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Efficient Numerical Procedure for Reduction of Computation Time in BIEM for Elastodynamic Analysis of Non-planar Faults

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1. Abstract

Recent progress in the boundary integral equation method (BIEM) have been enabled us to analyze dynamic rupture process on fully non-planar fault geometry, such as steps, bending, and branching both in 2D and 3D.

In the boundary integral formulations, the stress on the fault surface is represented in terms of the slip history on the fault surface only as $\tau(x,t) = \tau^0(x,t) + f(x,t) - \mu/2c\, V(x,t)$, where μ is the shear modulus, c is the shear wave speed, V is the slip rate, τ^0 is the loading stress, and f is a linear function of prior slip-rate over the causality cone. f is expressed as a double convolution integral in space and time. Evaluation of the convolution integrals is the most computationally demanding part of the elastodynamic analysis.

In order to reduce computation time we here apply " truncation of convolution integrals" to the time-domain BIEM in 2D in-plane problem. The principle is very simple: We truncate the convolution integrals in time and replace the stress contribution from the rest of causality cone with the static one due to the accumulated slip, i.e., slip rate summed up inside the rest of the cone.

*For numerical implementation, we combine dynamic scheme with static scheme. We try to choose truncation time L as short as possible without much loss of the dynamic stress contribution, where we always assume L is smaller than the total time step N in computation. For a large time step N, computation time is expected to decrease from N*N to N*L.*

Sorry,
I'm not here because of
the fracture of a collarbone.

2. Time-domain BIEM

● Boundary Integral Equation Method

$$T^{l,n} = -\frac{\mu}{2\beta} V^{l,n} + \sum_{i}^{space} \sum_{k<n}^{time} K_{dynamic}^{l-i,n-k} \cdot V^{i,k}$$

T: Stress, V: Slip-rate, K: Stress Kernel Function

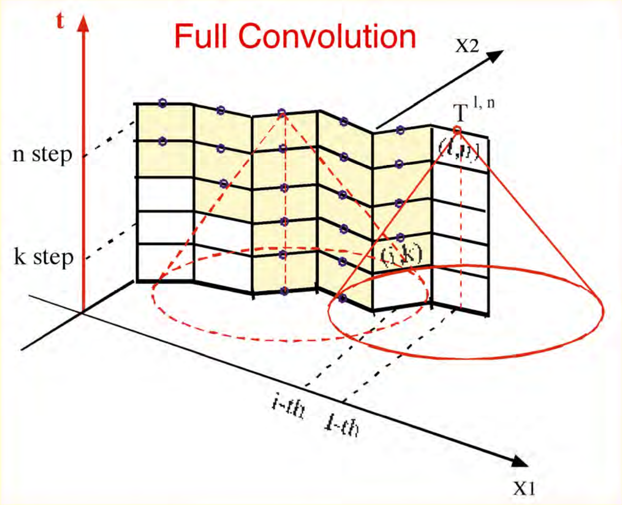

Fig.1a, Schematic illustration of double convolution in 2D BIEM inside the full wave cone.

The most time-demanding part:
→ Double Convolution
in space(i) and time(k)

Numerical example 1: Full Convolution

Spatio-temporal slip-rate (V) history with slip-weakening law
total=1000steps, nucleation=60grids, **cpu time=4100sec**.

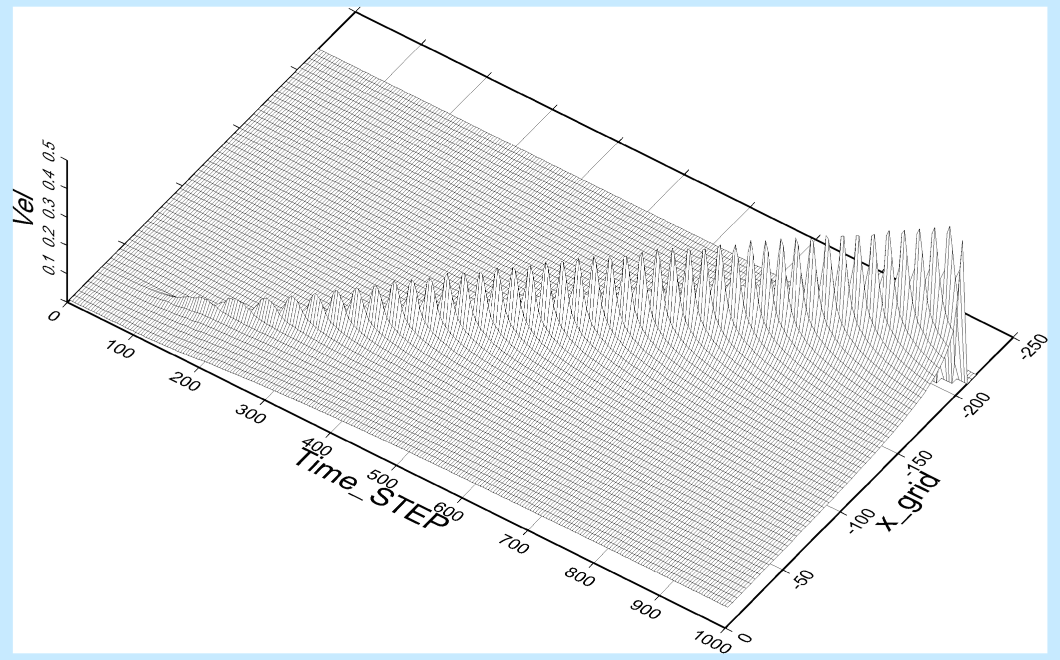

Fig.1b,Spatio-temporal slip-rate (V) history with slip-weakening law by the full convolution in time.

3. Reduction of Computation Time

● Truncation Method

$$T^{l,n} = -\frac{\mu}{2\beta} V^{l,n} + \sum_{i}^{space} \sum_{k>Trun}^{time} K_{dynamic}^{l-i,n-k} \cdot V^{i,k} + \sum_{i}^{space} K_{static}^{l-i} \cdot D^{i,Trun}$$

$$D^{i,Trun} = \Delta t \cdot \sum_{k<Trun} V^{i,k}$$

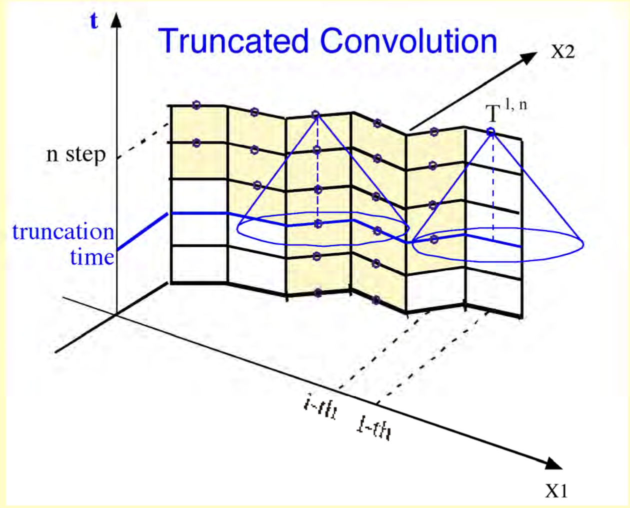

Fig.2a, Schematic illustration of double convolution inside the truncated cone.

Truncation in time by introducing static kernel

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Reduction of computation time in time step (k)

Numerical example 2: Truncated Convolution

total=1000steps, **truncation=500steps**, **cpu time=2500sec**.

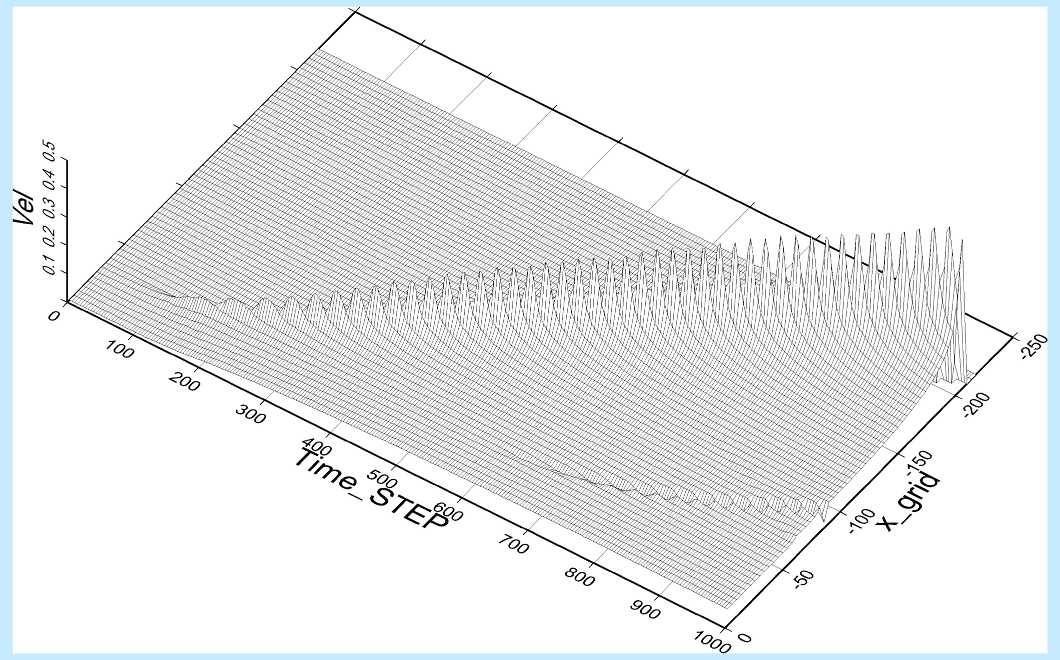

Fig.2b,Spatio-temporal slip-rate (V) history with slip-weakening law by the truncated convolution in time.

4. Discussion and Conclusion

1) Truncation method is tested to reduce computation time in 2D BIEM.
2) Slip rate just behind the crack tip is well represented by truncated convolution with significant reduction of computation time.
3) Truncation, however, produces artificial perturbation inside the crack surface. In order to overcome this problem we have to introduce some gradual decay in the 2D stress kernel for further studies (Truncation in this study means sudden cutoff of dynamic part of the 2D stress kernel after the truncation time step).

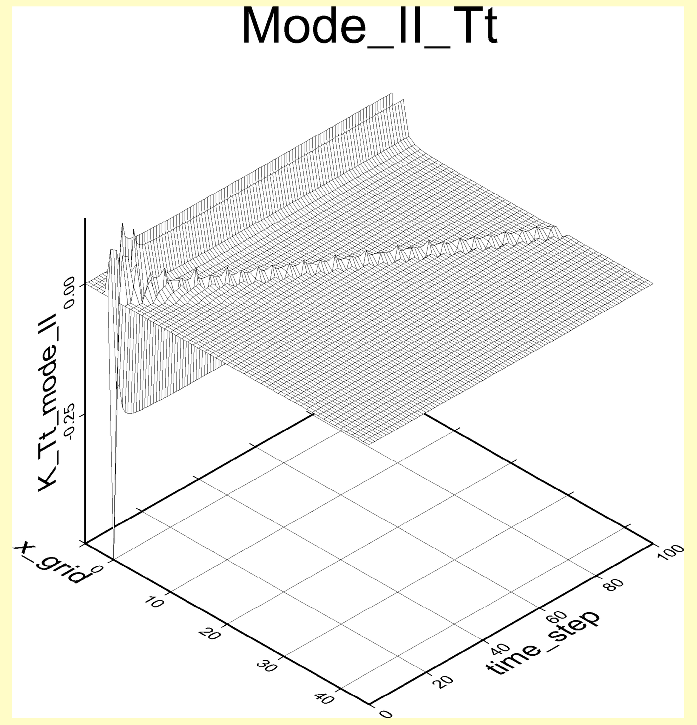

Fig. 3. Spatio-temporal distribution of mode II shear stress kernel function.

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Dynamic branching, arresting of rupture and the seismic wave radiation in self-chosen crack path modelling,
Nobuki Kame & Teruo Yamashita,
Geophys. J. Int.,(2003), 155, 1042-1050