Next Generation Attenuation for CENA (NGA-East)

SSHAC Workshop 2 – Proponent Discussions and Remaining Critical Issues and Data Needs

October 11-13, 2011

Shattuck Plaza Hotel, Berkeley

Events page: http://peer.berkeley.edu/ngaeast/events.html

Dr. BYKOVTSEV's MODEL
VERIFICATION AND VALIDATION RESULTS

8:30-10:00 **Thursday, October 13, 2011**

Regional Academy of Natural Sciences

Principal Engineer

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TECHNICAL APPROACH FOR GROUND MOTION SIMULATION

- **Boundary Element Method** (BEM) and **Bykovtsev's models** to produce broadband (0.1-20 Hz) synthetic seismograms are used.
- In Bykovtsev-Kramarovskii (1987&1989) publications an **EXACT ANALYTIC SOLUTION** was constructed for the non-stationary **3D- problem** of the propagation of a rectangular fracture area on which a **COMPLEX FRACTURE PROCESS** was given (two shear components with opening component).

For METOD and EXACT ANALYTIC SOLUTION details see main publications:

- Bykovtsev A.S (1986) Propagation of Complex Discontinuities with Piecewise Constant and Variable Velocities along Curvilinear and Branching Trajectories, *Appl. Math. Mech. (PMM)* 50, 5, pp. 620-628.
- Bykovtsev A.S. and Kramarovskii D.B. (1987), **On the propagations of a complex fracture area**, **Exact three dimensional solution**, *Appl. Math. Mech.(PMM)* 51, 1, 1987. pp 89-98
- Bykovtsev A.S. and Kramarovskii D.B. (1989), Non-Stationary Supersonic Motion of a Complex Discontinuity, *Appl. Math. Mech.(PMM) 53(6),1989. pp 779-786*

VERIFICATION with NUMERICAL GREEN FUNCTIONS SOLUTIONS-(Graizer-1984)

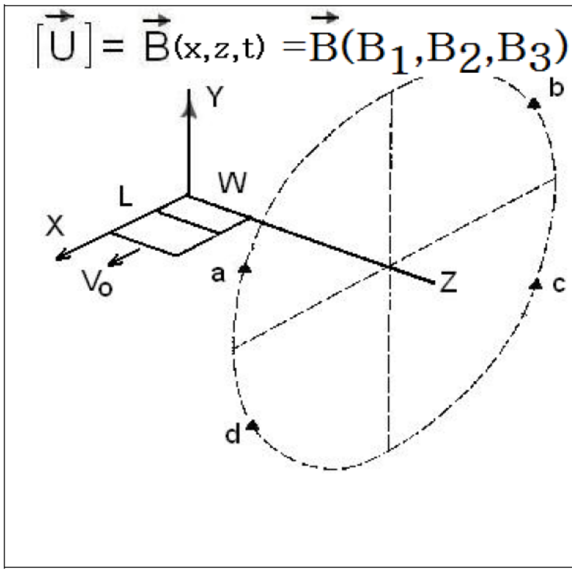
- Graizer, V. M. (1984). *"True" Ground Motion in the Epicentral Area*. Moscow: Institute of the Physics of the Earth of the USSR Academy of Sciences, 198 pps. (in Russian).

COMPARISONS MODEL WITH EMPIRICAL DATA Graizer-Kalkan (2007).

- Graizer, V., and E. Kalkan (2007). Ground motion attenuation model for peak horizontal acceleration from shallow crustal earthquakes.*Earthquake Spectra* 23 (3), 585–613.

VALIDATION TEST FOR TOTTORI EARTHQUAKE 2000 - SSHAC Workshop 2.

METOD and EXACT ANALYTIC SOLUTION



1. Bykovtsev A.S. and D.B. Kramarovskii (1987), **On the propagations of a complex fracture area, Exact three dimensional solution**, *Appl. Math. Mech.(PMM)* 51, 1, 1987. pp 89-98

2. Bykovtsev, A. S. [1987] **Mathematical Modeling of Fracture Processes in the Earth's Crust and on Its Surface**. *Doctoral Dissertation. Novosibirsk. 1987*. (441pp. in Russian)

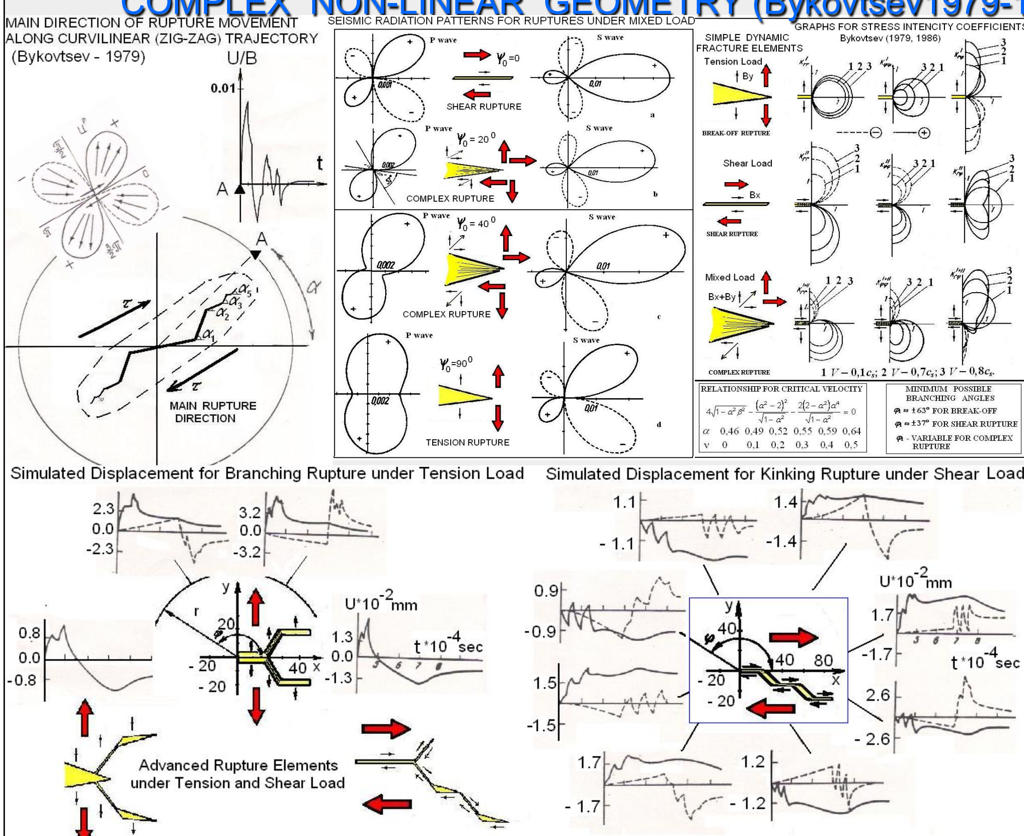
3. Bykovtsev A. S. and D.B. Kramarovskii [1989], "**Non-Stationary Supersonic Motion of a Complex Discontinuity**", *Appl. Math. Mech.(PMM)* Vol. 53, No. 6, pp. 779-786.

4. Bykovtsev, A.S., and V.Yu. Sokolov, [1989], "**Numerical Simulation of the Wave Field in the Near Zone of a Step-Like Propagating Curvilinear Fault and Analysis of High-Frequency Radiation**", *Izv. An. SSSR Fiz. Zem.* No. 3, pp. 3-16.

5. Bykovtsev, A.S., and V.Yu. Sokolov, [1990], "**Numerical simulation of wave fields and seismic intensity patterns in earthquake nearfield zones**", *Acta Geophys. Pol.* No. 38, pp. 111-133.

PLATFORM - All simulations were performed on the **HP Personal Computer** with Intel Pentium 4 CPU 3.2 GHz and 1.00GB of RAM.
Computer codes BASK-2011 version 21 (**Available**) were written on algorithmic language C # 2008
Calculations TIME for total **9 records** including 3 components for **Displacement, Velocity** and **Acceleration** with time step equal 0.05 second and out put file with total number of points approximately equal 5.000.000, usually take **45-90 second** for each **Station**.

VOLUMETRIC MODELS OF DYNAMIC RUPTURE ZONES WITH COMPLEX NON-LINEAR GEOMETRY (Bykovtsev1979-1989)



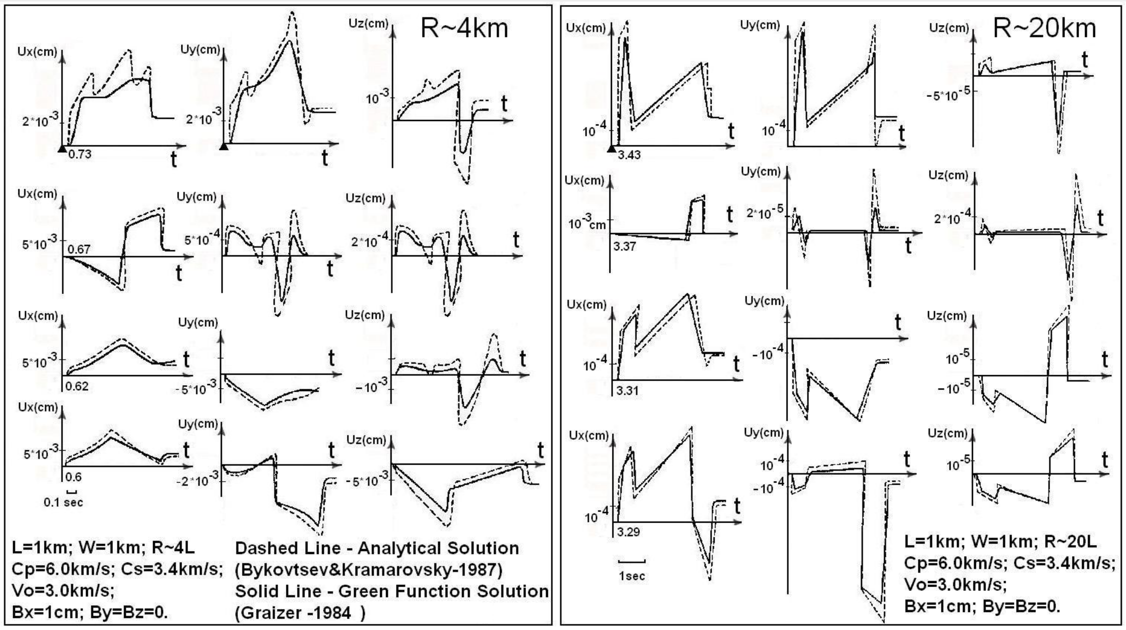
Main Advantages:
-PRINCIPLE NEW Physical EFFECT: Zig-Zag Movement Led to Formation of Variable-Sign Seismic Radiations!

CONCLUSIONS:
1-Volumetric Model Explains the Basic Majority of all Seismic Radiation Characteristics Including Variable-Sign Shape of Seismic Impulses

2-Volumetric Model Do Not Contradict To All Previously Obtained Results In the Framework of Model Concepts of the First Three Generations.

VERIFICATION with NUMERICAL GREEN FUNCTIONS SOLUTIONS

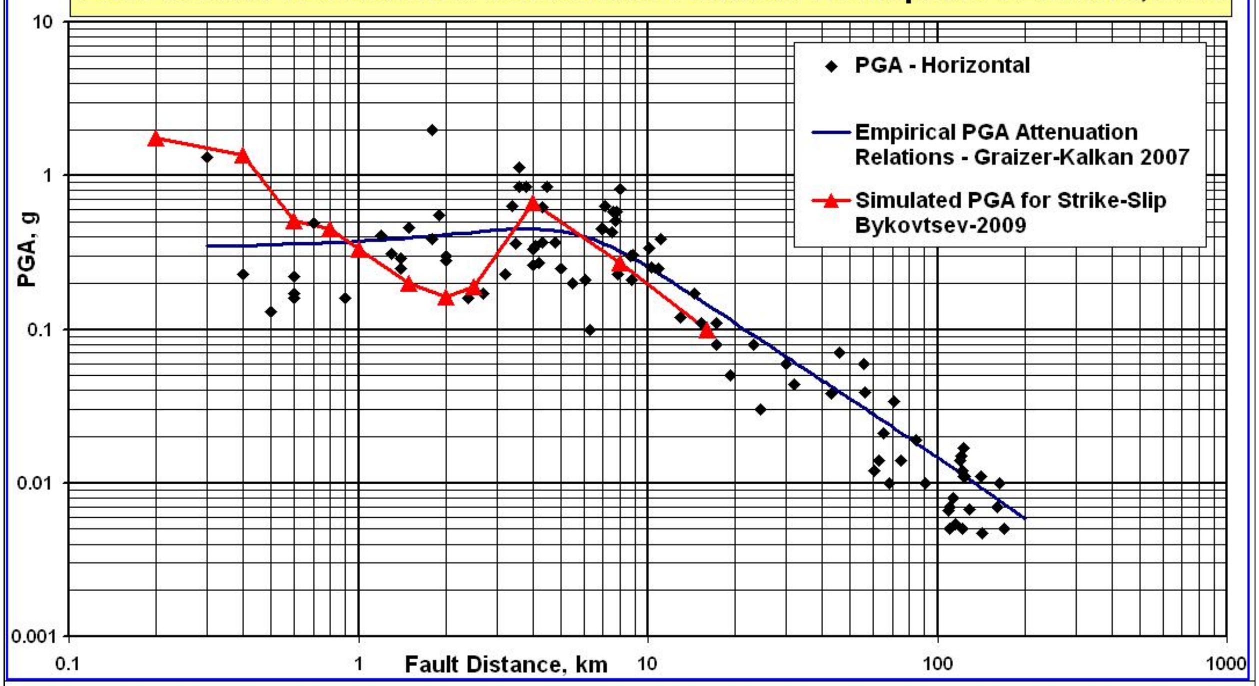
COMPARISON ANALYTICAL SOLUTIONS (Bykovtsev&Kramarovsky-1987) AND NUMERICAL GREEN FUNCTIONS SOLUTIONS-(Graizer-1984)



CONCLUSIONS:

1. Results for Analytical and Numerical Solutions are Similar and in Good Correlations for Different Distances.
2. Time of Computer Calculations based on Analytical Solutions is 10.000 Time Faster than For Computer Calculations based on Numerical Integration of Green Functions.

COMPARISON ANALYTICAL SOLUTIONS with EMPIRICAL DATA
Peak Ground Acceleration vs Distance Parkfield Earthquake of 9/28/04, M6.0



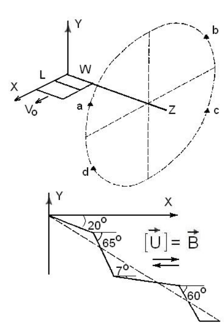
CONCLUSIONS:

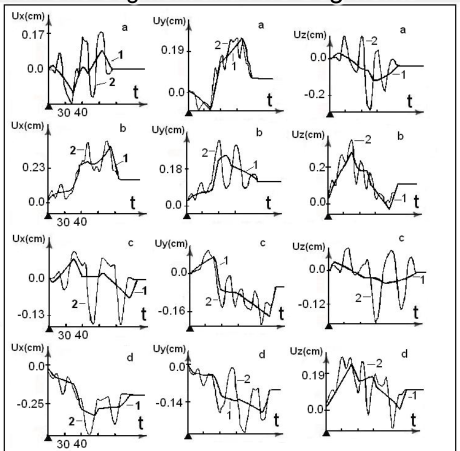
1. Comparison Results of Simulated PGA and Empirical PGA are Similar and in Good Correlations for Different Distances.
2. Amplitude of Ground Motion Definitely Amplify and Exceed 1.0 g for R< 300m from the Fault.
3. Simulated Records Provide Local Minimum (Dip ~0.16g) for R ~ 2km and Local Maximum (Bump~0.67g) for R ~ 4 km.
4. For Distances more than 5 km Simulated PGA Attenuates with 1/R.

COMPARISON SIMULATED TIME-HISTORIES FOR DIFFERENT MODELS

Bykovtsev A.S, and V. Y. Sokolov (1989) **Numerical Simulation of Wave Field in the Near Zone of a Step-Like Propagating Curvilinear Fault and Analysis of High-Frequency Radiation.** *Izv. Academ. Scien, USSR Physics of the Solid Earth.* **25** (3) 179-188 (1989)

Models for Rupture with One Segment and Five Segments





1 - Simulated Seismograms for Stright-Forfard Rupture with One Segment
2 - Simulated Seismograms for Curvilinear (Zig-Zag) Rupture with Five Segments

Different Models of Complex Ruptures

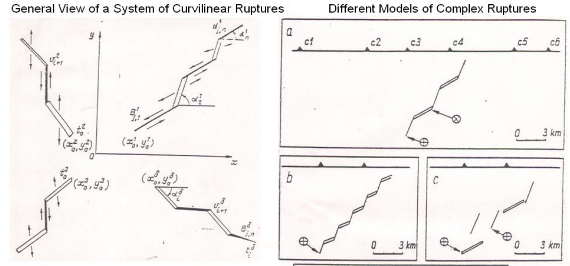


Fig. 1. Models of complex sources: *a* — nonplanar source with 5 subsources; *b* — nonplanar source with 10 subsources; *c* — nonplanar source with disconnected subsources; *d* — planar source with interrupted propagation. *1* — subsource with pure slip dislocation; *2* — subsource with tensile component in dislocation vector; *3* — initiation of unilateral propagation; *4* — initiation of bilateral propagation; *5* — observation sites; *6* — subsource number; *7* — point and time of arrest (in seconds) of the rupture propagation

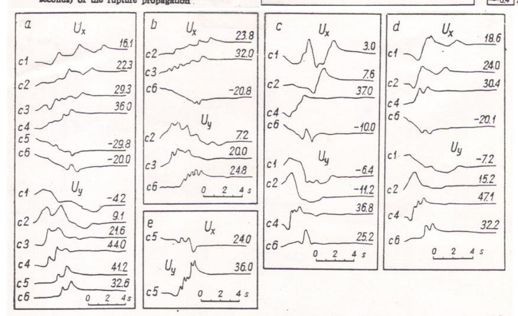
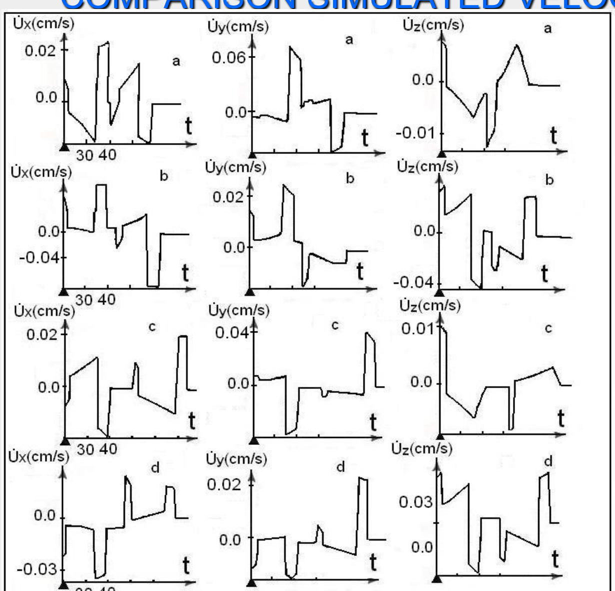


Fig. 2. Displacement time histories at different observations sites for various nonplanar source models. The numbers indicate maximum displacement amplitudes in centimeters. The displacements for models 1, 3, 4, and 5 are shown in figures *a*, *b*, *c*, and *d*, respectively, and for model 2 are in figure *e* (see Table 2)

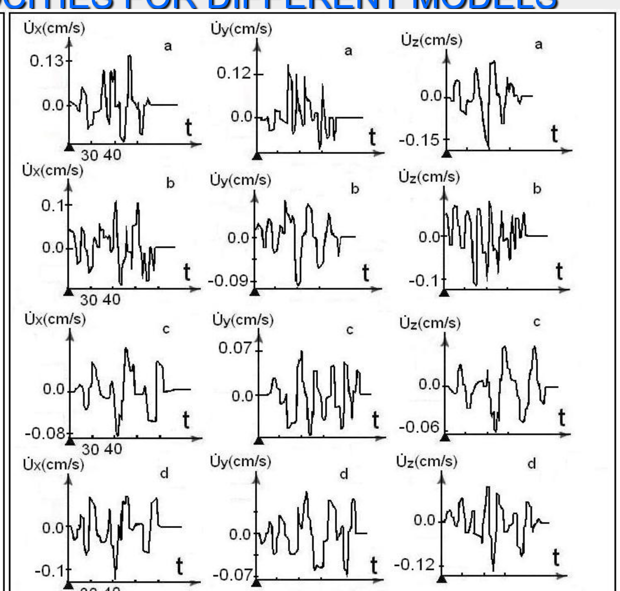
CONCLUSIONS:

1. The **Segmentations** of Fault Geometry Introduce Additional **Extremes** for Simulated Ground Motions. The Shape, Amplitude and Duration of Ground Motion Depend on the Site Location in Relation to the Fault, Main Rupture Orientation, Complexity of Rupture, and Mutual Arrangement of Subsources.
2. **Maximum** Amplitudes of Displacement and Acceleration as well as the Least Duration are Observed **Along the Main Fault Rupture Direction**.
3. The Fact Connected with the **Doppler Effect** can be taken into Account when **Choosing** the **Main Fault Rupture Plane** and **Rupture Directivity**.

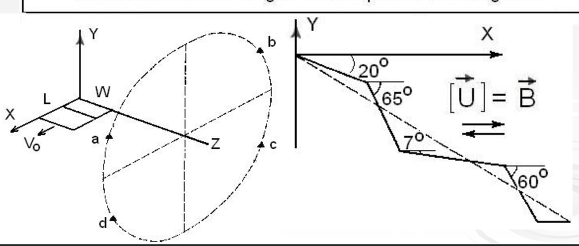
COMPARISON SIMULATED VELOCITIES FOR DIFFERENT MODELS



Simulated Velocities for Stright-Forfard Rupture with One Segment



Simulated Velocities for Kinking Rupture with Five Segments



If Rupture with One Segment and Rupture with Five Segments have Equal Time of Movement, then **Maximum Amplitudes** of Velocities **Increases** and **Periods** of Impulses **Decreases** with **Increases** in the **Number of Fault Segments**.

VALIDATION TEST FOR TOTTORI EARTHQUAKE 2000 - SSHAC Workshop 2.

TABLE 1. PARAMETRS OF RUPTURE - Flat Fault geometry – FIXED parameters of model.

Parameter description	Unit	Value
Total Rupture length (along-strike dimension)	rupL [m]	40000
Rupture width (down-dip dimension)	ddW [m]	20000
Vertical Depth to top of rupture plane.	hTop [m]	500
Horizontal distance along strike from top center of rupture plane to the hypocenter, in local rupture plane coordinates	hypoStrike [m]	0
Vertical distance along dip from top center of rupture plane to the hypocenter, in local rupture plane coordinates	hypoDip [m]	12000
Latitude coordinate of hypocenter	hypoLat [deg]	133,35
Vertical depth of hypocenter	hypoLon [deg]	35,275
Vertical depth of hypocenter	hypo [m]	12500
Seismic moment	M_0 [N-m]	1,70E+19
Strike	strike [deg]	150
Dip	dip [deg]	90
Rake	rake [deg]	180

Figure 1. Locations of Stations and Rupture projections on Earth's Surface

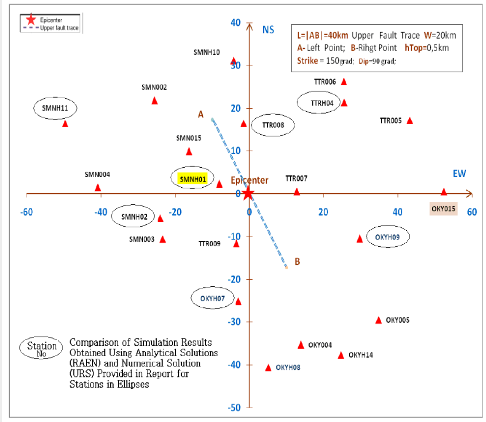


Figure 2. Static slip amount given by the prescribed rupture model.

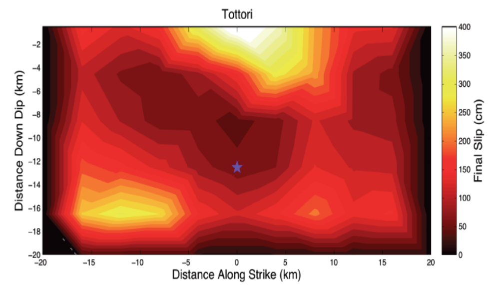
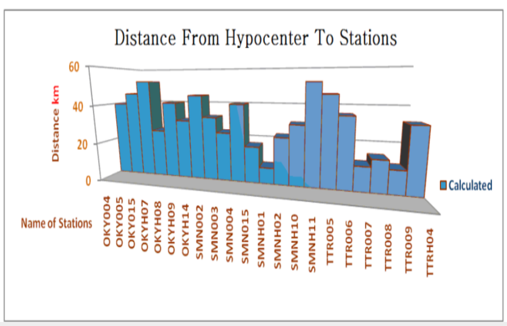


TABLE 2. PARAMETRS OF STRUCTURE CRUST OF DAMAGE ZONE

Thickness [km]	Vp [km/s]	Vs [km/s]	d [kg/dm^3]	Qp	Qs
2	5,5	3,179	2600	500	200
14	6,05	3,497	2700	500	200
12	6,6	3,815	2800	500	200
0	8,03	4,624	3100	500	200

INPUT DATA & FORMAT for October 2000 Tottori, Japan earthquake

Figure 3. Distance from hypocenter to stations

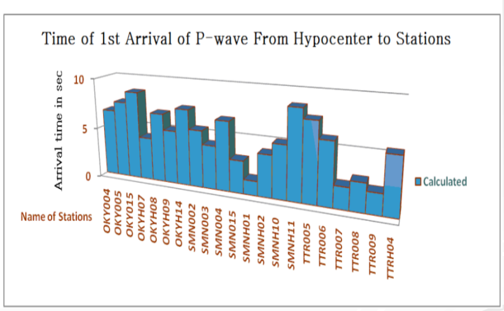


INPUT DATA & FORMAT for October 2000 Tottori, Japan earthquake.

1. **DATA about STATIONS and RECORDS.** Source of Data Base: *PEER*

PARAMETRS	INPUT FILE	OUTPUT FILE	FORMAT	Type Using
-Name Stations -Coordinates in Geo.Sys.Coor. -Quant. of Points of Segment. on Time - Step of Segmentations - Time of Records Duration - Seismic Record of Accelerations 3-comp. - Peaks of Displ., Velocity, Accel for 3-comp. - Units of Peaks	Seismic Records in digital form for 20 stations for each components : EW,NS,UD	In Solving Using perform format data In form txt file Location in graph	PEER Excel format	FIXED

Figure 4. Time of 1st arrival P-wave from hypocenter to stations



2 **PRESCRIBED DATA FOR RUPTURE MODEL**

Source of Data Base: *PEER*

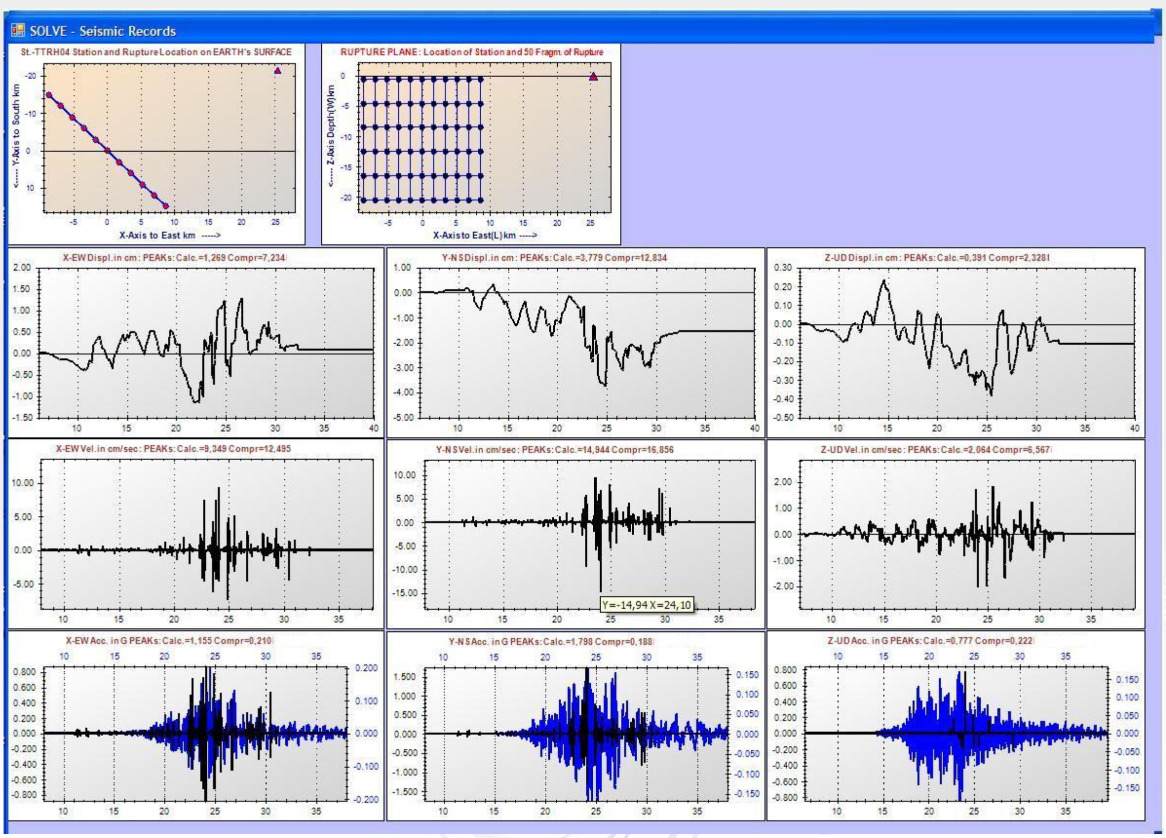
PARAMETRS	INPUT FILE	OUT FILE	FORMAT	Type Using
Data for Orientation of Rupture Plane (see Table 1, Figure 1)	ANSI TXT File	Digital & Graphic form of Model	ANSI TXT File *.emf format	FIXED
FAULT PARAMETRS (see Tables 1, 4, Figure 1)	ANSI TXT File	Digital & Graphic form of Model	ANSI TXT File *.emf format	FIXED
PARAMETRS OF STRUCTURE CRUST (see Table2)	ANSI TXT File	Digital form of Model	ANSI TXT File	FIXED
PARAMETRS OF DISLOCATION MOVEMENTS (see Table3, Figure 2)	ANSI TXT File	Digital form of Model	ANSI TXT File	VARIABLE

RESULTS – OUTPUT DATA - SIMULATED RECORDS AND MODEL PARAMETRS

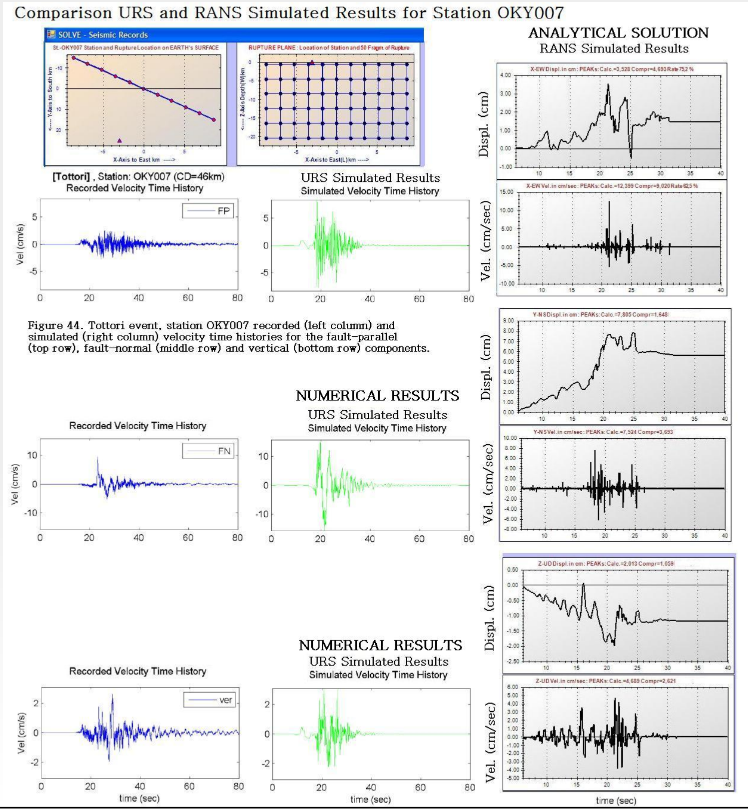
Source of Data Base: ***CALCULATION PROGRAMM*** – BASK-2011 ver.21

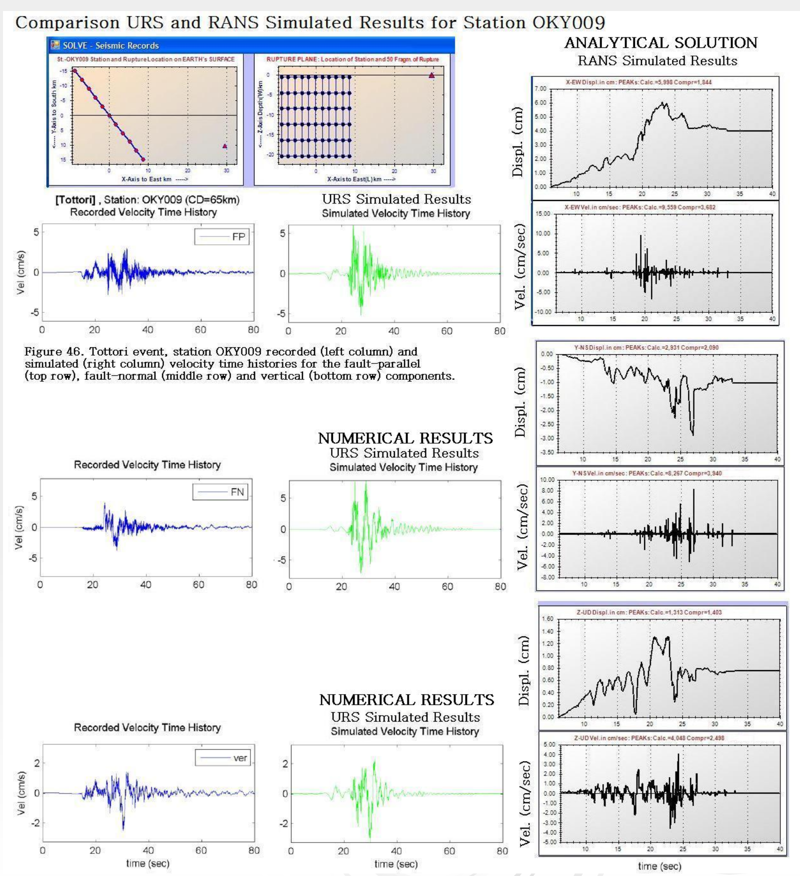
LIST VARIBALE PARAMETRS	INPUT FILE	OUT FILE	FORMAT	Type Using
FRAGMENTATIONS OF RUPTURE: Up to 300 sub faults with 50 segments on each subfaults	ANSI TXT File	Digital & Graphic form of Model	ANSI TXT File *.emf format	VARIABLE
SCENARIO PARAMETRS of Faulting Process: 1. Column; 2. Ring; 3. Ellipsis; 4.Other	ANSI TXT File	Digital & Graphic form of Model	ANSI TXT File *.emf format	VARIABLE
SEISMIC MOMENT BOUNDARY Mo ~ $(80.0x10^{17}$ N-m ÷ $140.0x10^{17}$N-m)	ANSI TXT File	Digital form of Model	ANSI TXT File	VARIABLE
RUPTURE VELOCITY BOUNDARY: 0 < Vrup < Vcritical ~ 0.6 ÷ 0.8 Cs	ANSI TXT File	Digital form	ANSI TXT File	VARIABLE
RISE TIME BOUNDARY: 0.08sec ÷ 0.8sec	ANSI TXT File	Digital form	ANSI TXT File	VARIABLE
PARAMETRS OF DISLOCATION MOVEMENTS: Three component of Displacement vector on each segment Bx, By, Bz	ANSI TXT File	Digital form of Model	ANSI TXT File	VARIABLE
CALCULATED SEISMIC RECORDS 1. Ux, Uy,Uz – DISPLACEMENT (in cm); 2. Vx, Vy, Vz – VELOCITY (in cm/sec); 3. Ax, Ay, Az – ACCELERATIONS (in cm/sec^2)		Digital& Graphic for 3-components In right-handed coordinate system EW NW UD	ANSI TXT File PEER GRAPH*.emf	VARIABLE
ESTIMATED CALCULATION TIME		Digital form	ANSI TXT File	VARIABLE

Figure 5. Example of plots of the simulated time histories of displacement, velocity and accelerations

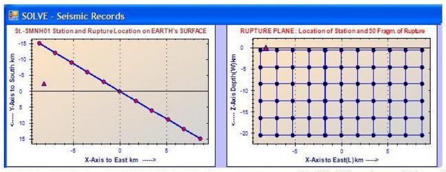


Comparison RAEN Analytical Solutions with URS Numerical Simulation Results and Recorded Velocity Time History for Different Stations



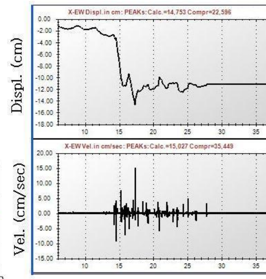


Comparison URS and RANS Simulated Results for Station SMNH01



ANALYTICAL SOLUTION

RANS Simulated Results



[Tottori] , Station: SMNH01 (CD=2km)
Recorded Velocity Time History

URS Simulated Results
Simulated Velocity Time History

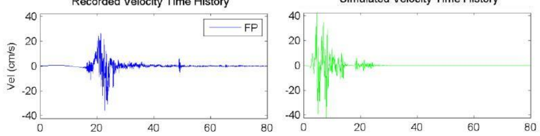
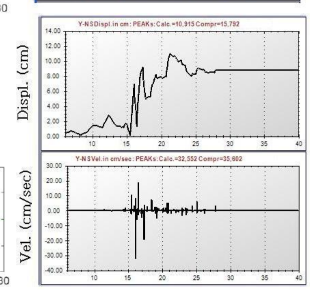


Figure 52. Tottori event, station SMNH01 recorded (left column) and simulated (right column) velocity time histories for the fault-parallel (top row), fault-normal (middle row) and vertical (bottom row) components.

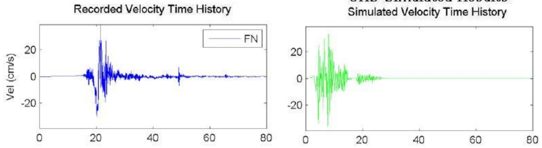


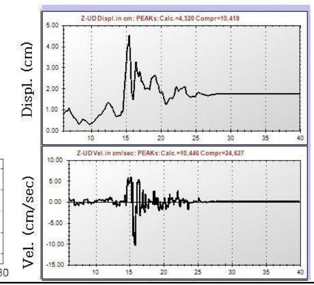
NUMERICAL RESULTS

URS Simulated Results

Recorded Velocity Time History

Simulated Velocity Time History



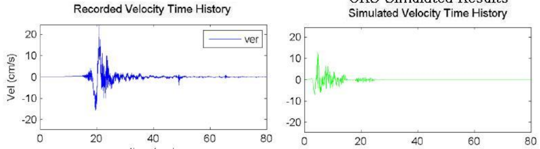


NUMERICAL RESULTS

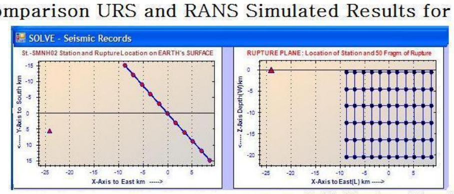
URS Simulated Results

Recorded Velocity Time History

Simulated Velocity Time History

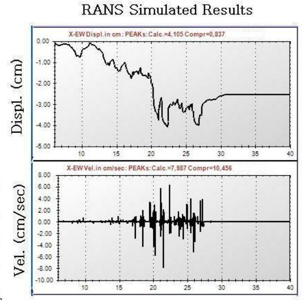


Comparison URS and RANS Simulated Results for Station SMNH02



ANALYTICAL SOLUTION

RANS Simulated Results



[Tottori] , Station: SMNH02 (CD=19km)
Recorded Velocity Time History

URS Simulated Results
Simulated Velocity Time History

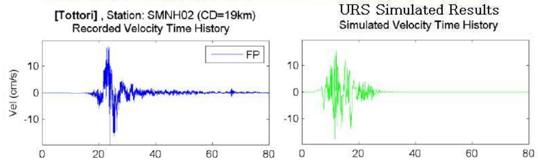
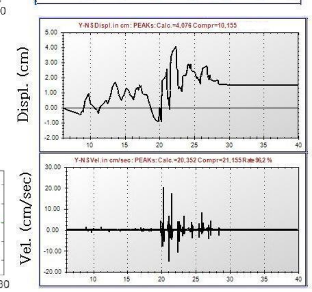


Figure 53. Tottori event, station SMNH02 recorded (left column) and simulated (right column) velocity time histories for the fault-parallel (top row), fault-normal (middle row) and vertical (bottom row) components.

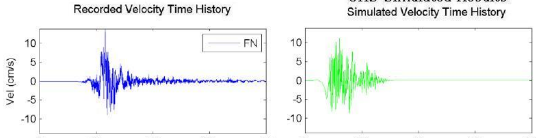


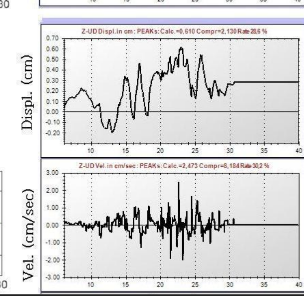
NUMERICAL RESULTS

URS Simulated Results

Recorded Velocity Time History

Simulated Velocity Time History



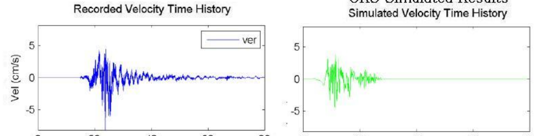


NUMERICAL RESULTS

URS Simulated Results

Recorded Velocity Time History

Simulated Velocity Time History



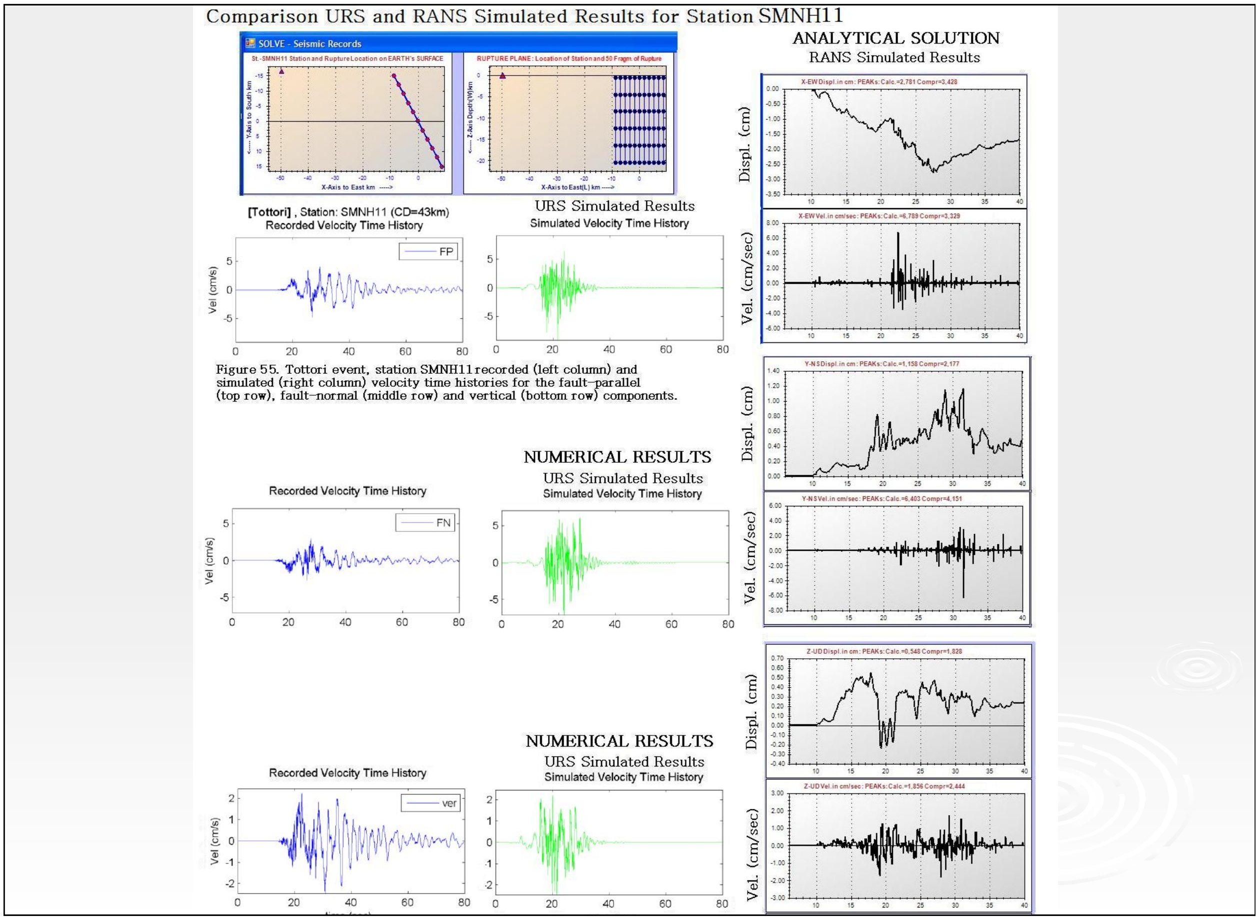


Figure 55. Tottori event, station SMNH11 recorded (left column) and simulated (right column) velocity time histories for the fault-parallel (top row), fault-normal (middle row) and vertical (bottom row) components.

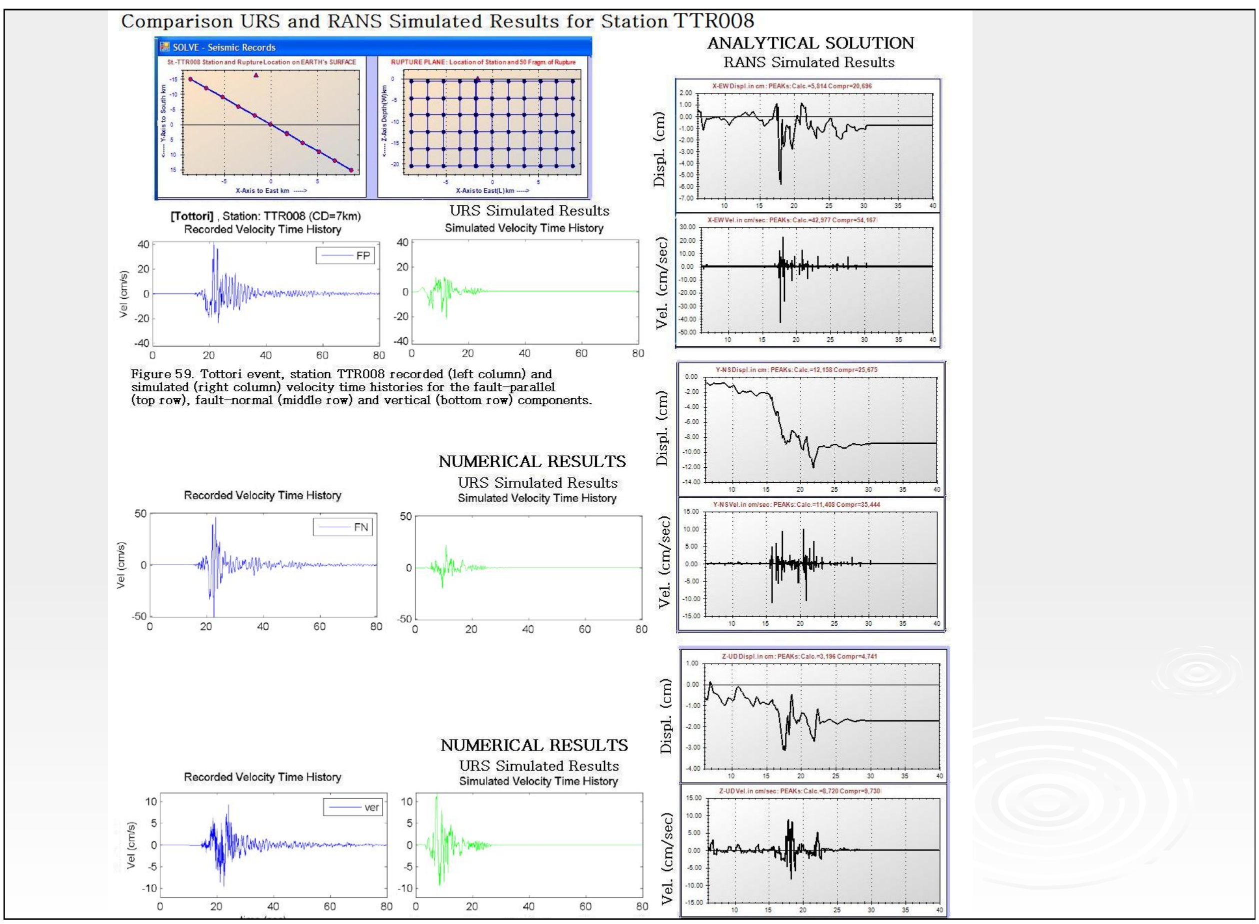


Figure 59. Tottori event, station TTR008 recorded (left column) and simulated (right column) velocity time histories for the fault-parallel (top row), fault-normal (middle row) and vertical (bottom row) components.

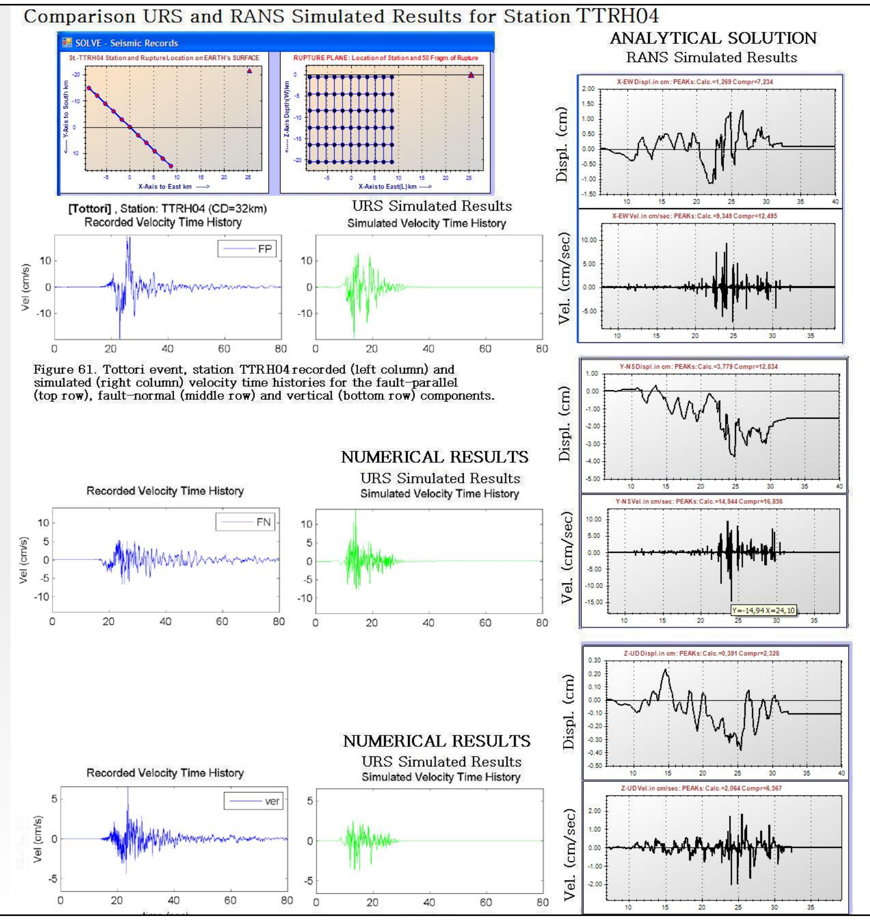


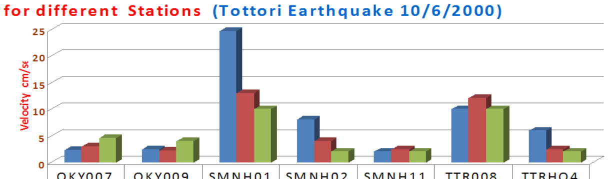
Figure 61. Tottori event, station TTRH04 recorded (left column) and simulated (right column) velocity time histories for the fault–parallel (top row), fault–normal (middle row) and vertical (bottom row) components.

RESULTS. Displacement and Velocity time history simulations and comparison RAEN analytical solutions with URS numerical simulation results for velocity time history are provided for October 2000 Tottori, Japan earthquake.

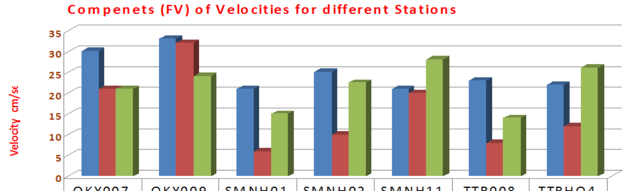
I. Plots of the time histories of ground displacement and velocity (all three components) for seven stations:
OKY007; OKY009; SMNH01; SMNH02; SMNH11; TTR008; TTRH04.

II. During comparison RAEN simulation results with numerical simulation presented by URS (see plots below), It was clearly demonstrated that both RAEN and URS results of simulated velocity time histories and recorded velocity time history are similar and in good correlation for different distances.

III. ASCII data files of the displacement and velocity time series are available in PEER format.

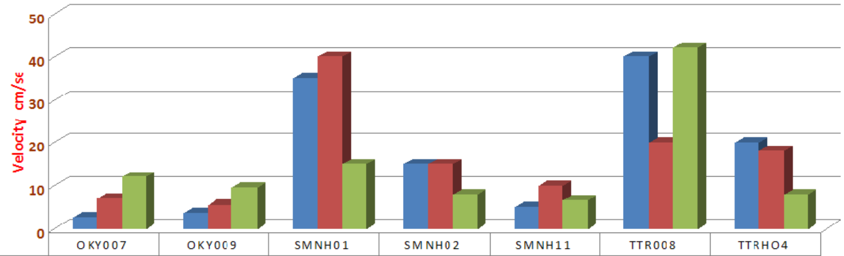


	OKY007	OKY009	SMNH01	SMNH02	SMNH11	TTR008	TTRH04
Peaks Recorded	2.3	2.5	24.6	8	2	10	6
Peaks URS Numerical Simulated Results	3	2.2	13	4	2.5	12	2.5
Peaks RANS Analytical Simulated Results	4.5	4	10	2	2	10	2



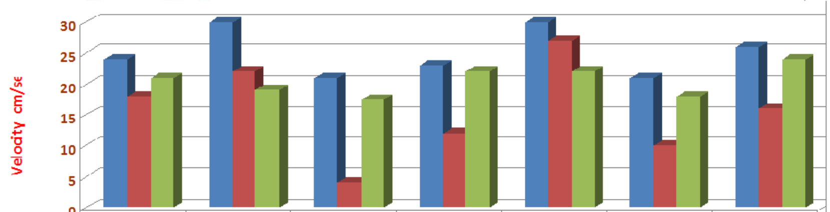
	OKY007	OKY009	SMNH01	SMNH02	SMNH11	TTR008	TTRH04
Arraival Time of Peaks on Recorded Velocities	30	33	21	25	21	23	22
Arraival Time of Peaks on URS Numerical Simulated Results	21	32	6	10	20	8	12
Arraival Time of Peaks on RANS Analytical Simulated Results	21	24	15	22.5	28	14	26

Comparison Simulated and Recorded Peak Velocities Value for Horizontal Componets (FP) for different Stations (Tottori Earthquake 10/6/2000)



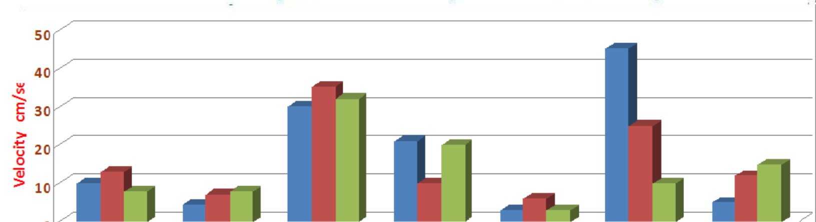
	OKY007	OKY009	SMNH01	SMNH02	SMNH11	TTR008	TTRHO4
Peaks Recorded	2.6	3.5	35	15	5	40	20
Peaks URS Numerical Simulated Results	7	5.5	40	15	10	20	18
Peaks RANS Analytical Simulated Results	12	9.5	15	8	6.5	42	8

Copmarison Simulated and Recorded Arrival Time of Peak Velocities Value for Horizontal Compenets (FP) of Velocities for different Stations



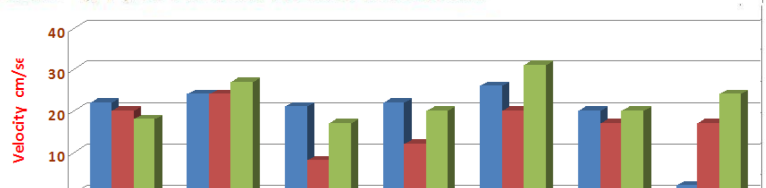
	OKY007	OKY009	SMNH01	SMNH02	SMNH11	TTR008	TTRHO4
Arraival Time of Peaks on Recorded Velocities	24	30	21	23	30	21	26
Arraival Time of Peaks on URS Numerical Simulated Results	18	22	4	12	27	10	16
Arraival Time of Peaks on RANS Analytical Simulated Results	21	19	17.5	22	22	18	24

Comparison Simulated and Recorded Peak Velocities Value for Horizontal Components (FN) for different Stations (Tottori Earthquake 10/6/2000)



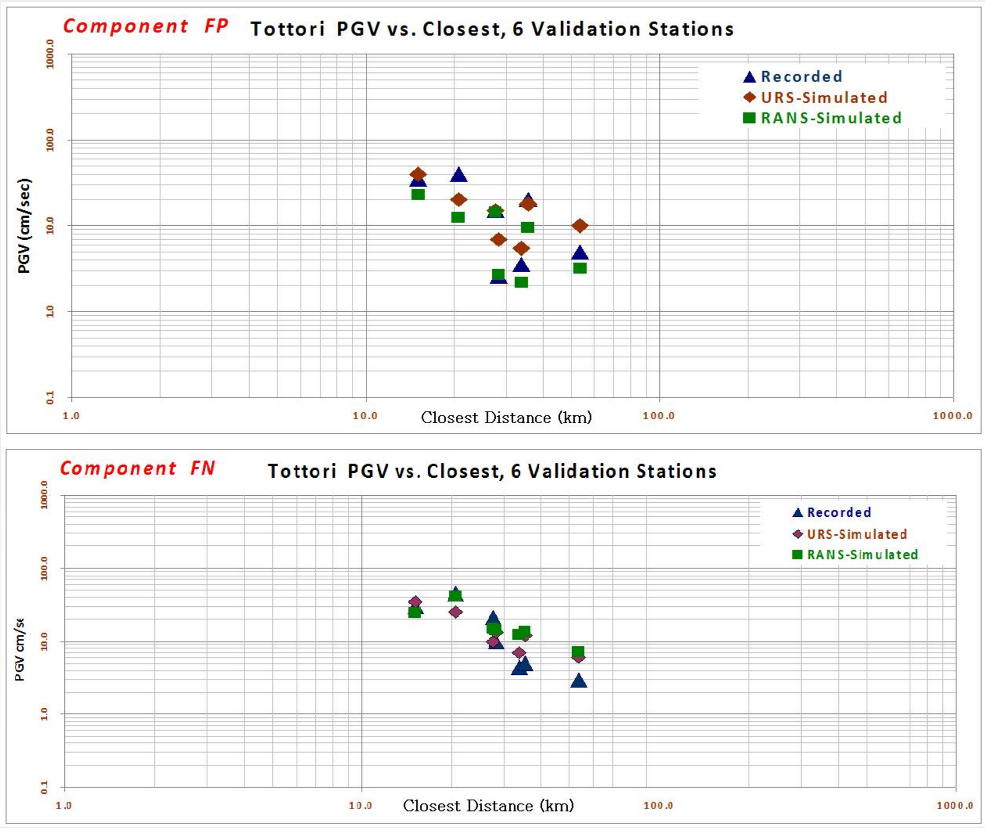
	OKY007	OKY009	SMNH01	SMNH02	SMNH11	TTR008	TTRHO4
Peaks Recorded	10	4.5	30	21	3	45	5
Peaks URS Numerical Simulated Results	13	7	35	10	6	25	12
Peaks RANS Analytical Simulated Results	8	8	32	20	3	10	15

Copmarison Simulated and Recorded Arrival Time of Peak Velocities Value for Horizontal Compenets (FN) of Velocities for different Stations



	OKY007	OKY009	SMNH01	SMNH02	SMNH11	TTR008	TTRHO4
Arraival Time of Peaks on Recorded Velocities	22	24	21	22	26	20	2
Arraival Time of Peaks on URS Numerical Simulated Results	20	24	8	12	20	17	17
Arraival Time of Peaks on RANS Analytical Simulated Results	18	27	17	20	31	20	24

Recorded and Simulated PGV as a function of closest distance to the fault for the Tottori earthquake



THANK YOU

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