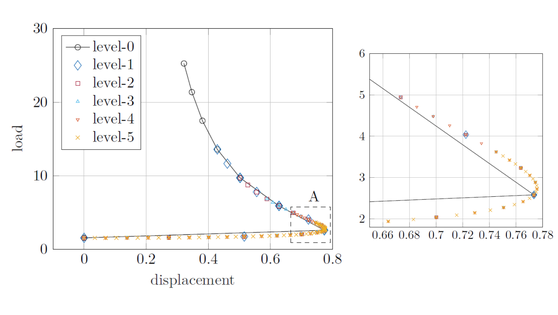
- Geometry



Geometry parameter		
L	1	$[m]$
W	0.01	$[m]$
t	0.01	$[m]$
Material parameter		
E	$75 \cdot 10^6$	$[N/m^2]$
ν	0	$[-]$
Load		
P	10^6	$[N]$

Boundary condition	
Γ_1	$u_x = u_y = u_z = \theta_x = \theta_y = \theta_z = 0$
Γ_2	$u_y = 0$
Γ_3	u_x, u_y, u_z *coupled*
Γ_4	$u_y = 0$

- Load-displacement curve



- Calculation time

Literatur

- Verhelst, H. M., J. H. Den Besten, and M. Möller. "An Adaptive Parallel Arc-Length Method." *arXiv preprint arXiv:2303.01075* (2023)
- Manfred Bischoff, Ekkehard R.: *Non-linear Computational Mechanics of Structures*. Bd. 18. Universität Stuttgart Institut für Baustatik und Baudynamik, 2022. – 1–34 S
- Rauber, Thomas; Rünger, Gudula*: Parallel programming*. Springer, 2013. – 1–7 S