

**FHWA Expert Task Group
Asphalt Fundamental Properties and Advanced Modeling
February 23-24, 2009
Beckman Center
Irvine, CA**

ETG Objective and Purpose

The primary objective of the FHWA Asphalt Fundamental Properties and Advanced Modeling Expert Task Group is to provide a forum for the discussion of ongoing asphalt research and also to provide technical input for future research related to fundamental properties and advanced modeling.

The meeting of the FHWA Asphalt Fundamental Properties and Advanced Modeling (Models) Expert Task Group (ETG) was held on February 23 and 24, 2009 in Irvine, California. Chairman A. (Tom) Scarpas with the Delft University of Technology, Co-Chairman Dallas N. Little with the Texas Transportation Institute and Secretary Katherine Petros of the Federal Highway Administration (FHWA) conducted the meeting. Ms. Lori Dalton with SME and Mr. Harold L. Von Quintus of Applied Research Associates, Inc. were present with Mr. Von Quintus acting as Secretariat and Ms. Dalton assisting with the meeting. Dr. Edward Harrigan with NCHRP (Transportation Research Board) was the liaison member in attendance. Attachment A is the meeting Agenda and Attachment B includes a listing of the ETG members.

*The following members of the FHWA Asphalt Models ETG **were** in attendance:*

A. Tom Scarpas, Delft University of Technology (Chairman)
Dallas N. Little, Texas Transportation Institute (Co-Chairman)
Katherine Petros, Federal Highway Administration (Secretary)
Imad L. Al-Qadi, University of Illinois at Urbana-Champaign
Jo Sias Daniel, University of New Hampshire
Jon Epps, Granite Construction
Edward Harrigan, NCHRP (Liaison Member)
Gayle King, GHK, Inc.
Bob Kluttz, Kraton Polymers
Charles Schwartz, University of Maryland - College Park
Linbing Wang, Virginia Polytechnic Institute and State University (Virginia Tech)

*The following members of the FHWA Asphalt Models ETG **were not** in attendance:*

Michael Anderson, Asphalt Institute (Liaison Member)
William Buttlar, University of Illinois at Urbana-Champaign
Julie Kliewer, Arizona DOT
Richard W. May, Shell Sulphur Solutions
Magdy Y. Mikhail, Texas DOT
Dave Newcomb, NAPA (Liaison Member)
Bob Statz, Consultant

The following “*friends*” of the FHWA Asphalt Models ETG were in attendance:

Terry Arnold, FHWA	Bob Humer, Asphalt Institute
Rashid K. Abu-Alrub, Texas A & M University	Richard Kim, North Carolina State Univ.
David Allen, Univ. of Nebraska at Lincoln	Sang-Soo Kim, Ohio University
Hussain Bahia, University of Wisconsin	Yong-Rak Kim, Univ. of Nebraska at Lincoln
Jason Bausano, SemMaterials	
Satish Belagutti, FHWA-HIPT	Rong Luo, Texas A & M University
Amit Bhasin, Texas A & M University	Robert L. Lytton, Texas A & M University
Audrey Copeland, FHWA	Eyad Masad, Texas A & M University
Jim Barnat, SemMaterials	Ioan Negulescu, LSU
Christine Bodden, Arizona Chemical	Chuck Paugh, FHWA/ESC Inc.
John Bukowski, FHWA	Geoff Rowe, ABATECH
Matthew Corrigan, FHWA	Shadi Saadeh, CSULB
Mohamed El-Basyoumy, Arizona State	Steve Salmans, WRI
Mike Farrar, WRI	Delmar Salomon, Pav't. Preservation Sys.
Ken Fults, Consultant (Round Rock, TX)	Osama Abdu Shati, CALTRANS
Nelson Gibson, FHWA	Fred Turner, WRI
Bill Grady, Arizona Chemical	Eric Weaver, FHWA
Murthy Guddati, North Carolina State Univ.	Haifaug Wen, Washington State University
Elie Hajj, University of Nevada at Reno	Randy West, NCAT
Tom Harman, FHWA	Jack Youtcheff, FHWA
Mike Harnsberger, WRI	Ludo Zanzotto, University of Calgary
Gerry Huber, Heritage Research	

SUMMARY OF HANDOUTS AT THE MEETING

1. Part 2 Item #6: Modeling Approaches; A memorandum summarizing the different type of models being proposed for use by the ARC.
2. ARC Theoretical and Computation Modeling capabilities
 - a. Table 1 – Continuum-based Modeling of Asphalt Mixes.
 - b. Table 2 – Micromechanics-based Modeling of Asphalt Mixes.
 - c. Table 3 – Characterization Models for Binder, Mastic and FAM.
 - d. Table 4 – Finite Element Capabilities.
3. Tabular Summary by Material Type of the Materials Testing and Responsible Agency, Detailing how the test data will be used.
4. Brochures
 - a. An Intensive Course on: Advanced Constitutive Modeling and Characterization of Asphaltic Materials; Texas A&M University, 21-25 September 2009.
 - b. 1st Announcement/Call for papers for the 2nd Workshop on Four Point Bending, Guimaraes, Portugal; 24-25 September 2009.
 - c. Call for Abstracts; Mini-symposium on Advanced Modeling and Characterization of Pavement Materials; 19-23 July 2010; Sydney, Australia.

DAY 1 (Monday, February 23, 2009)

1. Call to Order—Tom Scarpas called the meeting to order at 8:10 AM.

Welcome and Introductions – Tom Scarpas (Delft University of Technology)

Chairman Scarpas called the meeting to order and welcomed all in attendance. The first item was to review the agenda. Chairman Scarpas noted that the agenda was slightly changed and prepared to brief the ETG on work completed within year 2 and summarize what is planned for year 3. One of the goals of this ETG meeting is to establish the needs and criteria to evaluate what the ARC is finding and what is needed for the future. In other words, defining what the deliverables are and start interacting with the public or users of the system. In addition, start interacting between the researchers and ETG in terms of the vision of the product within the next 3 years – the end product, and start evaluating/discussing what we are getting from this research.

Scarpas asked if there were any attendees that had not attended any of the previous ETG meetings. None were noted. All of the participants were then asked to introduce themselves around the room.

Review of June 19 & 20, 2008 Meeting Minutes—Tom Scarpas (Delft University of Technology)

Minutes from the previous meeting was submitted prior this meeting. Chairman Scarpas asked if there were any corrections or additions to the minutes. No revisions or corrections to the minutes were identified. Scarpas did note that the statement in the minutes relative to the white paper being prepared between the TTI and Delft groups. Scarpas noted that the document exists but the Delft group have not completed their part of the document. **Scarpas noted that he would like to distribute the final document and close this issue prior to this summer or the next ETG meeting.**

Eric Weaver (FHWA) – Several documents regarding the TTI fracture energy and cracking have been prepared and distributed to the group. Katherine Petros had previously distributed these to the ETG and are on the FHWA website (date was December 2008). Report dated 2008 – Continuum damage model. The two documents distributed at the meeting (Part 2 Item #6: Modeling Approaches and ARC Theoretical and Computational Modeling Capabilities) and the future plans of the ARC are all on the web site. **The minutes from the previous ETG meeting states that the documents will be cross referenced between different websites, but that cross reference or cross-linking has yet to be completed.**

Attendance List and Sign-Up Sheet

The list of member information and participant sign up sheet were passed around the room for participants to log their attendance.

2. Overview of Meeting Objective—Tom Scarpas (Delft University of Technology)

Chairman Scarpas briefly reviewed the agenda and those items that will be presented. The first part of the ETG meeting this morning will be subdivided into two parts: model integration (researcher's presentations) and a discussion on the constitutive equations. The researchers were asked to focus their presentations on what each was to accomplish by answering specific questions. Dallas Little will initiate this part by over viewing where all of this modeling effort

and work is going. This overview on the issues should set the stage for the presentations from the ARC team members. As an example, some of these questions were:

- What is the vision of the researchers in terms of the end product?
- How will the different models interact or compliment each other?
- Who are the target users?
- What can we expect as users of the system?
- Etc.

For the second part, Chairman Scarpas asked the participants to focus their questions and comments on specific issues related to the constitutive models, which are:

- What are some of the computational problems we see?
- What would you like to see and what should be included in the constitutive model – its capabilities; what is the ideal HMA constitutive model?
- What are the issues, boundary conditions and limitations?
- In other words; identify the critical issues and problems, and try to resolve those issues as quickly as possible within the remaining time frame.

The second part basically includes discussion between the researchers and meeting participants – the sooner we discuss these issues, the sooner we know what can be done and what will be available.

3. Model Integration—Dallas Little (TTI, Texas A & M University); The memorandum that was handed out relates to this presentation.

Overview of Modeling Approaches:

Dallas Little requested that the questions and comments be held until the end of this presentation; there should be sufficient time available for detailed discussion. Dallas Little started by over viewing the work that has been ongoing through the ARC in terms of model development and goals in answering the questions noted by Chairman Scarpas. The models are grouped into three basic groups to predict performance: micro-mechanics, continuum damage models, and materials characterization models.

- Micromechanics Models – Purpose or goal is to predict the responses of the structure.
- Continuum Models – Goal is to develop three-dimensional visco-elastic-plastic continuum damage models and implement into a finite element method to predict rutting, fatigue cracking, and moisture damage.
- Materials Characterization Models – Purpose is to capture the impact of processes that alter the material properties in predicting mixture responses.

Little overviewed the background of the effort, how these models relate to each other, how they will be integrated, what are the goals for each type of model, identified and discussed some examples of these goals. He also reviewed what work is being done on these models, where is it being done, and identified the experts in the modeling area on the ARC. This information was presented to the ETG in a tabular format during the presentation. Little choose not to discuss the specific deliverables within the presentation, because others will do that and it will be discussed later within the meeting.

ETG Comments, Discussion, and Questions:

Abdu Shati – Asked Little to explain his statements about the models not being meshed together or uncoupled. Little response – Not what he meant; the models do mesh, but not in one coherent operational model right now. This statement generated much discussion between Abdu Shati

and the ARC team members in terms of the models and whether they can be coupled together. Abdu Shati opinion: Micromechanics models might not be comprehensive enough for this detailed work. Little asked for the other team members to provide their comments. Rashid Abu Abu-Alrub – These issues will be discussed in the presentations that will be given later. Bob Lytton – Dislocations are small scale or nano-size based if he understands the question asked by Shati. Shati agreed. Lytton noted, based on that response, that pavements are not nano-size, so the question back to Shati is how does one up grade the dislocations to what occurs in pavements – reality? In other words, how do you foresee dislocations coming into place in pavements to be practical and implementable? Shati discussed how he sees the dislocation mechanics (moving from a nano or micro-scale to a macro-scale) being used or applicable to predicting cracking and noted that one of the problems with the continuum theory is that once fracture or cracking occurs, you no longer have continuum. Shati opinion: Continuum damage approach has problems because it is not continuum throughout the damage area—need to start thinking about this issue. Rashid Abu Al-Rub – Disagreed with that statement and there are different theories that can be used. Dallas Little – What would be one example that a dislocation mechanics/theory would be applicable to a viscoelastic, viscoplastic relationship in terms of materials characterization? This question stimulated discussion and debate on the application of dislocation theory or mechanics.

Chuck Schwartz – Appreciated the difficulty of Little’s job, and complimented him and his team on what has been done. Schwartz asked Little – What are the goals? In other words, at the end of the day, what is the objective—is it to understand materials or how pavements perform or is it both? Little response – It is both. Schwartz replied and asked – What is the relative distribution for both; 30 and 70 or 70 and 30? Little originally noted that 30 to 40 percent of the effort is based on fundamental approach and that 30 to 40 percent of effort is what can be applied immediately. It is complex blend and no one item dominates the level of effort. The continuum damage model is viewed by many as the end product, but that is not the case. Little referred to their resource allocation handout (what work is being done on the models and where is it being done), but noted that it is a difficult question to answer, in terms of the overall investment. Amit Bhasin answered the question as 30 to 40 percent of effort devoted to the end product.

Scarpas – Going back to the numbers in terms of level of effort, finds it hard to separate the model from the data used to develop and execute the model. All of this discussion relates to the tables showing the level of effort by agency type in terms of the deliverables from the project.

Scarpas – Relative to the micro-mechanics and material characterization models; what is the philosophy between separating materials characterization model from the micromechanics model? Eyad Masad began answering his question and noted that they will be combined, but there were follow-up questions during the discussion. Abdu Shati – In response to the question asked by Tom Scarpas; the pavement community may benefit from this effort by learning something new, but if this community does not do it, then who will do it? Scarpas believes that much more effort needs to be devoted to bridging the gap between the theoretical models and approaches and what is actually done to implement the model. Eyad Masad – Even though we argue and discuss this point related to products from this study and up-scaling the micromechanics model, the material characterization and micromechanics models should guide the up-scaling of the models towards practice. Scarpas disagreed with that comment unless you find the link, otherwise then it will only become an educational tool. Dallas Little agreed with what Scarpas said and used the healing model as an example – the wetting part of that model that could be integrated into the final approach in the continuum model.

Scarpas reminded the group about Peter Sebaaly's approach on tire vehicle-pavement interaction and asked the question about building up on the continuum damage model to help with the implementation platform for the future. Abdu Shati – The basic problem with this approach is with the continuum modeling approach. Lots of discussion between Scarpas and Shati; Scarpas agreed with Bob Lytton's comment that we need to focus on how this will be used towards implementation in pavement engineering. Need platform on how this will be used and implemented.

Linbing Wang – Trusts what the team is proposing but there are many different approaches. He would like to see how these individual models are integrated and related to one another; how they are related and if they work, they must be linked together like a programming flow chart – it must be integrated. Little replied that they must be integrated together even if they are not directly related. In other words, they guide one another to the final goal on evaluating pavements and materials. Little noted in some cases they will stand alone and are not integrated into the continuum damage model but are used to rank or define the DNA of the material. Little further commented that there are two parts of this effort, the integration of the models in predicting performance and the individual parts for ranking the materials in other words defining the DNA of a material.

Eric Weaver – It is difficult to visualize or know what the final product will look like and how it all fits together (his comment was similar to Linbing Wang's comment, in that a model flow chart would be applicable to understand how the different models and parts fit together). Eyad Masad replied to explain or define what the final product or computational model will look like. He initially overviewed the end product in that it will be similar to what exists now. The second point is that the models are separated (uncoupled in programming terms) and will not be plugged into the traditional modeling approach, but will be separate and guide the continuum damage model. The continuum model will take you to a certain point and after that it will be empirical. Example that Masad used; you really do not know how the rest period causes healing to occur. In other words, do not know exact details, but you know it heals during the rest period. The materials characterization models guide the continuum modeling approach to consider healing and its affect on pavement performance indicators.

Nelson Gibson – I know you did not want to get into future users, but who will be the future users and what will their educational background need to be to use the product? Little replied that it would probably be those that designed pavements using the latest technology. Scarpas noted that the community can determine from this tool what is important and direct or guide the designer in making revisions to designs based on what is important. He also mentioned that the tool will act like an insurance program; in other words, if you are convinced with using this tool, you can use the continuum model or tool to show that the pavement design will perform as expected. Gibson noted that one future user would be design-build firms that have control of the design and construction. He also noted that future users could be agencies sponsoring the construction and experiments using test tracks and APT pads. Bob Lytton noted that it is applicable to developing new materials to enhance performance in specific environments. Scarpas noted that the tool will be much cheaper and faster to determine the better design (getting an answer much faster with using this tool) rather than using accelerated testing. Eyad Masad noted that you get a lot of insight in using the tool to see what is going on before you invest your money. Masad also noted that we are the potential future users of the tool. Gibson

noted researchers helping researchers, but you still got to come back to researchers helping the practicing pavement and material engineers.

Bob Kluttz – Has a more general question, what is the deliverable for this portion of the ARC? He wanted to know; are we delivering a blue print or something that we can go out and buy? Kluttz made a unique comment and comparison regarding the design and manufacture of a hammer relative to the ARC product or deliverable (is it the hammer or a blueprint for the hammer). Time between the blue print and how we actually use it is a big deal. As long as we understand that all we are getting is a blue print that is fine. But the ETG needs to understand that is all we are going to get. Dallas Little replied that he is of the option that the ARC will provide the hammer, rather than a blue print for the hammer.

Eric Weaver asked if the ETG could get the milestones for the deliverables. In other words, what are the deliverables and when will they be delivered? **These deliverables will be defined, as well as their expected dates and included as a handout for the next ETG meeting.** Little noted that the individual presentations will begin to answer that question on the deliverables and expected dates. Kluttz noted that all of the written material refers to the deliverable as a final report, not the program or tool – Is this correct? Little said the deliverable will be the tool or the program. Little went on to note that the models being developed by Richard Kim and TTI may not be integrated, but will be used to compliment one another. He asked for comments from Richard Kim and Eyad Masad – they did not comment, before moving on to the next comment.

Abdu Shati – NCSU model appears to be less comprehensive than the TTI model. Little noted that the NCSU model was the ground breaking model which led much of this effort.

Scarpas noted that Richard Kim is not on the agenda to present information on this model, and asked if time should be given time to Richard Kim to present his model – Is the NCSU model a part of the presentation? Little noted that Richard Kim had input but can enhance the discussion if needed. Richard Kim mentioned that his model is not a part of the ARC product. His part is to create a practical tool for implementation and how to extend his model for fracture. He feels that there is a way to extend the continuum damage model to cracking. Scarpas understood that there will be two models or approaches (or two hammers based on the example used by Bob Kluttz), but he does not see how each model fits into the final product, so Richard Kim can bring his model into the discussion – does not want to eliminate Richard Kim's model from the discussion. It was decided that Richard Kim would be given time to present his model tomorrow.

Nelson Gibson – Weather forecasting is difficult and uses multiple models to do the same thing. In other words, it is good to have more than one model to do the same thing like weather forecasting. His opinion was that having two models that are not tied together and based on different approaches is not a bad thing.

Bob Lytton mentioned the MEPDG and environmental prediction model. Lytton noted that they have a better model than the MEPDG. His opinion was that you do not build the pavement in a vacuum; you must consider all important parameters (including weather conditions) in building the pavement in a coherent and logical process.

Richard Kim replied to Bob Kluttz's comment regarding a hammer relative to the ARC product or deliverable. Objective is to have a software program where the designer can run an

experiment prior to building the pavement (lattice model), you input the material properties and look at the performance based on different combinations of volumetric properties. Dallas Little noted or replied that ARC is comfortable with the continued development of Richard Kim's model, which might ultimately develop a new hammer or not. In summary, the ARC team is comfortable with the work on two different models.

4. Asphalt Constitutive Modeling Requirements—Tom Scarpas (Delft University of Technology)

Presentation Summary

Asphalt Constitutive Modeling Requirements from the experimental point of view related to the physical and computational aspects. However, Scarpas added to the title – “A Shopping List.” The presentation was to focus on and set up a discussion on answering different questions, as listed below:

- What we are trying to achieve?
- What is there to model?
- What parameters are important?
- What we are trying to do?
- Are there models available to do that?

Scarpas noted that there are many models to choose from. He stated that for this presentation, discussion should focus less on the computational aspects and theoretical aspects. Items that are needed: material characterization models, material response simulation in terms of available models to predict response under wheel and thermal loads (HMA is a thermally sensitive material), etc.

Scarpas's summary was that we do have the tools right now to do a reasonable job in predicting the response of HMA under different loads. He used the IDT loading at different rates to failure for complicated states of stress in the IDT test. Example or theme was that we need the interaction between the models to increase the accuracy. But can we do a better job – take a simpler lab test like the uniaxial or triaxial test in tension. But is it really simpler? Scarpas used the direct tension test and rubber band to demonstrate his presentation on what happens when the specimen starts to cracks – strain starts to reduce but the crack width increases and load decreases. Cracking model before localization – localization is an unfortunate term to be used because specimen has not lost its resistance to load.

Next part of the presentation was directed towards predicting the response of a cracked specimen; must understand what the crack is going to do and how it propagates (crack response interpretation).

ETG Comments, Discussion, and Questions:

Most of the comments, questions, and discussion occurred during the presentation itself.

Abdu Shati disagreed with what Scarpas was showing in terms of HMA materials response simulation. Scarpas agreed with him – the slide was just a sketch and noted that it is was a bad plot or sketch (this had to do with the stress-strain diagram under different loads or stresses).

Gerry Huber – What happens when you go beyond the peak and there are two separate pieces of the specimen? Scarpas replied that after the crack initiates and the load is released you have dissipated energy but everything is not recovered.

Abdu Shati – What about the IDT test in using it to measure fracture properties? Scarpas replied; two points here, a uniaxial test is very hard to do, the IDT is very simple and easy to do. Are we making the test fit the theory or the theory fit the test? We are trying to define what happens in the specimens through localization, but before we go down that road to help the community we must understand the specimen response through a conceptual model. Once we understand the material response in terms of fracture, then we can help the community by simplifying the theory for implementation or application of that theory. There was some discussion of the dynamic effects on the computational effects. Scarpas did not want to go down the dynamic paths in terms of computational methods. Richard Kim noted that the IDT is being implemented into the AMPT or simple performance test. He believes that the IDT test can be used as a verification and modeling test because the stress distribution complicated but it is known. Richard Kim does not necessarily agree that it is a simpler test.

Richard Kim – What if you have the fracture path incorrect? Abdu Shati noted that he has a problem with the way the crack is propagating. He noted that three zones are present in cracking: 1. Process zone, 2. crack dominate zone, 3. remote button zone. All we are doing here is within zone two. Zone 1 is more complicated but we have had no discussion about this zone. Scarpas disagrees with that comment that there are three zones of fracture; he does not believe that they exist. Scarpas overviewed his theory on how the crack initiates and occurs in comparison to the three zones noted or defined by Shati. There was a lot of discussion on this topic during the presentation between Scarpas, Eric Weaver, John D’Angelo, Abdu Shati, Richard Kim, Eyad Masad, Murthy Guddati, and Gerry Huber. There was some confusion regarding the visual aid that was being used to explain the concepts and theories by Scarpas.

Comment [BC1]: The CD is not clear hear, I am not sure I correctly understood the words. It should be initiation, but that is not what I heard.

Imad Al-Qadi – When we discuss fracture, Al-Qadi agrees that there are three zones or phases, defined as: (1) softening, (2) initiation, and then (3) propagation. Scarpas believes that the propagation and initiation go together or are related. Al-Qadi noted that this would have been much simpler from the statement about softening near the tip of the crack, etc. There was additional much discussion and debate on this issue between numerous individuals (the same individuals noted above). In summary, Scarpas noted that he hopes the “dog wags the tail” not the other way around relative to this discussion. Murthy Guddati – What are we proposing to do here regarding the process zone; quantitative or qualitative approach in relative to determining the process zone crack size? Scarpas – He believes that Yong-Rak Kim would agree that this is a cohesive crack model; but Guddati’s question was never answered, because of the additional comments that were made.

Comment [BC2]: Lots of static on CD, difficult to hear the discussion to make sure I captured the correct discussion.

David Allen – Noted that what Scarpas said was really incorrect about their model in terms of fracture relative to the approach taken (University of Nebraska or Allen-Kim model). All three modes of fracture are considered. Much discussion here between what is model I, mode II, and mode III tests between Allen and Scarpas.

Abdu Shati had a question about what initiates a cohesion zone type of crack. Scarpas answered his question that he prefers to keep the material law on a crack plane because it is easy to conceptually visualize for an experiment, and then decide how to rotate the crack plane, but not

to mix different phases that have been used in the past. Allen noted that no one really knows what initiates the cohesive zone in HMA – it is an open question. Debate between Allen, Shati, and Scarpas regarding whether it is rate dependent and how to derive or determine the rate dependency without doing experimental tests. The intent of Scarpas presentation was to use the laboratory measurements for simulation by the model. David Allen and Scarpas disagreed but appeared to agree with what defines strain or rate dependent issues on the cohesive crack model. Abdu Shati joined in on the discussion about the validity of the concept and what is actually being done in the simulation theory. This debate was not resolved.

5. Moisture Damage

Two presentations were made under this item; the first by Eyad Masad and the second by Rashid Abu Al-Rub. The first one was to address the question: How do the Elements of the ARC/WRI Advance this Goal? The second one was to review the ARC Moisture Damage work (Year 2 Review: ETG Recommendations/Work; and overview of the year 3 work plan). All work will be wrapped up in year 3.

Presentation #1 Summary – Eyad Masad (TTI, Texas A & M University)

Eyad Masad first passed out the information on the course that will be hosted later this year by TTI and UMD.

Masad overviewed the work completed in the moisture damage area under three subtasks; everything else from previous meetings remains the same. The team is ready to submit the moisture damage using DMA test protocol to AASHTO. This test protocol was a goal to evaluate the moisture sensitivity of HMA mixtures. He summarized what has been accomplished within year 2 and what is planned for year 3. Masad noted that determining asphalt film thickness of the binder was difficult. All work has been documented.

Dallas Little noted the work previously completed using DMA and being able to differentiate between the moisture damage potential of different aggregate and mixtures. This has been found to be effective in identifying those mixtures and aggregates that are susceptible to moisture damage. Masad noted that a new simplistic probabilistic model has been developed and added to the approach. Masad overviewed the modeling and material characterization and the effect of moisture on those items related to cracking. He also presented many of the numerical simulations to illustrate the effect of moisture on the bonding and fracture strength of the mix – probability of cracking in a dry versus wet specimen.

ETG Comments, Discussion, and Questions:

Most of the comments were made or questions were asked during the presentation itself.

John D'Angelo – Relative to Masad's comments about getting more binders to be used within this task, D'Angelo mentioned that Masad might want to review the FHWA's work for picking additional binders that are different. Jack Youtcheff and Terry Arnold could give you information on picking more binders that are different from their PPA work. Dallas Little commented that they have already received this information from Terry Arnold to select other binders that could be used.

Shati – Also asked about the probabilistic density function of diffusion that is included in the model. Masad – The average value or property for diffusion will be used and it will be in an input to the micro-mechanics model to predict moisture damage, similar to what Yong-Rak Kim is doing. ARC is using a probability density function for diffusion but not for this experiment.

Abdu Shati – What is the difference between the original model and what is being presented here? Masad – There is an exponential function. Dave Allen explained the difference between the original model and the expanded version or what is being presented here (this has to do with the dove-field paper). It is a cohesive model that is energy dependent.

Jon Epps – Is there a diffusion coefficient for the aggregate and asphalt? Masad – Right now they are using an average value, but will expand to specific material coefficients.

Presentation #2 Summary – Rashid Abu Al-Rub (TTI, Texas A & M University)

Rashid Abu Al-Rub continued with the discussion/presentation on the moisture damage effect on the unified continuum model. He overviewed the work plan and goals of this effort. These were: develop a continuum damage model for predicting pavement distress (the model is to include viscoplastic and nonlinear viscoelastic components); and include mechanical and moisture damage and then validate the model using the data from APT facilities and test tracks.

ETG Comments, Discussion, and Questions:

David Allen – Isn't this just a pull down window to be used by a highway engineer? Al-Rub – Yes it is. This will make the tool much more able to implement.

Jon Epps – What about the aging models within this system? Right now no aging model is included, but the plan is to include aging in future work. Dallas Little clarified that the aging model does exist, but not just in the micromechanics continuum damage model. Al-Rub also noted that both the healing and aging models will be included.

Abdu Shati – What about the parameters in Schapery's equation related to nonlinear viscoelastic and viscoplastic model, are they included? David Allen replied to the question about the variables within the Schaprey equation and defined each of the parameters. Most of the parameters are nonlinear functions of the material. This discussion or explanation had to do with the g' factor within the equation.

Scarpas – You go from a tensor formulation to a one-dimensional scalar equation? Al-Rub – Good comment and point. Going to the 3-D, one component of the total strain can be expressed in the deviatoric component can be expressed as a tensor format and the volumetric component as a scalar format.

Abdu Shati – Are you assuming linear, visco-plastic behavior? Al-Rub – No, it is non-linear visco-plastic behavior. Abdu Shati –Are the parameters of the viscoplastic model in series or not? Masad – Yes, they are in series.

Abdu Shati – Are the material properties being updated/changed over time or just going through the different parts or cycles of the model? Rashid Abu Al-Rub – The material properties are being changed due to hardening and damage (distress), but moisture damage is not yet included in this part of the procedure or tool.

Richard Kim – Is the single creep-recovery test in tension or compression? Masad – The single creep-recovery test is in tension and compression. Scarpas also asked how the tool will be calibrated relative to using this test or how does this relate to determining the model parameters? Masad and Al-Rub replied that you have to calibrate for both tension and compression individually in determining the model parameters.

Abdu Shati – Complimented the team on the work completed to date. His additional question that had to do with how do you move from the undamaged to damaged part of the model, in other words what is the evolution of damage and what is the damage variable? Rashid Abu Al-Rub noted that will be coming next. This is an energy release rate concept.

Broke for Lunch @ 12:50 PM Reconvened @ 1:45 PM

Scarpas opened the meeting after lunch to questions for Masad and Al-Rub prior to breaking for lunch. Discussion between Allen and Scarpas on localization and the viscoplasticity of the material; Guddati also joined in on the discussion. Allen disagreed with Scarpas comment on the distribution of relaxation times over a large number of loading rates related to the localization zones. Guddati – One motivation of the spatially non-local model is for localization but another goal is to introducing inherent link scale that exists in the material behavior itself.

Richard Kim – What is the value of Tau in the nonlinear viscoelastic model? Masad – It is just a notation or evaluated at a given time. Kim – Your G_2 is the C-term in our continuum damage model. Murthy Guddati – What is the G_2 in that same model? Masad – It comes from experimental data and is the nonlinearity; it is a nonlinear function of stress or temperature. It is a nonlinear function of stress and strain levels but does not change as a function of damage or number of loading cycles. David Allen also stated that Richard Kim was really correct in a special case of what Schaprey developed. At the time that Schaprey wrote the original paper, he was not talking about damage, but you can induce damage from G_2 . Al-Rub also noted that G_2 can be related to damage from the experimental data or include damage within the G_2 term. Guddati – Is there experimental evidence that demonstrates a model that separates damage or explains damage using this parameter. Masad – Yes there is. In 2003, Lytton showed that there is no damage from the initial cycles (linear) and then after many cycles damage begins to occur or becomes evident and the response is nonlinear, but the material property does not change.

Richard Kim – How important is this G_2 -term in relation to performance predictions of HMA pavements. Kim believes that you have to capture more in terms of explaining damage and nonlinearity. Haifang Wen noted for the binder at intermediate temperatures, the nonlinear effect is very small. Masad did not necessarily agree with that statement, especially at the higher test temperatures for the mix. Scarpas – Do you see a difference between damage and micro-cracking through the continuum model or is damage micro-cracking, as non-dimensional direction cracking (is it directional or not)? Richard Kim – Considers damage as cracking. Al-Rub – It is directional. Masad – We do have experimental data to show nonlinearity that indicates that it should be included in the model. Masad also thanked Richard Kim for sharing his data with the ARC. The sharing of data saved a lot of effort.

6. Fatigue, Aging, and Healing

Presentation Summary; Amit Bhasin (University of Texas at Austin)

Amit Bhasin gave a review of the year 2 accomplishments and then overviewed the year 3 plans. Bhasin gave his presentation in a reduced amount of time because of the schedule and being behind time for this afternoon. The ARC team investigated not only the type of failure but the condition of failure in relation to moisture. He first gave an overview of the fatigue cracking effort. This was followed by the effects of aging on fatigue related to the oxygen transport model. The next item discussed was healing in terms of fatigue cracking for developing the micromechanics model. The healing model has two components: a wetting component and a cohesion component.

ETG Comments, Discussion, and Questions:

Scarpas – What happens when you do a controlled stress test and convert to a controlled strain test in terms of the h_1 , h_2 , and g_1 and g_2 ? Bhasin and Masad – You would see as long as you do not increase stress beyond a particular point, the parameter would remain relatively constant. Richard Kim – In terms of localization, as long as you know where the localization occurs, the parameters are related and fall within the same damage characterization curve. Richard Kim noted that he will address this issue in his presentation for tomorrow.

Nelson Gibson – Related to air voids that you cannot see versus those that you can see, how do you estimate the size of the voids that you cannot see? Bhasin – Using equipment that can get down to a micron level. The other issue is what is a micro-void and how do you define it. Glover at TTI is working on this so Bhasin did not want to speak for Charles Glover at TTI.

Frank Fee – Can this procedure/model be simplified down to our standard practice and definitions? Bhasin initially replied to the question. Bob Lytton spoke to this question and issue and summarized how compaction affects the structure related to air voids and water vapor. Laboratory compaction affects the magnitude of the voids and compaction does make a difference. Lytton believes that we now know how these are related and then how to address this in the future related to practical items. Abdu Shati – The void distribution has already been explained or described; not following the discussion. Dave Anderson – This is not just a compaction issue as related to Bob Lytton's comment. Anderson believes that lab and field compaction is not the same thing.

Dave Anderson also wanted to know, what aging model is used or applied in the task? Anderson believes that we should get away from film thickness because it is not a property or factor. Film thickness is diluting the issue, so his opinion was to get away from film thickness. Bhasin did not want to speak for Glover but believes that we can get something that works. Anderson believes that something else is causing differences in variations in film thickness and we should get away from that. Bob Lytton replied to Anderson's comment – Charles Glover is doing some work in terms of how does oxygen diffuse in the asphalt so we will have some idea to estimate the amount and size of the real voids in the mix and how the asphalt responds to weather (air and climate). John D'Angelo – Aging affects more than just modulus but modulus is the basic property included in most models. Lytton also noted that aging affects other items not just modulus. Lytton noted that Glover is looking into the issue of how does oxygen diffuse into a surface. Bhasin – All of the material properties that are included in the micromechanics model are affected by aging.

Imad Al-Qadi – Are you assuming that the stresses causing the crack to close are viscoelastic?
Bhasin: No.

Imad Al-Qadi – You are assuming that all fracture that you have is within the binder? Bhasin – Yes. Al-Qadi – How do you calculate the work of cohesion? Bhasin – They are not measured or calculated, just estimated for a comparison of results. Al-Qadi – What temperature is used? Bhasin – Room temperature.

Scarpas had multiple questions about the model; the wetting component or process part of the model and is it a simplification of reality to say that the material has healed at the macro level. Bhasin – Excluded wetting by bringing the two phases in contact, reducing it to one at a particular time.

Abdu Shati had a question about the size of the element related to the model. Bhasin – Not a measured parameter, but a computed parameter or computational element.

Imad Al-Qadi – Still confused by the work on cohesion; cohesion and wetting should be independent on the geometric size? Bhasin – Just a hypothesis that tells us that short times after wetting, the strength gain will increase. Cohesion and wetting are two completely different things; both Dallas Little and Bhasin disagreed with comment – they are related.

Scarpas – Noted that he is still confused; what is the difference between molecules across the interface or crack, and if they jump across the interface or crack, does the continuum disappear? Why do molecules migrate across the interface? Bhasin replied to the question but it was not resolved. Scarpas – What is the difference between the edge of specimen and the edge of a crack? David Allen had a comment about this question in terms of a crack and cohesion – molecules jumping across cracks, etc – The molecules jumping back and forth across the crack and not back and forth along the specimen edge is the difference between the two. This discussion was cut short because of time.

7. Engineered Materials

The part of the agenda was divided into two presentations. Bob Lytton and Rong Luo started the presentation on engineered materials, which was followed by Hussain Bahia and Elie Hajj.

Presentation #1 Summary: Bob Lytton and Rong Luo (TTI, Texas A&M University)

Bob Lytton made the introductory comments regarding the engineered materials and calculating mixture properties and Rong Luo gave the detailed presentation. Lytton's provided comments in terms of what this is all about. Compression versus tension because they are different, what we were hoping is to determine how to quickly determine these properties that is the first part of the presentation. The second part of the presentation has to do with our progress to determine the pseudo-strain and the third part is how to use a different version of the micromechanics model, an older version, to increase our ability to capture or predict the mixture properties (a simplification process). Lytton and Luo made use of the master curve (Complex modulus) relationship to develop the formulation for evaluating materials. They overviewed the process or procedure for computing the dynamic modulus in the vertical and horizontal directions for the mixture. The next part was to overview how to determine the pseudo-strain in the model formulation for when the material is undamaged. Lytton & Luo are using pseudo strain energy

for fatigue cracking and for distortion. The next part of the presentation was for the forward and inverse models for predicting the mixture stiffness properties from the physical properties of the materials. For the inverse model the bulk modulus and shear modulus are computed for the aggregate. For the forward mode, the bulk and shear modulus of the mix are computed.

ETG Comments, Discussion, and Questions:

Jack Youcheff – Do you see a difference in properties of the mix related to the thermal fatigue of the aggregate properties (thermal coefficient expansion of the aggregate and mix)? Lytton – Properties of the aggregate dominate in terms of fatigue cracking. Lytton noted that there is a much better way to determine the thermal coefficient of contraction-expansion of composites than the linear estimation of the coefficient of thermal contraction that is usually used to estimate the value.

Geoff Rowe – Does not understand why phase angle is so high as shown on the visual aids. Hussain Bahia's model was used to determine the phase angle shift and it worked very good. There was a lot of discussion between Rowe and Lytton. Lytton had a question for Rowe – If the measurement transducer had mass, can the mass of the transducer affect the readings? Rowe mentioned that there is no calibration process for phase angle. Lytton mentioned that the phase angle tells a lot about the energy that is lost and that they used Hussain Bahia's approach and it worked much better – to determine the shift factor. Both agreed. Richard Kim noted that for the phase angle calibration they use an aluminum block run at different frequencies to ensure that there is no phase shift, so you get a phase angle for the material. Lots of discussion started at this time relative to the calibration for phase angle.

Scarpas decided to cease the discussion on this topic related to calibration of shift or phase angle. Rowe's opinion was that we are always only calibrating to a phase angle of 0 or 90, not between those values. This difference was not resolved during the presentation and discussion.

Presentation #2 Summary: Hussain Bahia (University of Wisconsin) – ARC Update on Engineered Materials

Hussain Bahia reviewed the specific work elements that were in the original proposal. Lytton reported on the first one in the micro-mechanics model for mastics and mixtures. Bahia will report on the remainder of the work elements. This report summarizes what was done in year 2 and what is planned for year 3. Elie Hajj will report on critically designed HMA mixtures.

Reaching the goal: from components to mixtures is the first part, the second part is the mix design, binder grading, and the third is the green technologies. Bahia summarized each of the task elements. Modeling response to load – Rutting has provided positive results; for fatigue, problems with the indentation device. Have abandoned the small scale indentation device, and have decided to increase scale of large indenter to estimate proof of concept. Rowe mentioned that Europe has been using the indentation device for roofing standards and chip seals for some time. Bahia appreciated the comment and will look into that. Warm and cold mixes – have studied many of these mixtures using the gyratory compactor. Bahia noted that Jon Epps recommended that the foaming of warm mixes be studied and tested in lab because it is so cost effective. Bahia noted that they have a foaming machine in the lab and it is now operational. Presentation was to determine how much of the additive you need and how effective is the additive – this was related to the lubrication. They plan to focus on the mineral, surfactant and foam materials. Still plan to use the gyratory compactor and will use dynamic modulus and flow

number type of tests. Regarding the cold mixtures, Gayle King assisted in the area. The types of tests being conducted include the residual recovery, pull off test, and the breaking and setting. High RAP content mixtures and properties of binder in RAP (BB testing of RAP mortars).

Many of the tests are influenced by geometry of the test specimen. They are using the cone plate because it is less dependent on the geometry of the specimen. Do not want to confound the experiment or correlations with mixtures that are geometry influenced.

ETG Comments, Discussion, and Questions:

Abdu Shati – In terms of workability and energy analysis, how do you measure energy needed? Bahia noted that he may have misused this term in its true sense of the definition. Rowe noted that there are other organizations that do these energy computations and there are different ways to do this. These need to be done in a systematic way. Rowe will send Bahia the information on this group for standardizing the energy computations.

Gayle King – How is temperature being affected in the mastic in the ABCD machine, and how much did the temperature change between the asphalt and mastic? Bahia noted that the machine is handling the mastic very effectively but did not remember what change there was between the mastic and binder.

Abdu Shati – Why are you not looking for using the elastic foundation in fatigue testing. Bahia was not sure why the elastic foundation is necessary.

Tom Scarpas – You are doing tests to determine the modulus, so how does this overlap with some of the other task activities and elements of the ARC? Bahia requested that Ed Harrigan respond to this question. Ed Harrigan mentioned that these are looking at simple tools for mixture designs rather than advanced materials characterization. They give performance indications but not theoretical properties for advanced material characterization.

Abdu Shati – Are you using these to combine all of the effects of aggregate, binder, air voids, etc.? Bahia replied that we hope so and that would be guided into Bob Lytton's micro-mechanics model.

Bob Kluttz – The effect of loading is strain dependent and not stress dependent. The deviation of the binder compliance is not a stress dependent property but is dependent on the strain. Bahia disagreed but believes that this is very important. Lytton believes that there is a critical strain level beyond which accelerated deformation occurs regardless of the stress level to achieve that strain level. Question becomes important regarding stress or strain dependent in terms of when tertiary flow occurs.

Nelson Gibson – Are you looking to develop relationships that can be used in mixture design and specification development? Bahia – We will share data and TTI will check our models developed under this part which is very empirical. Nelson believes that the aggregate will dominate the important properties related to performance or the prediction of distress. Gibson is unsure why we are doing less mixture testing and characterization and more related to the binder and then predicting the mix properties. Masad – Once the ARC calibrates the model using Kim's work, they will determine which one dominates.

Presentation #3 Summary; Elie Hajj (University of Nevada at Reno)

Elie Hajj – Overviewed the work element on critically designed HMA mixtures, and on the testing matrix that will be used in year 3 for this effort. He identified the matrix parameters and how they will define the critical conditions for the testing conditions. This topic is related to the work that Ray Bonaquist and Don Christianson are completing under NCHRP project 9-33. Hajj noted that they the ARC is recommending the use of a confining pressure of about 30 psi and a deviator stress of about 80 psi at the high test temperatures. He quickly overviewed the work under this task in the interest of time.

There were a few questions related to this topic at the end of the presentation. One question was what testing conditions were being used to measure the mix response. Hajj response is provided above in the presentation summary. The other question was related to the loading frequency or loading time selected, which was related to vehicle speed. Speed was less information than temperature.

Chairman Scarpas decided to move to the next topic in the interest of time. Time was noted in reducing the questions during this presentation and discussion.

8. Field Validation/Forensic Studies

Two presentations were given under the field validation and forensic studies topic. The first was given by Mike Harnsberger and the second by Elie Hajj.

Presentation #1 Summary: Mike Harnsberger (WRI) – Field Validation/Forensic Studies

Mike Harnsberger noted that they are a couple of validation efforts on going throughout this process of the ARC. Harnsberger overviewed the types of projects that are being used for validation and where that data and materials are coming from. These include the LTPP MRL, WMA field site monitoring program and RAP projects. About 31 of the LTPP SPS projects (SPS-5) are being used to test the virgin asphalt. Harnsberger reported on the Yellowstone and Arizona sites where different aging levels occurred, and the Minnesota site. The Minnesota site: some of the test sections are beginning to exhibit some distress. This was reported not to be a construction defect, not an aggregate problem and not a binder problem; it is believed to be a mix problem. Another site for future validation is the Manitoba WMA project with RAP. The RAP content is about 30+ percent. The Texas DOT is included in the RAP validation part of the plan. These sections will include none to a low to high percentage of RAP. The Manitoba WMA project also includes additional sections with various amounts of RAP.

Presentation #2 Summary, Elie Hajj (University of Nevada at Reno) continued with the discussion on using the MEPDG flexible pavement sections. Nevada, Wisconsin, and South Dakota all have sections that will be used within this effort. These are design-build sections. The ARC is using these three projects for validation. They will begin with collecting the basic design information and data. All of these are reconstruction projects. One goal is to get them familiar with the MEPDG. Nevada project: existing pavement has a CTB and HMA surface (semi-rigid pavement). Hajj noted that the global calibrated model was used, but that the mix will be a PMA. He briefly reviewed the pavement cross sections that were designed with the MEPDG.

ETG Comments, Discussion, and Questions:

There were only a few comments and questions related to this topic. Frank Fee mentioned that NCAT is preparing to redo the test track next year and that some validation sites or test sections could come from these sections. Mike Harnsberger mentioned that they looked into this but the cost of the sections was the issue. **Fee recommended that they discuss this with NCAT.**

Chairman Scarpas noted that the agenda was changed; the meeting in the morning will now start at 8:00 AM rather than 8:30 to give Richard Kim time to present his model.

Chairman Scarpas adjourned the meeting at 5:30PM.

DAY 2 (Tuesday, 24 February 2009)

Call to Order—Tom Scarpas called the meeting to order at 8:05 AM. Chairman Scarpas requested that all participants sign the attendance lists, but only once. Chairman Scarpas then asked Richard Kim to start his presentation.

9. Richard Kim (North Carolina State University)

Summary of Presentation

Richard Kim gave a status report on NCSU's VEPCD modeling research. This presentation was added to the ETG meeting. Kim first overviewed their overall modeling philosophy and the important elements driving the modeling development and how it will be used from the mathematical computations to measuring the properties in the laboratory. Kim's opinion is that the Asphalt Mixture Tester improved through the FHWA is an excellent device for measuring the properties of the HMA mixtures.

Kim overviewed each of the model components of the VEPCD – Elastic-Viscoelastic Correspondence principle (linear viscoelastic effects), work potential theory Micro-cracking related degradation), viscoplastic model (permanent deformation growth) and time-temperature superposition with growing damage (time-temperature effects). The C versus S Functions are the backbone of the VEPCD method for simplifying the testing program with not having a negative effect on the accuracy of the model. Kim also reviewed the aging and healing models incorporated into the VEPCD. In summary, dynamic modulus with the AMPT to get C versus S relationship is the only test that Kim uses in support of his model.

Kim then reviewed the thermal cracking model based on the VEPCD. Kim concluded with comments on the application of his VEPCD model in pavement design and analysis. He noted that predicting the HMA response in compression is much harder because of the aggregate interlock.

ETG Comments, Discussion, and Questions:

Rashid Abu Al-Rub – Do you believe that the viscoplastic model parameters are reasonable as defined from the tension test? Kim – The viscoplastic model in compression is much harder to simulate than in tension because of the aggregate interlock.

Imad Al-Qadi – What type of fatigue tests are you running and what type of specimen geometry? Kim – Controlled cyclic or ram movement test; you are not really controlling stress or strain – it

is a mixed mode test. The standard AMPT test specimen geometry and monotonic test under controlled strain rate in tension and compression using the strain decomposition principle.

Scarpas – Monotonic; what do you mean by that and are you going into the viscoplastic range of the model? Kim – Monotonic = Controlled cross head rate or ram movement until the specimen fails. The test temperature is 5C and the test rate is fast enough so that the viscoplastic part is minimized and you capture the viscoelastic component. Viscoplastic model is for tension.

Abdu Shati – What strain rate are you using? Kim – Strain rate are fast enough to minimize the viscoplastic component. Abdu Shati – Why was the strain hardening component used? Kim – Component was evaluated many years ago based on Schaprey's work and it was found to work well based on Jacob Uzan's work, so they decided to include it. Discussion on the strain hardening component between Scarpas and Shati regarding whether it is linear or nonlinear from the strain rate.

Jon Epps – How did you measure the N failure from typical fatigue tests as related to Kim's testing scheme? Kim – Evaluating and measuring changes in the phase angle was found to provide a good indicator of the mixture property. Kim referred to Geoff Rowe's experience and data related to phase angle changes.

Rahsid Abu Al-Rub – Why does the simplified healing model recover at the same rate, as shown in the visual aid? Eric Weaver noted that it is pseudo-strain versus damage rather than number of cycles, so the damage normalizes the healing or recovery and that is the reason for the same rates; uses the same rate of healing and damage. Kim agreed.

Imad Al-Quadi – How does the model predict the moisture damage response of HMA specimens? Kim replied that moisture conditioning is required on the AMPT test specimens through the experiment and then run the simulations.

Linbwing Wang – In your simulations, how do you determine whether or when there is any cracking? Kim – C value below 0.25 is a good localization criteria or guideline. If the C-value of any element goes below 0.25, we count those as cracked. Wang – Is there any physical evidence substantiating that criteria or value? Kim – All of the monotonic tests completed that exhibit C-values below 0.25 do indicate and show cracks, so there is physical evidence.

Eyad Masad – Referred to a previous paper regarding anisotropy; is the interparticale friction related to material softening and hardening? Kim noted that is what they are trying to include in the model based on some of the experimental results. The model used is the HISS-Krempf viscoplastic model.

Imad Al-Quadi – As an ETG member, a lot of detail from yesterday and today, how does this all fit together? Kim noted that parts from the TTI team on moisture conditioning and aging can be included, but as Dallas Little noted yesterday, all of the models will probably not come together, there are different approaches – hopefully all will learn from each other. Little noted that Richard Kim said it well. The ARC is looking into different micro-mechanics model for explaining all of the different aspects. Little does not see that they will ever merge, each has their own strengths and weakness. Kim's model is not developed into the lattice model but they are parallel for different applications. Yong-Rak Kim (University of Nebraska) – The thermal

model coefficients, how they are determined? Richard Kim – need to have these measured and they are based on average values that were used in the example runs.

Eyad Masad – Noted that all of the testing and findings are being used and sharing of data to compare the different models. Eyad Masad also asked a question to the group: Why do we need to combine the different models? There are two different approaches – you can have two different hammers based on the example from yesterday. Chairman Scarpas noted that before that question is responded to, Nelson Gibson will give his presentation.

10. Nelson Gibson (FHWA) – Synthesis of Day 1 – The Physical and Computational Aspects

Presentation Summary and Overview from Monday

Nelson Gibson noted that he only has four slides for summarizing the discussion and presentation from yesterday. Gibson noted that a lot of others helped him put this together. At end of the contract, we had hoped to have a deliverable software package and tool, which probably will not be the case, but we are making a lot of progress. It is envisioned that the tool will be a software package that will help researchers help researchers – not researchers helping the practicing engineers. Chairman Scarpas noted lets take each question individually and then discuss between the ARC and ETG.

Slide 1 of 4: End product will be a blue print for a hammer, rather than the hammer. Do we really need to focus on the application or a mini-module within each topic area? What are the tools going to look like? (A finite element program as a whole or for each topic area?)

Abu Shati, Richard Kim, Tom Scarpas, Eric Weaver were all involved in discussion of what will be the product and how will that product be used. It appears that there is disagreement between how much time it will take to convert the results presented can be converted into a usable tool for pavement engineers. Richard Kim does not think it will take that long, while Abdu Shati thinks it will take a much higher level of effort.

Eyad Masad – What is the likelihood of a polished 2DFEM VEPCD product. Masad replied that it will only be a blueprint model that can be put into ABAQUS and will not be a product that can be put into the laptop. The different topics will be available for aging, moisture damage, etc. Chairman Scarpas requested Richard Kim respond to this comment from Masad – Kim noted that a lot of effort has been devoted but would not confirm that it will be easy. The word “polished” was a problem – Kim noted that it will not be on a laptop.

Chuck Schwartz noted that the cart is getting ahead of the horse; Schwartz noted that we really have to demonstrate that we can do this in predicting pavement performance and distress. We really need to take both approaches and apply to a realistic field condition and get predictions that are close to what we actually measure. Eyad Masad replied that 70 percent of the effort is devoted to getting or determining the very important material characterizations that have to be integrated for making the model complete (moisture, aging, healing, etc.); or providing a blue print from the ARC. Little supported what Masad said and thought Schwartz did an excellent job of summarizing what is going to be delivered through the blueprint and tool. The focus of the effort is to develop a blue print in developing the micro-mechanics model – that was really the task. Schwartz clarified that we are looking for more than just a blue print, he is looking

more for the structure (in terms of building a house). Little and Masad agreed with Schwartz's comment (the walls up, the roof on, but the house is not complete).

Scarpas – Was it the intent to make this a public domain tool or product (question was to both Richard Kim and Eyad Masad)? Eric Weaver – This is the first time that the ETG has seen what the ARC has identified what the tool will look like. We need to continue with this and get a grip on the product or tool. Abdu Shati – Are you planning to use ABACUS as the engine? Nelson Gibson – Lets get back to Weaver's questions. Masad – The plan is to have the models embedded in ABAQUS, if the ETG wants this outside of ABAQUS that can be done. Weaver – What type of programming will be done, C++? Masad – Yes, it can be plugged into any environment. Weaver believes that at the end we do get an application version so that it is useful.

Frank Fee – The industry perspective, work from the top of the structure down. The focus area needs to be surface down (i.e.; top down cracking prediction model). Testing time has to be reasonable, if there is no practical version, it will not be implemented. Does not have to be 100 percent, a lower reliability is fine. Industry is struggling with some of the distress prediction models.

Gayle King – More of a matter from a materials characterization and the needs for the current system (example, the interlayer between PCC and HMA for overlays); must have a means to bring the product to the market. If the ARC can deliver an implementable system just based on fatigue cracking, that would be a huge benefit. Gibson summarized individual models and individual specifications can be a huge benefit, even if it is not implementable or used in predicting the distress. Eyad Masad answered – 60 to 70 percent of the ARC effort is exactly what the ARC is concentrating on. Allocating resources to the individual topics that can be trusted. A tool for predicting distress is not the issue or the most important need.

Richard Kim – Proposed to look into the NSCU model to be considered with the AMPT to make it available to the public for use. Masad stated that their material characterization model is now ready that can be delivered now. Scarpas stated that the use of finite element programs must be used to tie all of this together. The intent to integrate all of the tools allows us to get the interaction because the individual pieces may not tell the whole story – must know the interaction. Scarpas – 60 to 70 percent of effort for the individual components, but the final is the most important for tying it together that will take considerable effort. By themselves, the value is limited. Scarpas and King disagree about the value of the individual components as opposed to an integrated system. Lots of disagreement regarding the components and integrated system or tool. Many different opinions on what the deliverable should be to define success. **This needs to be discussed in greater detail so that everyone agrees or at least clearly understands what the deliverable will look like and how it will be used.**

Dallas Little – Components are emphasized a great deal to understand the overall system and it takes a lot of resources to develop the individual programs or models (mechanisms), but that does not mean that it reduces the importance of the integrated system. Little believed that the tools or components can be integrated but not to the nth degree. The house will not be finalized but it will have a frame and structure. But we really do not have that big pot of funds to develop all of the tools and components.

Jon Epps – Gave comments related to industry’s view based on many projects from Granite Construction. A few things that the ARC needs to keep in mind from a company that builds a lot of pavements. Projects that Granite is involved in are design-build, warranty, and traditional projects. The warranty projects are how this work gets into the local practice much faster. Must have all of this stuff together to meet a 2 to 4 week window regarding the testing program in support of the components or models. Epps also emphasized the accuracy that is needed – it must be accurate! Another issue: Who is going to do the training to ensure that the tools will be properly used? Epps noted that he deals with consultants that are good and those that cannot properly use the 1993 AASHTO design guide. Scarpas – Overviewed and went through the design-build process that is used in Europe. Agrees with what Epps summarized. European clients do not wait to build the libraries for taking steps to get the materials properties for specific projects. Interaction between the universities and contractors is important. Sophisticated tools will not be used, if industry is not confident in those methods or if they have no improvement is the way industry does business. Epps noted that industry in the U.S. is 20 years behind Europe; this will not happen the way industry operates today.

Question 3 (Slide 3 of 4): What about feedback, should the ETG be asking the ARC to do more tangible goals for model verification (APT facilities and full scale roadways or tests)?

Question was more related to what type of verification should we be focusing on? [John Bukowski noted a point of procedure here; that the ETG can not advise the FHWA on directing the contractor; they can only provide technical input. Gibson noted that he stands corrected.]

Richard Kim – I would include something like random loading at different temperatures, rest periods, loading rates, etc. prior to verification steps. Laboratory versus roadway test comparisons; just lab verification or roadway verification is insufficient. Gibson – Should this be an agenda item, do we want to bring this into an agenda item? Scarpas – We also need to define what we are combining. Chuck Schwartz – What Richard Kim was talking about is a given regarding the laboratory test verification. Schwartz is not convinced that there is a lot of verification or validation work with the torture tests is all about (APT pads, test tracks, etc.). We need to demonstrate that we are in the ballpark for the predicted distresses using torture tests for APT pads. How do we improve validation testing? Frank Fee – If we are doing validation, we need to use field compacted mixtures – do not get mislead about laboratory compacted specimens. Richard Kim – On caution about using torture tests; what is the stress range in testing a model? The stresses should be within the same range of the operational conditions.

Imad Al-Qadi – Suggested that when we start the next meeting with Dallas Little noting at the beginning to set the stage that there are two different model development going on and they are parallel; plus identify what the differences are and identify what appears to be the best model, etc. Possibly present the validation plans for each of the models.

Chuck Schwartz – You do not need the full integrated package to go forward. Each component can go forward by itself. Epps – Validation or verification is extremely important to convince the bonding companies to go forward and using the program. Even though the individual models are important, the integrated system is what will be used in practice (for example, design-build projects). Epps and Schwartz both agreed with their individual opinions, it is a matter of timing.

Question 2 (Slide 2 of 4): How close to reality is sufficient? The roughness of the models. How good is good enough? Are we done when we start refining?

Scarpas – The tests in themselves can be used to determine what is missing and what is important, as well as what is unimportant. We might want to wait until we look at the tests and their verification. Richard Kim – Different levels of accuracy may be needed or will have a more importance related to rehabilitation, so the accuracy may vary. We need to keep our minds open here and not go for everything at the beginning. Scarpas – Products will be produced for different users (i.e., a different hierarchy, so there will be a whole range of users and the accuracy needed).

Epps – How accurate is accurate enough? If these modes can predict to the 1/8 inch will help. If they cannot do not better than 0.5 inches, they will not help. For fatigue cracking, within 10 million trucks will not help, but if we get within 10 percent we will be satisfied, even within 20 percent will be okay. For thermal cracking, if it develops or not will probably be sufficient. Reflection cracking – how many come through and more importantly how soon they come through. Geoff Rowe – Do you (referring to Jon Epps) believe that some thickness difference will be more important than truck applications (difference between the different models could be quite small). Scarpas, referring to Chuck Schwartz's opinion or statement about computational efforts, the purpose of computing is insight not the numbers.

Gayle King – Regarding rehabilitation, aging models is hurting us in terms of predicting aging of these mixtures. These tools must be able to predict how soon cracking starts in these mixtures. The component of the tools are what is needed and can be very valuable, not necessarily the whole model for answering some of these questions and to make use of these tools or components.

Nelson Gibson asked: Do you think you are getting there; in other words, how deep do you need to mill based on aging model? Little noted that is what Charles Glover is supposed to do or answer those types of questions. Little turned the question around in terms of: What do you mean by roughness of the model? Nelson noted that you have the model working to get the insight or relative differences to determine relative effect from multiple properties, but you might not have the accuracy to get the actual predictions. Abu-Alrub – Start with the simplest model and fewest tests; the ARC is taking this into consideration to predict the response. [He missed or does not understand the true question.] Scarpas – You cannot answer this question unless you complete real cases. Little – What both Scarpas and Abu-Alrub are saying is correct. On the other hand, the general question related to aging – You must begin with the laws of physics, but you do not know if the laws are correct, so you must use real data to make sure you are on the right path. The micro-mechanics models are being used to ensure we are on the right path.

Murthy Guddati – Always think in terms of what are the quantities that exist and are they good enough. Scarpas – Definition for ruggedness is what? The question by Scarpas led into a lot of discussion on the accuracy of the components versus accuracy of the final tool or prediction model.

There is a huge difference in what different ETG members are discussing – laboratory or predicting laboratory measured behavior of materials and predicting measured distresses on the roadway. Masad – The components do have predictive power, this is one level of ruggedness.

The next level is when you incorporate into a finite element model and check the predictions. So you can turn components off and on, if you need that component and if it is important. These are done after the development of the model has been completed. Any APT test is extremely valuable. Schwartz reminded everyone of Bob Lytton's comment – you have to make it complicated before you can simplify it. Schwartz reminded everyone of the R^2 value of the 1993 AASHTO Road Test – less than 0.3. Chuck also rephrased the question, how close can we get? Schwartz's question was not resolved or answered.

Most of the discussion was focused on validation of the individual models versus the final prediction model of what the users need. Little thought that an experiment or factorial could be developed to demonstrate their application and validity.

Question 4 (Slide 4 of 4): Identification of hierarchy of users of the tool or components of the tool? Last item or topic, Computational and material models for parallel processing and large cycles are unclear at this time – When or how do we bring this in when the rigorosity of the materials models are still being worked out.

Little reiterated the individual components and that the hierarchy of users is dependent on the individual components. There was discussion between Tom Scarpas, Richard Kim, and Murthy Guddati on the time limits and the processing of the simulations (computational methods) relative to the users.

Nelson Gibson asked; is there ongoing work being done on the users side on the micro-mechanics side that is suppose to be used by different category of users (academic, designers, etc.)? Abu-Alrub – This will take a long time and does not see these micro-mechanics models being implemented on practical scale. Guddati disagreed with comment – Depends on how you look at this, because you can use in the continuum model or micro-mechanics model to answer different questions and can scale up from micro scale to application scale within a reasonable time frame. Richard Kim – Some micro-mechanics models use a different approach; NCSU approach is to use the lattice model in combination with the JMF and asphalt properties to up scale it to get the distress predictions.

Eyad Masad – Yesterday the ARC passed around a document for different users. Richard Kim is proposing to determine material specifications, others are proposing to give insight to the materials behavior (for example, Yong-Rak Kim, University of Nebraska). David Allen said that Nebraska is doing up scaling as Richard Kim noted, so that if you have accurate physics of the problem and simulations, then they can tell you the life of the pavement. The problem is the constitutive models and improving them. We assume that the physics is correct but it might not be. Finite element analysis is simply a geometry simulation of the problem. The key issue is the constitutive models and how we use them to solve different problems.

Chairman Scarpas – Proposal for the next meeting: we should present and discuss what are we planning to do for the next level, and requested ETG response to looking at the different levels? Scarpas asked if anyone disagreed with that item being the agenda. No one disagreed, so the agenda will be prepared along those lines.

Jon Epps noted that part of the next meeting should include a discussion on the deliverables from this work. Epps noted that the deliverables appear to be all over the board, in order for the ETG

to give direction, they need to understand what the deliverables are, at least from the contractors point of view. Dallas Little agreed.

Eric Weaver – Noted that there were changes to the results from the overview of the year 2 work plan from the ETG. These are on the web site or will be so additional direction can be documented. He also mentioned that the types of tests needed for the model, what types of application the models are intended for, etc. are in a table on the web site for review. He mentioned that the ARC could benefit from comments related to these tables in the year 2 work plan. He requested any comments on those tables – comments are appreciated.

Lindwing Wang – Some of the model parts can be simplified, it would be good or helpful if the ETG could see the ARC opinion on this item. The other item is if the ARC can develop an interface for the model or tool that can be used to create the input for the finite element analysis method. This has to do with the license for software use – the interface would be very helpful. Masad – The most important part or component is the engine. The ARC will try to develop this interface but is concentrating on the engine part right now. The interface is the plug in part. Schwartz acknowledged that creating the final part or program is not an inexpensive effort. It takes a lot of time to create software.

Scarpas thanked the ETG for their attendance at this meeting from himself and Dallas Little.

Jon Epps requested dates for the next meeting as a draft. Katherine Petros mentioned sometime in early September, the first two weeks. Masad reminded everyone that the short course for the advanced model is the third week of September 2009 in College Station, Texas.

Chairman Scarpas adjourned the meeting at 11:50 AM.

SUMMARY OF ACTION ITEMS FROM THIS MEETING OR SUGGESTED TOPICS FOR NEXT MEETING

1. Chairman Scarpas requested that the white paper prepared between the TTI and Delft groups be distributed for comment and closure on this issue prior to this summer or the next ETG meeting.
2. The documents included on the FHWA website will be cross referenced or cross-linked between different websites prior to the next ETG meeting.
3. The project deliverables and/or documents and their expected delivery dates will be identified in a handout prepared prior to the next ETG meeting.
4. Geoff Rowe will send Hussain Bahia the information for standardizing the energy computations.
5. NCAT is preparing to redo the test track next year. Mike Harnsberger agreed with Frank Fee that they will discuss this further with NCAT about sponsoring test section(s) for the validation effort.

6. Chairman Scarpas requested that Dallas Little set the stage for the next ETG meeting relative to the ongoing effort to develop two different models and identify what the differences are and advantages of one model over the other. If applicable, present the validation plans for each model.
7. Chairman Scarpas requested for the next meeting: present and discuss what the ARC is planning to do for the next level. The ETG will respond to the different levels?
8. Eric Weaver requested comments on the tables included on the FHWA website that summarize the changes from the overview of the year 2 work plan.
9. There were many different opinions on what the deliverable should be to define success. This needs to be discussed in greater detail so that everyone agrees or at least clearly understands what the deliverable will look like and how it will be used (see action item #3). This will be presented and discussed at the next ETG meeting.

ATTACHMENT A

FHWA Fundamental Properties and Advanced Models ETG Meeting Agenda

Irvine, California
February 23 & 24, 2009

Monday, February 23, 2009

08:00 – 08:15 Welcome, Introductions, Approval of Minutes ETG Chairs

Model Integration

08:15 – 09:15 Overarching GOAL of ARC Modeling Efforts Dallas Little

- Target Users?
- What are the deliverables?

Discussion ETG

Asphalt constitutive modeling requirements

09:15 – 10:45 Physical and computational aspects Tom Scarpas

10:45 – 11:00 Break

HOW DO THE ELEMENTS OF THE ARC/WRI ADVANCE THIS GOAL?

Moisture Damage

11:00 – 11:30 Year 2 review: ETG recommendations / work Dallas Little
Discussion ETG

11:30 – 12:15 Year 3 plans to support GOAL Eyad Masad/Rashid
Abu Al-Rub

- Materials and tests
- Physical and computational issues
- Incorporation into final product

Discussion ETG

12:15 – 13:15 **Lunch**

Fatigue, Aging and Healing

13:15 – 13:45 Year 2 review: ETG recommendations / work Dallas Little
Discussion ETG

13:45 – 14:45 Year 3 plans to support GOAL Amit Bhasin

- Materials and tests
- Physical and computational issues
- Incorporation into final product

Discussion

ETG

Engineered Materials

14:45 – 15:15 Year 2 review: ETG recommendations / work Robert Lytton
Discussion ETG

15:15 – 15:30 Break

15:30 – 16:15 Year 3 plans to support GOAL Hussain Bahia

- Materials and tests
- Physical and computational issues
- Incorporation into final product

Discussion

ETG

Field Validation/Forensic Studies

16:15 – 16:45 Year 2 review: ETG recommendations / work Mike Harnsberger

Discussion

ETG

16:45 – 17:30 Year 3 plans to support GOAL Mike Harnsberger

- Test section identification and establishment
- Acquisition and sharing of materials and tests

Discussion ETG

17:30 Adjourn

Tuesday, February 24, 2009

Asphalt constitutive modeling requirements - Revisited

08:30 – 09:30 Synthesis of Day 1 - Physical & computational aspects Nelson Gibson
Discussion

Model Integration – The Details

Critical path to GOAL: What needs to happen when?

Tom Scarpas
and Dallas Little

- Oversight and coordination of elements:
 - Sharing of software, test results, materials, etc.
- Underlying assumptions
- Decision points:
 - When?
 - Based on what?
- Integration proof of concept
- Deliverables (software modules, ANN, ...?)
- Intended Users

Discussion

ETG

11:30 – 12:00

Other ETG business

ETG Chairs

12:00

Adjourn

ATTACHMENT B

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