Final Report for SCEC Award #21127

Submitted by Ruth Harris and Michael Barall
to the Southern California Earthquake Center

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December 3, 2021 SCEC Workshop

Dynamic Rupture TAG – The 2021 Ingredients Workshop – Stress Conditions
(SCEC Project 21127)

Co-Principal Investigators:

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(U.S. Geological Survey)

Proposal Category: Integration and Theory
Three SCEC Research Priorities (among others): P1.d, P4.a, P2.d

The Southern California Earthquake Center (SCEC) workshop "Dynamic Rupture TAG – The 2021 Ingredients Workshop – Stress Conditions" was convened on December 3, 2021, in Zoom. A total of 56 people participated. Our workshop attendees included scientists from at least 35 institutions and 14 countries (United States of America, Australia, Brazil, Czech Republic, China (mainland, Hong Kong, Taiwan), France, Germany, India, Italy, Japan, Mexico, New Zealand, Saudi Arabia, and Switzerland). Eighteen of our workshop participants were students or postdocs. The workshop agenda and participant list are on the last page of this report, and the workshop agenda and presentation videos and slides of most of the talks can also be found on our SCEC workshop website: https://www.scec.org/workshops/2021/dynrup. Many thanks to Tran Huynh and Edric Pauk for helping to make this fully online event a success.

This workshop was the fourth in our series of four SCEC workshops designed to evaluate the importance of each of the four ingredients required for dynamic earthquake rupture simulations (Harris, 2004). The four ingredients are: fault geometry, fault friction, rock properties, and initial stress conditions (**Figure 1**). The previous three workshops in the 'ingredients' series were the November 2018 SCEC workshop that focused on ingredient #1, ***fault geometry*** (https://www.scec.org/workshops/2018/dynrup), the January 2020 SCEC workshop that focused on ingredient #2, ***fault friction*** (https://www.scec.org/workshops/2020/dynrup), and the October 2020 workshop that focused on ingredient #3, ***rock properties*** (https://www.scec.org/workshops/2020/dynrup-oct). This fourth workshop included presentations about how our choices of stress conditions affect simulated earthquake ruptures and ground motion. We had one presentation that was in memory of U.S. Geological Survey (USGS) retired scientist Joe Andrews, a former member of our group who died in September 2021 at the age of 85. Joe pioneered numerous advances in earthquake source and ground motion science, including the practice of conducting dynamic rupture simulations for producing realistic ground motions. Joe and his work on the maximum possible ground shaking at Yucca Mountain (Andrews et al., 2007) were the motivation for our collaborative group exercise that tested our codes' abilities to replicate extreme ground motion results in 2D and 3D, with and without plasticity (Harris et al., 2011).

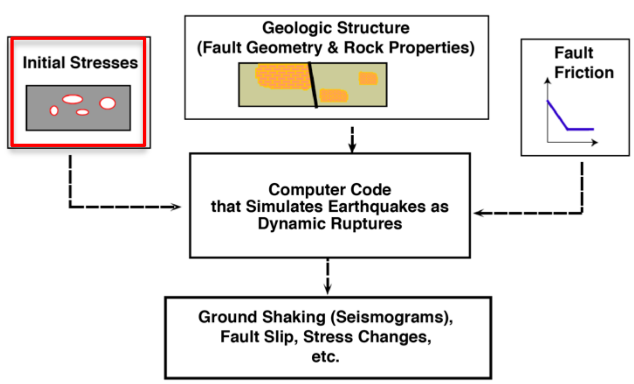

Figure 1. (Lightly modified Figure 1 from Harris et al., 2018). Components necessary for a dynamic (spontaneous) rupture simulation. Dynamic earthquake rupture simulations need assumptions about the initial stresses on the fault (and also off the fault, if the medium is inelastic), the fault geometry, the rock properties, and a failure criterion that describes how fault friction works. The red box highlights the initial-stress component, the subject of our fourth workshop. These physics-based computer simulations can be used to produce many different types of results, including patterns of fault slip, ground and sub-surface shaking, and heat generation. Please also see Harris (2004).

Ruth Harris (U.S. Geological Survey) began the workshop by welcoming the participants. She then introduced and briefly summarized how dynamic rupture simulations work. She noted that the SCEC-USGS Dynamic Rupture Code Verification Group (also see our website https://strike.scec.org/cvws/) has done a good job verifying that code results are reproducible for a variety of assumptions about the initial stresses, fault geometry, rock properties, and fault friction, as discussed in Harris et al. (2018). Going forward, what is mostly needed is a basis for choosing among the wide range of possibilities for these ingredients.

Harris presented the workshop participants with some topics to consider. These included: At what scales do we need to include initial stress heterogeneity? Should information inferred from field observations of regional stress directions or stress drop be used to assign the initial shear and normal stresses for dynamic rupture simulations? In terms of the ingredients, how do the stress conditions effects compare in relative importance to the effects of the fault geometry, the fault friction, and the rock properties?

Following Harris's introduction, the participants then introduced themselves in the Zoom chat.

The next three talks of the morning described a SCEC community model and two SCEC Technical Activity Groups (TAGs), all of which are closely tied to our workshop theme of stress conditions.

Jeanne Hardebeck (U.S. Geological Survey) presented the SCEC Community Stress Model, the CSM (https://scec.org/research/csm). She showed the variety of approaches used by different groups within the SCEC community to determine stress directions and stressing rates. Hardebeck noted that the stress models agree well on stress orientation, but not on absolute level of stress (and that focal mechanisms cannot provide an absolute stress level). She also noted that stressing rate models provide information about the highest stressing rates along the major faults. Hardebeck provided helpful directions on how to access the CSM database, and how to obtain information that might be useful for dynamic rupture simulations; this is particularly useful for modelers who use regional stress directions to assign initial shear and normal stresses.

During and after her talk, Hardebeck received many thoughtful questions:

Brittany Erickson (University of Oregon) asked about the stress tensor derived from physical modeling of tectonic loading, and if the results have been compared to those from earthquake cycle (SEAS) models. Hardebeck replied that the physical models include Peter Bird's SHELS and NeoKinema models, as well as Michele Cooke's models of fault loading, and that she was not sure if these models have been compared with SEAS models.

Dunyu Liu (University of Texas, Austin) asked about the spatial resolutions of the stress and stress rate models. Hardebeck replied that the grid is 2-km x 2-km, but the resolution of the different models varies and information about it can be found in the individual models' metadata. There were a number of questions related to depth dependence. Brad Aagaard (USGS) asked if there is a consensus in the CSM for the normal stress profile as a function of depth, and if it is consistent with overburden and hydrostatic pore pressures. Hardebeck replied that the low-stress model requires pore pressure that exceeds hydrostatic. Betsy Madden (Universidade de Brasília) mentioned that her group has a new preprint focused on normal stress variations with depth: https://doi.org/10.1002/essoar.10508297.1, and Yehuda Ben-Zion (University of Southern California/SCEC) mentioned his papers showing that there is some evidence that the stress orientation changes with depth, based on inversion of focal mechanisms: doi:10.1007/s00024-018-2055-y and doi:10.1029/2020JB019482.

Ralph Archuleta (University of California, Santa Barbara) noted that the presented differential stress does not show the linear increase with depth that would be associated with the overburden. Hardebeck agreed, replying that while the overburden increases with depth, the differential stress does not. David Oglesby (University of California, Riverside) asked if depth-dependent differential stress would be inferred from observations of small earthquakes. Annemarie Baltay (USGS) replied that they do observe some increase of stress drop with depth, but it may just be due to incorrect modeling of increasing attenuation that makes it seem that stress drop is increasing, due to tradeoffs between source and path.

Our next speaker was Rachel Abercrombie (Boston University), who described the goals and progress of the SCEC Community Stress Drop Validation technical activity group (TAG) (https://www.scec.org/research/stress-drop-validation) that she and Annemarie Baltay (USGS) are leading. Abercrombie presented information about the approaches used by the different groups of stress drop modelers, and showed results for the earthquakes that have been investigated to date. Stress drop is fundamental to earthquake source physics, but as Abercrombie explained, estimates of stress drop vary by three orders of magnitude. It is not yet known to what extent the differences are real and due to magnitude dependence, spatial variability, or stress dependence, and to what extent they are artificial and due to measurement uncertainties, resolution, or simplifying assumptions. As an example, Abercrombie compared several studies for a Prague, Oklahoma, earthquake sequence. She noted that there was a factor of ten difference in stress drop estimated by several methods within just this one sequence, although relative values agree better than absolute values. Estimation of stress drop begins with looking at the corner frequency of seismic radiation; given some assumptions, stress drop is proportional to the cube of corner frequency. The first goal is to separate source and path effects. Abercrombie showed how seismic recordings at the Earth's surface are attenuated at high frequencies and enhanced at low frequencies compared to recordings in deep boreholes, producing a different corner frequency. Another issue is if a single "stress drop" is the best way to characterize an earthquake. Abercrombie mentioned attempts to create better methods, including simultaneous inversion for source, path, and site terms, and the use of empirical Greens functions, but these methods still leave questions unanswered. One issue is if the depth dependence seen by some methods is real, or due to different attenuation in shallow versus deep rock. Baltay (USGS) noted that the Abercrombie et al. (2021) paper on the depth-dependence (or not) of stress drop is now published.

During and after Abercrombie's presentation, Luis Dalguer (3Q-Lab) and Betsy Madden (U. Brasília) asked if the "stress drop" determined by these observational methods is the same thing as the "stress drop" in dynamic rupture simulations, which is initial minus final stress in the simulation. Baltay responded that she hopes so, but the matter has not been studied robustly, and in the future the SCEC Stress Drop TAG might explore this issue by applying their methods to synthetic data produced by dynamic rupture simulations. Baltay also commented that the data often show a complex structure which may indicate multiple subevents, calling into question of whether or not there is a single stress drop. Dalguer (3Q-Lab) followed up by asking if it would be possible to get both the mean and standard deviation of stress drop across a rupture, and Abercrombie responded that the current methods do not give information about the variability of stress drop across a rupture. Dunyu Liu (UT Austin) and Yongfei Wang (USC) both commented that in simulations, fault roughness tends to increase apparent stress drop (by generating more high frequency energy in the spectra, thereby increasing the corner frequency, and making the stress drop look higher), and wondered if observational methods might be able to see this effect. Abercrombie also noted that one relatively reliable observation from the analysis of smaller earthquakes is that the real variability in stress release of different earthquakes in a single sequence is much larger than the difference between the average values for earthquakes in different tectonic settings. She noted that earthquakes (small and large) are very variable.

Next up, Brittany Erickson (University of Oregon) introduced the work of the SCEC Technical Activity Group (TAG) working on Simulations of Earthquakes and Aseismic Slip (SEAS) https://strike.scec.org/cvws/seas/. This SCEC group started in 2018 and has convened five workshops as of November 2021. The SEAS TAG's goals include using computational simulations to advance predictive models of earthquake source processes, determining which physical processes explain observables, and complementing and informing dynamic rupture simulations and 'earthquake simulators'. An overarching approach of the group is to use benchmark exercises to test SEAS models and computational codes. Erickson noted that for the SEAS benchmark exercises, the instructions for each benchmark include the description of a mathematical problem to solve, but each modeler chooses their own implementation parameters. Erickson pointed to their group publications that describe SEAS progress and results, including Erickson et al. (2020). She noted that after a short initiation process and short spin-up period, the SEAS models provide physically self-consistent conditions, including the initial stresses at the beginning of the dynamic rupture parts of the simulations. This is in contrast to single-event dynamic rupture simulations (e.g., Harris et al., 2009, 2011, 2018), where an artificial nucleation process is used to initiate rupture, before it becomes spontaneous. Erickson showed results of comparisons between dynamic and quasi-dynamic simulations, and also showed comparisons between 2D and 3D simulations.

Erickson noted the challenge of performing comparisons of long-term simulations that diverge rapidly due to the chaotic nature of the system. For fully dynamic simulations, Erickson pointed out that quantitative agreements among the code results require sufficiently large computational domain sizes, and that for some types of codes (volume-based codes) the results are sensitive to boundary conditions and grid stretching approaches. She also noted that the simulation results depend on when the switching is done between the quasi-static (interseismic) and dynamic (coseismic) solvers. Erickson finished her presentation describing some of her group's future plans, including incorporating fluid effects, incorporating bulk viscoelastic effects, and incorporating other types of heterogeneity. She also noted that they are interested in general investigations into what produces complexity in earthquake behavior.

For the questions, Harris (USGS) noted that the 'earthquake simulators' in consideration for use in the Uniform California Earthquake Rupture Forecast version 4 (UCERF4) haven't traditionally included complex rock properties (e.g., velocity) structure. Harris asked if SEAS models will be able to do this, or if it would work better to separate out the dynamic rupture parts of the computations (with a complex velocity structure) from the rest of the earthquake cycle. Erickson replied that this is one of the SEAS group's proposed upcoming benchmark problems, to consider material heterogeneities, and that these heterogeneities would be considered in both inter/aseismic and dynamic rupture periods. Continuing on this theme, Michael Barall (USGS) asked if Greens functions will need to be obtained for the material heterogeneity, or if it is possible to operate without Greens functions. Erickson replied that at least for volume-based codes, they can operate without Greens functions and specify a variable shear modulus, which goes directly into the discretization.

The next set of talks began with Dunyu Liu (University of Texas, Austin), who presented his work on simulations of earthquakes cycles and how nonplanar fault geometry fits into the picture, with direct application to large earthquakes on the San Andreas fault system near the 'Big Bend' in southern California (Liu et al., 2021). Liu presented a quick overview of his SEAS code, then showed how he chose the ingredients for his earthquake cycle models. He used the SCEC Community Fault Model 5.2 to create his fault geometry and a geodetic model by Smith-Konter and Sandwell (2009) to evaluate the orientation of the maximum strain rates. He also showed comparisons between his model's calculated long-term slip rates and UCERF3 geologic slip rates (Dawson and Weldon, 2013), in tests where he assumed high (0.7), moderate (0.5) and low (0.3) values for the static coefficient of friction. Next he showed results for simulated earthquakes in his models, using his preferred 0.5 friction value, and presented comparisons with paleoseismic observations. He showed that 1857-type ruptures occur in his simulations, preferentially nucleating north of the 'Big Bend' and propagating southward, and overall he noted that stress heterogeneity occurs due to interactions between fault geometry and dynamic ruptures, and that this produces a range of earthquake rupture extent and earthquake recurrence intervals.

There were a number of questions related to Liu's talk, on the topics of friction and geometry. Yongfei Wang (USC) asked how much the choice of friction impacts the results. Liu replied that it does have an effect: a high static friction of 0.7 will lead to more rupture segmentation, while a low static friction of 0.3 will lead to less rupture segmentation and favor large ruptures. Christos Kyriakopoulos (University of Memphis) asked how the results could change if a 3D geometry were used instead, and Julian Lozos (California State University, Northridge) mentioned his new paper showing how a change in dip along a strike-slip fault can affect dynamic rupture propagation https://doi.org/10.1130/GES02391.1

The next speaker was Shuo Ma (San Diego State University). He began with a tribute to USGS retired scientist and SCEC dynamic rupture TAG participant Joe Andrews (1935-2021). Ma's talk was based on Andrews' final two papers, including Andrews and Ma (2016), and he focused on using heterogeneous initial stress in dynamic rupture simulations to produce realistic simulated ground motions. Among Andrews' insights was that effects from fault roughness, stress heterogeneities, and other fault complexities can all be modeled by performing dynamic rupture on a planar fault with self-similar heterogeneous stress having certain statistical properties. According to Andrews, this can explain why earthquakes have a magnitude-frequency distribution with $b = 1$, and why stress drop is independent of magnitude. The longest-wavelength stress variation determines the extent of the rupture, which stops spontaneously. Shorter wavelength heterogeneities are chosen to be part of the same spectrum, which generate the appropriate high-frequency radiation. In this view, earthquake self-similarity is an emergent law. The use of time-weakening allows stress to drop abruptly, to produce high frequencies. Ma showed results from several simulations of M6-7 earthquakes, illustrating how the ground motions agree with ground motion prediction equations (GMPEs).

There was lively discussion during and after Ma's talk. Michael Barall (USGS) asked if the sort of stress variation Ma described could arise spontaneously in SEAS-type multi-cycle simulations, and Ma replied that he doesn't think so, because the SEAS-type models don't include the complexities from which self-similarity could emerge. Ralph Archuleta (UCSB) commented that if the random stress produces the same ground motion as the GMPEs, then the standard deviation of the ground motion in the GMPEs may be aleatory variability that is natural and irreducible. Dunyu Liu (UT Austin) asked how the self-similar stresses are maintained, given that the final stresses of one earthquake become the initial stresses of the next. Betsy Madden (U. Brasilia) wondered what these insights could reveal about physical parameters, and Kim Olsen (SDSU) added that it would be interesting to compare Andrews' stress distribution to the stress distributions results from SEAS-type simulations. Yongfei Wang (USC) asked if the method can extend to magnitudes outside the M6-7 range, and Kyle Withers (USGS) wondered about the motivation for using a fixed aspect ratio of 4 for the longest-wavelength stress variation. There were questions about how to apply Andrews' method to distinctly non-planar fault geometries such as bent or branched faults, and Ma replied that he doesn't know but wishes Joe Andrews were here to work on the problem. A number of the questions and discussion points during Ma's talk addressed intriguing problems to solve in the future, and are a sign that Joe Andrews' contributions to our science will continue to lead us toward new discoveries.

The next speaker of the day was Arben Pitarka (Lawrence Livermore National Lab) who talked about the 2019 M7.1 Ridgecrest, California earthquake and heterogeneous initial stress (Pitarka et al., 2021). The observed ground motion for the Ridgecrest earthquake is significantly lower than predicted by GMPEs at periods less than 3 seconds. Since the Graves and Pitarka (GP) kinematic rupture generator is designed to match GMPEs, the GP parameters needed to be modified to produce satisfactory kinematic models of Ridgecrest. To derive parameters, Pitarka et al. (2021) used a series of dynamic rupture simulations in an effort to make the simulated final slip match the slip obtained from a stress inversion by Wang et al. (2020), and to make the simulated near-fault ground motions match seismic recordings. The dynamic rupture models feature a weak zone in the upper 3 km where stress drop is low or negative. Between 3 km depth and the brittle-ductile transition, there is a background area with low to moderate stress drop, and three square asperities with high stress drop. The asperities are placed at the three locations of highest slip in the Wang et al. (2020) model. The dynamic rupture simulations were performed by a finite-difference code, using linear slip weakening friction and a planar fault set in a 1D velocity model. Then, Pitarka et al. (2021) iteratively adjusted the stress drop and friction parameters, ran a dynamic rupture simulation, and compared the final slip and near-fault ground motion to the desired results, until satisfactory agreement was obtained. Given a satisfactory dynamic model, the GP parameters could then be adjusted to obtain kinematic slip-rate functions that matched the slip-rate histories seen in the dynamic model. The end result was a set of dynamically consistent and depth-dependent slip rate functions that could be used for kinematic simulations. Pitarka showed results from several kinematic realizations of the Ridgecrest earthquake using the modified GP generator, and the simulated ground motions agree well with observations.

Following Pitarka's talk, Brad Aagaard (USGS) asked if Pitarka's asperity model implies that the initial stresses were not self-similar. This is in contrast to the Andrews and Ma (2016) method that does assume self-similarity. Baoning Wu (UCR/USC) asked what determines the ratio of rise time to slip duration (which characterizes the shape and high frequency content of the slip-rate function), and in particular if it depends on asperity size. Wu also asked if Pitarka's derived stress-drop distribution could be compared to stress drops obtained from aftershocks. Frantisek Gallovic (Charles University) wondered if the depth-dependence of the slip rates is considered when adding stochastic high-frequency radiation to the GP model. Yongfei Wang (USC) pointed out that Ridgecrest is considered a slow-propagating event, and asked if the GP and dynamic models used a realistic rupture velocity or if the anomalously slow rupture velocity is imposed via some special treatment. Pitarka replied that since the simulations use a single planar fault, they could not reproduce the slow rupture velocity observed at Ridgecrest, which was probably produced by the rupture jumping from segment to segment. Due to this, a time shift had to be applied to the waveform comparisons at stations to the south.

The final speaker of the workshop was Kyle Withers (U.S. Geological Survey). Withers presented the work of his SCEC dynamic rupture code validation group (Withers et al., 2021), which currently consists of about a dozen members whose goal is to use dynamic rupture simulations as predictive tools for near-field ground motion from large earthquakes, particularly in the 0.1-10 Hz range that is relevant to structural engineers. Withers' group aims to determine the influence of source characteristics on both earthquake ruptures and ground motion patterns, and as part of this process, they are developing a database of simulated ruptures to compare with a database of existing models of real earthquakes and ground shaking. For their simulated ruptures, they set up guidelines and a few of the 'ingredients' assumptions, such as the basic fault geometry, the final magnitude, and the 1D velocity structure (to create the same path effects for each model), but the modelers are free to choose the other ingredients such as the type of fault friction and the initial stress conditions, and they each use their own codes to conduct their dynamic rupture simulations.

Among the geometry ingredient choices for the strike-slip faults investigated to date, four sets of the group members chose to assume geometrically rough faults, and the others assumed stochastic stress on a flat fault. Withers noted that hypocentral location in particular affected the resulting ground motion. He then showed comparisons between the simulated ground motions and features of ground motion models from empirical relations, for spectral accelerations of 0.3, 1, and 3 Hz. He noted that there was decent agreement between the two, for the rough-fault approach, although at least one of the rough-fault models needed to implement over-pressurization of pore fluids. The flat fault models were equally successful. In the future, the group plans to investigate dip-slip faults, background stress conditions, low-velocity zones, and inelastic off-fault response.

During and after his presentation, Withers received questions on a range of topics. Betsy Madden (U. Brasilia) asked if all of the participating modelers include 3D fault roughness in their simulations, or if some are using stress variations as a proxy for fault roughness, and if there are notable differences between the approaches. Pitarka (LLNL) asked if they've looked at the effect of the rupture parameterization on the frequency-dependent ratio of fault-normal/fault-parallel motion. Withers replied that not everyone uses fault roughness, but everyone implements some form of heterogeneity. He noted that it is not yet clear if the results arise from the rough-fault geometry or from the heterogeneous stress conditions, but Pitarka's suggested approach is worth looking into, to differentiate between the effects. Martin Mai (King Abdullah University of Science and Technology) mentioned that they have a set of dynamic rupture simulations on rough faults, along with the resulting ground motions up to 6-7 Hz. He wondered if these results would be useful for participating in the code validation group. Withers replied yes.

Wrap-up Discussion

During the workshop's discussion session, there was continued lively discourse and further mention of novel work from the past, and new work soon to appear online. The participants also voted on the relative significance of the four ingredients (fault geometry, friction, rock properties, and stress conditions). Stress conditions won the competition, but it was accompanied by the frequent comment 'it depends'. This is because dynamic rupture simulations are used to simulate both earthquake rupture behavior and the resulting ground motions. The preferred application (source behavior versus ground motion) generally helps decide which ingredients play the biggest role, although as shown in the presentation by Withers, it is often the combination of ingredient choices, rather than just a single ingredient choice that determines the outcome. It is clear that our field still has important problems to solve if we are to fully understand how earthquakes operate. We look forward to future science gatherings such as this one, to continue learning and moving forward.

Acknowledgments

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SCEC Dynamic Rupture Group Ingredients Workshop on Fault Friction
SCEC Award and Report: 21127
Conveners: Ruth Harris and Michael Barall
Location: Zoom (online) **Date:** December 3, 2021

Agenda:

09:00 - 09:15	Introduction to the Workshop	Ruth Harris
09:15 - 09:25	Participant Introductions	*All (in zoom chat)*
09:25 - 09:40	SCEC Community Stress Model	Jeanne Hardebeck
09:45 - 10:00	SCEC Stress Drop Validation Project	Rachel Abercrombie/ Annemarie Baltay
10:05 - 10:20	SEAS Verification Project and Spontaneous Initial Stress	Brittany Erickson
10:20 - 10:40	Group Discussion: CSM, SDV, SEAS	*All*
10:40 - 11:00	*Break*	
11:00 - 11:15	Earthquake Cycle Simulations, Stress, and the Paleoseismic Record	Dunyu Liu
11:20 - 11:35	Andrews & Ma (2016) Heterogeneous Stress Models	Shuo Ma
11:40 - 11:55	The Ridgecrest Earthquake and Heterogeneous Initial Stress	Arben Pitarka
12:00 - 12:15	Dynamic Rupture Code Validation Project	Kyle Withers
12:15 - 12:35	Group Discussion: Applying Heterogeneous Stress Conditions to Solve Earthquake Problems	*All*
12:35 - 13:15	*Break*	
13:15 - 14:00	Group Discussion and Survey	*All*

Workshop Participants:

Brad Aagaard (USGS)	Rachel Abercrombie (Boston)	Pablo Ampuero (U Côte d'Azur)
Ralph Archuleta (UCSB)	Annemarie Baltay (USGS)	Michael Barall (USGS)
Yehuda Ben-Zion (USC)	Jordan Cortez (UCR)	Luis Dalguer (3Q-Lab)
Roby Douilly (UCR)	Ben Duan (TAMU)	Eric Dunham (Stanford)
Kenneth Duru (ANU)	Brittany Erickson (U Oregon)	Joseph Flores Cuba (Sorbonne)
Alice Gabriel (LMU)	Frantisek Gallovič (Charles U)	Hector Gonzalez-Huizar (UTEP/CISESE)
Jeanne Hardebeck (USGS)	Ruth Harris (USGS)	Evan Hirakawa (USGS)
Sebastien Hok (IRSN)	Yihe Huang (Michigan)	Tran Huynh (USC)
Junle Jiang (U Oklahoma)	Yuko Kase (AIST, GSJ)	Jeremy Kozdon (NPS)
Christos Kyriakopoulos (Memphis)	Valère Lambert (UCSC)	Duo Li (LMU)
Chen-Ray Lin (NCU Taiwan)	Dunyu Liu (UT Austin)	Julian Lozos (CSUN)
Shuo Ma (SDSU)	Betsy Madden (Brasilia)	Martin Mai (KAUST)
Shiying Nie (USC)	David Oglesby (UCR)	Kim Olsen (SDSU)
Kadek Palgunadi (KAUST)	Edric Pauk (USC)	Andrea Perez (Victoria)
Arben Pitarka (LLNL)	Yuk Po Bowie Chan (CUHK)	Jan Premus (Charles U)
Marlon Ramos (Michigan)	Surendra Somala (IIT Hyderabad)	Taufiq Taufiqurrahman (LMU)
Elisa Tinti (LaSapienza)	Jagdish Vyas (KAUST)	Yongfei Wang (USC)
Kyle Withers (USGS)	Baoning Wu (UCR)	Hongfeng Yang (CUHK)
Jiuxun Yin (Harvard)	Zhenguo Zhang (SUSTech)	