FHWA
Asphalt Fundamental Properties and Advanced Modeling
Expert Task Group
June 19-20, 2008
Chicago, IL

The meeting of the FHWA Asphalt Fundamental Properties and Advanced Modeling (Models) Expert Task Group (ETG) was held on June 19 and 20, 2008 in Chicago, Illinois. 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. Robert James and Jimmy Brumfield of Burns Cooley Dennis, Inc. were present with Mr. James acting as Secretariat and Mr. Brumfield assisting with the meeting.

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

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
William Buttlar, University of Illinois at Urbana-Champaign
Jo Sias Daniel, University of New Hampshire
Gayle King, GHK, Inc.
Julie Kliewer, Arizona DOT
Bob Kluttz, Kraton Polymers
Magdy Y. Mikhail, Texas DOT
Charles Schwartz, University of Maryland - College Park
Bob Statz, Consultant
Linbing Wang, Virginia Polytechnic Institute and State University (Virginia Tech)

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

Jon Epps, Granite Construction
Richard W. May, SEM Materials, L.P.

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

Jongeun Baek, University of Illinois
Herve Di Benedetto, ENTPE
Amit Bhasin, Texas A & M University
Silvia Caro, Texas A & M University
Ghassan Chehab, Penn State University
Murthy Guddati, NC State University
Elie Hajj, University of Nevada
Gerry Huber, Heritage Research
Hussain Khalid, University of Liverpool
Minkyum Kim, University of Illinois
Richard Kim, NC State University
Yong-Rak Kim, Univ. of Neb.-Lincoln
M. Emin Kutay, Turner-Fairbank
Eyal Levenberg, Purdue University
Rong Luo, Texas A & M University
Robert L. Lytton, Texas A & M University
Eyad Masad, Texas A & M University
Daniel Perraton, ETS
Rey Roque, University of Florida
Geoff Rowe, Abatech
Roberto Soares, University of Nevada
Shane Underwood, NC State University
Harold Von Quintus, ARA
Eric Weaver, FHWA
Haifang Wen, University of Wisc.-Madison
Jack Youtcheff, FHWA

OBJECTIVE

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.

DAY 1 (8:00 AM, June 19, 2008)

Welcome and Introductions – Tom Scarpas

Chairman Scarpas called the meeting to order and welcomed all in attendance. This meeting of the Fundamental Properties and Advanced Models ETG was scheduled immediately following the Sixth RILEM International Conference on Cracking in Pavements. Scarpas reported that the RILEM meeting was a success and had over 200 attendees. Self introductions were made around the table. Attendance sheets were passed around for all visitors to log their attendance.

The minutes of the previous meeting held in Tampa, FL were reviewed and approved page by page. Bob Kluttz asked that one change be made on page 12 to the last sentence (Bring morphological connection between spin cast film and hot melt.) of the discussion section that followed his presentation which deals with Peter Sabaaly's work. Tom Scarpas asked that Bob put in words the text he would propose to be in the minutes and send it to Katherine Petros. Although the members approved the minutes as they were presented, with the exception of the one change offered by Bob Kluttz, additional contributions may be submitted to Katherine Petros for addition to the approved minutes.

The morning discussion as indicated on the agenda is entitled, "MEPDG Flexible Models: How Will They Be Enhanced?" NCHRP presenters were invited to give an overview of their work as it pertains to the models ETG.

(1) Rutting: NCHRP 9-30A – Harold Von Quintus

Harold Von Quintus gave a presentation on the NCHRP 9-30A project regarding the calibration of rutting models for HMA structural & mixture design. During this presentation Von Quintus reviewed the project structure, schedule, laboratory testing plan, preliminary results, and preliminary findings. Some of the preliminary findings include: the use of confinement is important for plastic vertical strain & deviator stress transfer functions; repeated load permanent deformation tests (vertical strain and shear strain) significantly reduce bias; and modulus differences alone do not adequately explain difference in rutting; the need to use permanent deformation factors for multiple layers; deep function incorrectly reduces significance of underlying layers with inferior properties; and finally, the shear and vertical strain transfer functions can be used with similar accuracy after calibration. The total measurement error found in the models has a significant component created by the differences in measurement in the LTPP rut depth measurements.

Chuck Schwartz continued the presentation on NCHRP 9-30A modeling efforts. There are two objectives to this portion of the project: (a) a near-term goal of enhancing the current MEPDG models for predicting rutting in the asphalt layers; and (b) a longer-term goal of advancing the

state-of-the art of advanced mechanistic modeling of pavement distresses. A fringe benefit of the advanced modeling effort is better insight on how to create simpler M-E models.

ETG Discussion: From the practical side, do you use a stiff or elastic binder in the top or underlying layer? Is there an easy way to use the triaxial test results for the redistribution of the stresses so that every layer has its own contribution? In the MEPDG right now, each layer has its own dynamic modulus, but permanent deformation properties are treated as global and are the same for all layers and mixtures. The enhancement would be that each layer would have its own dynamic modulus master curve and its own repeated load permanent deformation properties.

Can you use modulus measured by triaxial test to avoid a separate master curve for each layer? Schwartz thinks that the predicted E* master curves from the various empirical models (e.g., Witczak, Hirsch, Ceylan et cl.) are probably a better approach than to estimate from triaxial RLPD tests.

You should be able to capture temperature and loading rate effects, but I'm not sure it can be done from the repeated load permanent deformation tests without the master curve. Most libraries being set up by states for the MEPDG are only including the dynamic modulus information and not the repeated load permanent deformation.

How the does the visco-plastic model account for slower speed traffic at high loads and temperatures? This work has not been completed yet. The model should capture loading rate effects, but yet have enough experience with it to determine its realism. A model is needed to simulate the morning traffic versus afternoon traffic, different speeds and different temperatures. In the current MEPDG, it is possible to tie traffic to time of day, but not speed to time of day. It would be interesting to investigate the effects of doing this; however, most users are probably guessing about tying the traffic to the time of day anyway, as well as the average design speed input in the MEPDG . It would also be interesting to look at creep and recovery testing at different loading frequencies.

With the stress redistribution and the stress reversal as you load and unload the pavement, you can continue to see incremental strains continue to develop cycle after cycle. With visco-plasticity there is a short load pulse and the stress state is outside the flow surface. The flow surface does not have enough time to migrate up to the applied stress state via hardening by the end of that load cycle. Viscoplastic saturation will eventually occur when the flow surface migrates (hardens) to the applied stress state, but analysis results to date have not yet reached this point.

(2) Reflective Cracking: NCHRP 1-41 – Bob Lytton

Bob Lytton continued with a presentation on NCHRP 1-41, Models for Predicting Reflection Cracking for HMA Overlays. The overlay design guide will be a companion to the existing MEPDG. It will use all of the existing inputs for the MEPDG and require a few more inputs for the overlay design. Lytton introduced mechanisms for reflection cracking and the reflection cracking model to be used in the overlay design guide. The model will need to be calibrated to local conditions. The reflection cracking model also required a better calculation of temperature than the existing MEPDG temperature prediction model. Lytton discussed the test plan of the project as well as the field sites that were analyzed with the model.

Rong Luo continued the presentation by discussing the reflection cracking model and a new pavement temperature model. The new pavement temperature model requires the inputs of

hourly solar radiation, hourly air temperature, hourly wind speed, and thermal coefficients of the pavement structures. This model is necessary for more accurate prediction by the reflection cracking model. Luo also discussed the more precise results of the advanced neural network models as opposed to the non-linear regression model.

Bob Lytton continued with a discussion of the calibration process of the reflection cracking model and a review of ongoing work. Calibration coefficients are created for 5 different scenarios involving the different mechanisms of cracking. These must be calibrated to real conditions.

ETG Discussion - We didn't see a lot of types of interlayers that are going to be considered. How would they be modeled and where would the inputs and material properties come from? Lytton – There is a lot more detail than we had time to get into. The options are: asphalt on top of asphalt, asphalt on top of cracked asphalt, asphalt on top of jointed concrete, asphalt on top of a stress absorbing membrane inter layer. We would like to have the manufacturers do this testing for the interlayer materials and come up with the effective modulus E*, cross sectional area, spacing and thickness of ribs. The crack always starts at the bottom of whatever overlay is in place. If a leveling course or reinforcing interlayer is used, the crack starts at the bottom of that layer and moves to the top of the layer until it hits the grid. The crack does not go through the grid, but restarts at the top of the grid.

(3) Top Down Cracking: NCHRP 1-42A – Rey Roque

Rey Roque continued the meeting with a presentation on NCHRP 1-42A (Models for Predicting Top-Down Cracking of Hot-Mix Asphalt Layers). Roque described the top-down cracking mechanisms and the approach that the researchers are using to develop, calibrate and validate the model. There are two phases that occur in the development of a top-down crack that must be considered, the initiation and the propagation phases. Aging, healing, effect of damage zones on load stresses, thermal stresses and the critical condition concept are important to developing an appropriate model. The critical condition approach allows the researchers to identify the situations that need detailed calculations and avoids spending computational energy on the less critical set of conditions.

ETG Discussion - Is block cracking just top down cracking that has aged so much that vehicular loading plays a minor role? Yes, in block cracking, loading becomes much less important.

Roque - Block, thermal and fatigue cracking can be dealt with the same techniques. Environment, loading, embrittlement and change in properties in asphalt mixture and the reduction in healing potential with time are the important factors that cause cracking. Research has shown that we do get significant healing in younger pavements. Permanent damage will occur when the mix can no longer heal or conditions exceed the mixture energy threshold. Roque recommended the direct or indirect creep test for dynamic modulus. Creep stiffness is an indicator of the mixture's healing potential assuming healing is associated with flow. Dissipated creep strain energy (DCSE) is the energy required to induce initial fracture. Does fracture start before or after the peak load? There was some disagreement, but in Roque's work it occurs below peak load.

There are two models being examined, the VECD-FEP++ model predicts the crack initiation and the HMA fracture mechanics model predicts the propagation of the crack. Predictions for field

sections show that the model predicts initiation and crack growth. The models are basically rank-ordered for the sections that were analyzed.

Comment [p1]: Roque please check this statement

In the section tested by the HVS, accelerated aging was promoted by using ultraviolet lights. The accelerated aging is more than is ever seen in Florida, but is perhaps realistic for the Arizona desert.

Cracks can begin at surface or near surface. There are many mechanisms that cause cracking depending on the system of conditions. One slide shows viscosity increasing with aging, with samples taken from three depths: very near surface, middle and bottom. The mixture testing showed aging in all samples, but much more in the top. Even after aging the binder in the lab the fracture energy is much higher than in the field, which indicates that we are not aging in the lab the way things are being aged in the field.

Pros, Cons, Assumptions and Input Requirements of the ARC Proposed Models

(4) Micro-Mechanical Models – Dallas Little

Dallas Little continued the discussion with modeling approaches by the Asphalt Research Consortium (ARC). ARC modeling approaches should be viewed as components of an overall mechanics approach to predict pavement performance. Each model contributes to the ability of the approach to reliably predict damage in asphalt pavements. Some of the models are intended to extract or "filter" material properties from test data or characterize (or even rank order) material behavior (binders, mastic and mixtures) and other models are intended to focus on the prediction of performance at a macro-scale. Little described two types of models, the performance prediction models and the materials characterization models.

Richard Kim continued the discussion with a presentation on lattice models. The main advantage of the lattice models is computational efficiency. Lattice models can be orders of magnitude more efficient than their average micromechanical counterparts and thus more amenable to statistical averaging resulting in material properties along with error bars.
The disadvantage of lattice models is that they give only the average properties and are not ideal for detailed understanding of the actual phenomenon of micro-crack interaction and coalescence. More detailed micromechanical modeling is necessary for this purpose.

Comment [p2]: Kim please confirm the validity of this statement or clarify it further.

ETG Discussion - Could the fine aggregate just be acting as a thickener? Kim – It is possible, this is something that could be tested with different sizes of aggregate. Binder in a thin film may have less mobility. ETG - The origins of this model was to support the binder acceptance specification, is this now to become a specification for a performance model? This is to support the understanding of the continuum damage model and create a link between the micro mechanical model and continuum damage model.

Comment [p3]: Kim to confirm the validity of this statement.

Yong-Rak Kim continued discussion on the Development of a Micromechanics Model, similar to the North Carolina State study, but different in some aspects. The research for this model was performed because there is a need for a novel methodology for predicting the performance of HMA mixtures without conducting (or at least significantly reducing) HMA performance tests which are costly and time-consuming. There is also a need for better understanding of HMA fracture-damage behavior (such as fatigue) which is strongly associated with individual

component properties and interactions among mixture components so that design engineers can select and combine materials in a more appropriate manner.

ETG Discussion – In the slide with a simulation of binder results (Stress vs. Displacement for multiple binders) what are the inputs to cause the differences in the binder? The material properties are characterized from testing or surface energy measurements.

When you look at the slides representative volume elements and you converge, if the material characteristics varied, would the convergence vary? Yes, we need investigate various mixture characteristics such as volume fraction, gradation, orientation of particles and so on then get a common value satisfying all of them, you need to look at several things together..

When you are including so many cohesive elements in the model, the friction will not exist. How do you calibrate for the friction caused by the model? We haven't looked at that yet.

Scarpas: The cohesion constant together with the frictional slope provide a failure criterion normal to the crack direction for tensile loading. If you reverse the load and the crack faces are subjected to compression, what will happen when you reach zero crack width and you continue loading? There is nothing to tell the model to stop deforming when the crack width reaches zero. This is an inherent problem with this type of models.

ARC: The model cannot handle compressive forces yet in a perfect manner. That part of the mesh will overlap. But this interpenetration issue can be handled by implementing constraint conditions such as the Lagrange multiplier or penalty constraints. We are currently working on this.

Scarpas:Also, as you refine the mesh you are adding more flexibility in case of using cohesive zone models.

(5) Continuum Damage Models – Eyad Masad

Eyad Masad continued discussing the continuum modeling approach work done by Texas A&M. Masad discussed challenges first. Some of these challenges include an extensive testing program, the environmental effects on properties must be investigated, methods to measure damage and limited computing power. Guidance has been found on these topics in literature and the literature can provide good foundations for our models.

ETG Discussion – As the mastic stiffness goes up the anisotropy of the material diminishes and the material becomes more isotropic. How do you differentiate in the models from viscoplastic with damage to viscoplastic without damage? Masad - We don't. ETG - A time temperature shift is built in the model, what about aging, is that built in? Yes, in the same place. There are age-shifting coefficients.

Comment [p4]: Masad please verify the validity of this statement

Richard Kim continued the meeting with a presentation on continuum damage mechanics and fracture mechanics. The project that they are working on is trying to close the gap between continuum damage mechanics and fracture mechanics. The project is FHWA DTFH61-08-H-

00005 Project "HMA-PRS Based on VEPCD Models." VEPCD stands for viscoelastoplasic continuum damage.

ETG Discussion – How does the multiaxial relate? Tensile behavior under confining pressure.

Comment [p5]: Voice record is inaudible. Kim, do you recall the question? Your response was that it will be in NCHRP 1-42 as a place holder.

(5) Material Characterization Models – Amit Bhasin

Amit Bhasin continued discussing material characterization models. Materials characterization models are designed to capture the impact of a process or processes that alter the material properties and consequently the engineering response of the material or composite. Examples of these include: rate of crack wetting and/or intrinsic healing of asphalt binders (healing); fatigue characterization of FAM using DMA (fatigue cracking); or material characterization models for binders (rheology of binders in mixtures, master curves).

(6) Coordination of Modeling – Eyad Masad

Eyad Masad continued by discussing how the models work together from parallel projects that have apparent redundancies. The ARC is attempting to characterize materials with parameters that have a physical meaning, not, for example, number of cycles to failure.

ETG Discussion - Is there a distinction between micro crack growth and macro crack growth in these models? I think you can use a crack growth approach, but micro crack reduces stiffness of the material. Micro crack growth may not be related to macro crack growth. Masad – I've seen data that shows this. ETG - Usually the younger materials have a more rapid rate of micro crack growth, but have a high potential for healing. Whereas aged materials that tend to be brittle may not exhibit much micro crack growth at all but have a very low tolerance of macro crack growth. We need to be careful and make the proper interpretations. Little - The propensity of the material to develop micro cracks and the potential for that to reduce the stiffness of the material should be shown by this characterization well. Masad - The continuum damage model will lump the cracks together. It is possible that the micro cracks cause the nonlinearity. We should investigate this. Bhasin – We need to take into account the total capacity as well as the initial state of the material. This approach accounts for cracking from a certain state. ETG – You need to be very clear in the language use to describe cracking. Scarpas – The model starts from the micro cracking phase and develops all the way to where the tensile strength has been exhausted to zero and the fracture energy has been dissipated. A crack is the generation of two surfaces in a material. You start with a micro crack developing and end with a macro crack so you have covered the whole range; the difficulty is in including these models into a continuum model. ETG - How do you get from the micro damage to the macro state, what defines that state? You need to have an energy that is expended in the formation of the crack.

Comment [p6]: This statement is in contradiction with the cohesive crack models of Y-R Kim and those of TU Delft. Can Masad expand on this?

Comment [p7]: Masad probably meant "micro-cracks". Masad to confirm.

Kim – The crux of the problem is pre-localization versus post-localization. Until what point can I use the definition of strain? When you have the first micro-cracks you can use the strain until the localization point (threshold value). At this point we have to switch to something else. We have shown that the viscoelastic continuum damage model can do that. Apply this model and you will see very good predictions. Should we throw this away and do it from the beginning until pre-localization using another model?

(7) Continued Discussion on Materials Characterization of Previous Day

Bob Kluttz - Numerous material characterization models were discussed many in great detail, some where not discussed in much detail at all. What do the models look like that were not discussed? What are the inputs and how fundamental are they? Lytton – Charles Glover is working on the aging models. There is an oxygen diffusion model. It is coupled together with a temperature model. The temperature at a point and the availability of oxygen fuels a reaction rate. There is also a geometric design component of the mixture where he is characterizing the access of oxygen to a particular point in the mix through uniformly spaced holes. Kluttz - Is the oxygen diffusion model binder independent or binder dependent? If it is dependent, what characteristics of the binder contribute to the model? Lytton – It is binder dependent and it is directly tied to the viscosity of the binder. Kluttz - For material characterization like diffusion, what material properties are going into the model and does that really cover it? The model is solely dependent on the binder viscosity, is that correct? Lytton – The diffusivity of air into the mixture and the viscosity of the binder. Kluttz – The diffusivity is a constant for all binders? Lytton – I'm not sure that it is. Kluttz – Then this is an empirical model. Will there be a diffusion rate model, or will this always be a measured property? Lytton/Bhasin – As of now it is a measured property. Little - What will be mechanistically and what is done empirically? This may be a good topic of discussion for a future ETG meeting.

King – The pavement preservation committee is very interested in this subject, but from a different point of view. What can we do to reduce the oxidation? It appears that the fog seal does almost nothing to reduce the oxidation; all we can do is add rejuvenators. The chip seal showed a significant reduction of oxidation. A big question is where the oxygen is coming from. Little – This may also be a good discussion for a later ETG meeting.

(8) FHWA Recommendations Based on ETG Comments - Eric Weaver

Eric Weaver continued the meeting by discussing the response to comments from the ETG regarding the ARC year 2 work plan (Attachment 1). This is the result of several meetings with FHWA personnel and teleconferences with ARC personnel. Quarterly reports are up on the ARC website.

Chairman Scarpas requested a better warning system so the ETG could know that the quarterly report was available. Possibly ensure that all of the ETG members are receiving the newsletter or posting the quarterly report or a link to the report on the ETG website.

Masad – These are administrative reports; do they really need to be public since they are not technical reports as in the past? Scarpas – If it is not public, why is it posted on the ARC website? Could the technical report be posted and not post the administrative information? Yes, if it is not too complicated of a task.

Weaver – A material management plan has been submitted and a database framework has been designed. ETG – Does this effort coordinate with the materials research library at Reno? Weaver - The plan is to, as we collected material for validation sites, store materials there. Materials will be stored for future work as well. Weaver presented an example of what this database would look like. There are three levels of database accessibility through the website, from full access to browsing access.

Bahia continued by discussing a revised experimental plan regarding the modified binders for the project. The modified binders will be provided by the suppliers. We selected the most widely

used additives and have suggested to the suppliers that three levels modification be used: unmodified, low level of modification and high level of modification. We have suggested these grades so that we can get the same grades from all suppliers. The focus of the plan is on the performance of the modified binders, includes MSCR test etc.

Weaver continued discussing Attachment 1 regarding validation sites. Even if states are going to overlay the LTTP sites, they may be good candidates because there is so much of the supporting information available. Schwartz (post meeting): Yes, but there is little/no material available for testing. If one cannot characterize the materials, the performance data will be of little value for validating models. I think that pursuing LTPP sites for model validation will ultimately end up a blind alley.

Weaver also discussed some accelerated pavement testing options. It is now time to get APT planned. States are reluctant to agree to these validation sites because there is some risk involved, but if any states have the same concerns as the ARC is working on, now is the time to get this coordinated. The ARC is to provide criteria, material quantity requirements and recommendations for monitoring after the ARC project. Schwartz (post meeting): I found it most disappointing that there was little/no response from the contract team on what they proposed to do with regard to APT recommendation.

ETG - Are you planning to have ALF instrumented? Weaver – I'm sure we would have some, but we are in the very beginning stages. King made a suggestion to get the ARC tied into the new MnRoad pooled fund study.

Kluttz – With the regard to the five items discussed in the technology development item, is there a summary available of the response? Weaver said it would be made available. King - Is aging document available to the public? Weaver - It will be sent out when the year 2 work plan is complete.

(9) Surface Energy and Modeling White Paper Discussion – Eyad Masad

Masad – In the last meeting there was much discussion about the value of surface energy and how it was used in models. There is now a white paper available discussing this topic, but was asked not to be distributed until they discussed it with the Delft group because many of the comments came from Niki Kringos. The modeling white paper should be complete by the end of July.

(10) Model Integration Discussion

Scarpas gave a summary of yesterday's post meeting discussion regarding the implementation of models and the importance of the expediency of such an effort. Multiple models need to be integrated; There are at least two continuum models and two cracking approaches. These should be integrated into one so we don't reinvent the wheel.

ETG Discussion - King - Does this not start by defining what we want this model to do? Scarpas - My concern is that we spend too much time on separate models. We don't want to over invest in the wrong model. We need a model that is not biased, but general. R. Kim – I agree with Scarpas on the issue of complexity involved in integrating the models. Every step is computationally very difficult. It will take a lot of time to go through each of these steps.

Masad – I think the reason that there are two different approaches is that there are philosophical differences between the models. Scarpas - We don't need to rush these models to verify something, because as we agree we don't have the collective model. Masad – I think the next step is to determine what happens when my model goes from compression to tension to compression. I need to invest my time in questions that I don't know the answer to. I don't see these differences as a waste of time; we can learn from each other. Scarpas – This is where we disagree, you are convinced that in two years you will be able to put the models together. Perhaps you can, but suppose you can't. Lytton – I have a lot of faith in the approach that Masad is following, because it characterizes all the things that we know are important to the performance of pavements including plasticity and fracture. I think we need to start with a continuum approach. There will be a continuing change of material properties as they interact with the environment. We have to concentrate on something that people can use and that means developing these subroutines that can help in identifying the material properties that can be measured, input and described by distributions that will allow us to make predictions of existing pavements. We should aim at what an existing pavement is going to do in service. Al-Qadi – For APT's you can now control environmental effects, but I am unaware of an APT that can do more than 10 miles an hour. The other issue is that most of the time we are doing everything for a stationary load in 2-D, I believe this is the biggest problem in all the work that we are doing. If we model for the speed and try to get the response from APT, we can extrapolate that to 60 or 100 mph, but I don't think we are considering the speed. Scarpas – Although we have environmental controls, we cannot change the diffusion coefficient of the material. Also, the majority of the models are 3-D, but because of computational limitations, we reduce them to 2-D. Hopefully soon, computing power will not be an issue. Weaver – We have some computational resources available for this project, if this is holding people back, we can certainly take advantage. We can use the Transportation Research Advanced Computing (TRAC) clusters. Scarpas – It takes some investment to do this, but it has been a great help in the work we do with Masad in Delft.

Comment [CWS8]: Lytton's comments on this subject as recorded on the audio tape were more extensive than suggested here. Among other things, I believe he was arguing against use of APT for validation.

Kluttz – I have a concern about traffic speed, but it is actually the opposite of Al-Qadi. The Washington beltway is going to become the norm with majority high speeds, and a couple of hours of slow speed. Al-Qadi – As far as I know we don't design for speed at all. Scarpas – We had the discussion in Tempe, AZ we had some present to us on the influence of speed and we got a lukewarm response. We haven't solved this issue, because this issue is related to strain rate. Kluttz - I would counter that intersections are designed differently. Lytton – The Texas pavement system has provisions for highway, city streets and intersection speeds. As the speed slows down, the increase of plastic flow increases and the influence of fracture decreases. This is incorporated in designs in Texas. Kluttz – It is not just speed, but it is also acceleration and deceleration that need to be considered.

Weaver – I have another point of view regarding the model integration. When we began this project, we had this collection of entities that have put a lot of time and effort into their work and decided to get together in this consortium. At the last ETG we said we should reduce parallel tracks to a singular item, but I am questioning the practicality of doing this. It may be beneficial to have 2 or 3 options rather than a unified model. Is it practical to assume we can have a unified model? What if we take a few useful models and try to put them together and run out of time, are we going to end up with a model that is not useful? I don't want to set up false hopes that we will end with a single model.

Little – The ideal approach would be to come together, but R. Kim's model has been established and is successful, Masad's has done the same, there is a possibility that there would be two successful tracks, the question is could those two be put together? It would be wonderful if they could, but if not we may have two viable systems. Klutz – The ultimate desire is the theory of everything, but that is unlikely. The reality is there is a variety of theories and models, there are heavy duty models that can solve complex things, but they may be unwieldy. Simpler models may be used for simpler situations. I think that all of these models moving forward, more than one answer may not be a bad thing. King – It is best to have both and start with the model you think will fit your situation the best, but with this it is very important that all of the objectives of the models are met. Which model gives the deliverable with more efficient calculations? Use their relative benefits when they fit the best. Scarpas – You are asking the designer to start with a bias and that is wrong. The ideal computational tool should guide the user, not vice versa. Many things happen at the same time and that is the challenge. The model should include all of these things. R. Kim – Even to predict fatigue, you must have the compression model so that they can work together. Klutz – If I have a sophisticated tool, I can take one of my options and test it to see generally how my pavement will respond. Then I would take a rapid screening tool to evaluate which samples need to be tested. I need a combination of sophisticated and simple tools. Scarpas - There is a distinction between design tools and analysis tools, we are trying to design a tool that will provide knowledge, a tool to help you make a decision. I think it is not easy to decide on the goodness of a material simply by looking at material property curves, this is accomplished by looking at the pavement response. Pavement response is the result of both, the material and the pavement structural characteristics. The same material, may perform well for one structural configuration and badly for another one.
Scarpas - You don't design a material to test it in the lab you design it to perform in the field. The advantage of starting in the lab and exporting the data to a model will allow you to perform testing that would take a very long time in the lab. Kim – It is not because the model is wrong, it is because the boundary conditions are different. Scarpas- I fully agree. ETG – We can't expect to have a model in three years that will encompass everything that happens in a pavement, it can only approximate some things, and it is an ongoing process. Scarpas - Parallel paths means that at the end of the project we shall end up with two cracking models and two rutting models but, in a pavement, cracking and rutting happen at the same time possibly at different locations.

Masad – (inaudible) I have faith that I have ideas and we have people with good mechanics to work on these models and advance them. I can't promise that I'm going to predict everything in three years. I think we are often rushed to predict. The parallel track is good and bad, it is good because we have good idea, and it would be a bad idea if we did not share data and compare notes. ETG – Could you an R. Kim sit down today and decide whose model is better? Masad – No, we could not. ETG – Since both of you have valid ideas then we really have no choice but to pursue parallel tracks.

Scarpas – As ARC where do you want to go in the next few years?

Daniels – Bringing this back to the ETG, the ETG needs to think beyond the ARC work and look at modeling work being done worldwide. It would be valuable to have the data available to everybody at the end of the project. You will be creating a wealth of data. ETG - The data will be available in the database. Daniels – As the ETG, we need to look at more than just the ARC work.

Bahia – Don't look at models irrespective of input parameters. Sometimes these parameters are very difficult to get.

Scarpas – I agree that we need to look outside the ARC group. But, there are not too many people out there that do this kind of work outside this group. Masad - Did you organize a workshop to discuss models and input parameters? Scarpas- No. Kluttz – What are the necessary inputs especially for the material characterization models, how valid are the assumptions versus actually making the measurement? Would it be better to just make measurements or develop models?

Al-Qadi – Should the ETG meetings be split into research discussion once a year and the other meeting choose a topic and come to some conclusion? It doesn't have to be just with the research group. Scarpas – I was hoping that we would hear the response of the researchers to the suggestions from last meeting whether they agreed or disagreed and why. I understand the shortness of time because of the meeting coinciding with RILEM. But I do hope that this does not become a one way meeting as it seems now. If someone disagrees should there not be the courtesy of a discussion? Weaver – Did this not happen? This is my job as agreement officer's technical representative. We discuss in this meeting, the FHWA makes a request of the ARC and the ARC responds to the FHWA and the FHWA presents their resolution to the ETG. Scarpas – I'm trying to avoid that the ETG makes a suggestion and the result is a one side white paper, we need to have a discussion. It is the specifics we are interested in, not the generalities.

Al-Qadi – What I am suggesting is that in one meeting a year, we discuss the ARC and the other meeting we discuss other things relevant to us. I think it would be more focused. Scarpas –You aren't addressing the issue I am discussing and that is, when do you expect a response to your expert opinion? The scheduling makes this very difficult. Bahia – I am a bit lost here. I think you got a brief response on 6 of the 7 suggestions made at the last meeting from Weaver today. Scarpas – I disagree. We have seen the "Desired Actions". Not the ARC response. Schwartz (post meeting): This is true. And since no one from WRI (the prime contractor) was present at the meeting, there was no way to get an oral update. Scarpas - I can think of several technical issues like moisture damage, which is a very generic topic, the issue of surface energy and the issue of model integration for which we have not seen response from ARC. Masad – Our presentations yesterday were intended as a response to your comments. Scarpas – Yes and No. Little - We prepared a document that summarized the different model approaches and the presentations were modeled after that document. Masad – We responded to each of the comments and Eric reviewed our responses.

King – There has been discussions regarding these comments. We had a conference call regarding a particular issue and I am a lot more comfortable. Scarpas – Apparently there has been some sort of discussions. These are discussions of which I have not been made aware. Have you had any discussions Jerry? Huber – No. R. Kim – Maybe what Tom is trying to say is that a document is not a dialogue. He wants a response from the team in the form of dialogue.

Al-Qadi – Now we are looking for a written response. It should make complete sense if the ETG submits requests in writing. The researchers would probably be more than happy to respond in writing through an email to the group. The ARC has been assuming that a presentation to this meeting is enough of a response. This email conversation can be done and probably more effectively. The researchers in the ARC are feeling overwhelmed, some come over prepared others come not prepared and not wanting to present. Masad – Every comment required time

and writing and meetings. We have responded to everything, but at some point we need to work and not spent so much time on responding. Little – If there is a better way to respond we need to know it. Any lack of apparent response was not for lack of effort. Scarpas – It was hoped that the white papers would bring us together. Hopefully these will be used and not just create paper work. Their goal was to develop a discussion. I strongly believe in the white papers. I hope that these are an opportunity to communicate. I disagree that you can spend too much time responding to peer opinion. It is certainly in one's best interest to listen to what their peers have to say. Masad – One cannot underestimate the value of peer review.

Daniels – I think there is a way that as an ETG that we can do all of this. All of this feedback and dialogue does not need to be a day and a half. I think we can make this more efficient. Scarpas – Apparently, a day and a half was not enough?

Wang - What are we achieving? We are spending a lot of time discussing thing that are not relevant. We need specific objectives to achieve. In this meeting the critical question could have been what do these models achieve and how could they be integrated together. We need to define objectives. There are numerous things we could discuss specifically about the models. Scarpas – Can you look at the first page of the agenda, should we spend time in looking at one topic only? Wang - With the time limits we have, yes, I would prefer one topic discussed in detail. Scarpas – I agree with you.

(11) Meeting Wrap-up Discussions -

King – Regarding pavement preservation and the emulsion task force, specifically the pavement preservation road map, some projects that are getting pushed up by TRB include: *performance specs for emulsions* and *triggers and timing for preservation activities*. Everybody is asking when is the right time, nobody knows when or how. Fogging a brand new pavement will reduce the permeability by 90 percent but the only thing that is effective to avoid oxidation is to completely seal the surface. Would an initial seal over a new pavement help? We have no idea. It would be good to have a model to help us make decisions. We don't know where the oxygen is coming from and how deep the oxygen affects the pavement. Permeability and moisture susceptibility is an important issue. Any ideas that you have would be helpful.

On the performance specification side, we need a low temperature recovery method for emulsions. We also need an aging process that doesn't reheat the material. Basically a whole new class of tests that do not reheat the material and use mainly the DSR are what we are looking for, we would like test procedures for these. We think we can use 10C DSR data to help predict cracking. We are working on aging tests and stability tests. We are considering UV light in the aging. We would like input from you on what needs to be done and if anyone has resources to help would be greatly appreciated. It was not perceived as a need for funding, so we have to find other means of getting the work done. Subcommittees are working on various specific tasks. You are more than welcome to help in any capacity.

Scarpas – Regarding the setting of the next agenda. I prefer to keep the discussions technical. I found it to be superficial taking three hours to discuss generalities. The agenda is set by FHWA, next time we should set the agenda with cooperation from the chairs. I suppose the purpose of the next meeting is to discuss the third year plans. The meetings as we have them now are too overloaded and too general. The next meeting we can focus on the part of the plans that relate to the models. Let's agree that we will limit the topic to scrutinizing models. (The

ETG agreed). We need to engage the mechanics and the chemists, so we want to be specific, but general enough to engage all.

I hope the white papers will become opportunities for all of us to get together. My suggestion for the next meeting of the ETG would be to continue the discussion but I am afraid the discussion will be one way if there is no response. The ARC should also be here to learn from the expertise of the ETG members. The ETG shall continue the discussion irrespective of their response.

Bahia – I hope the idea of the white paper will continue to evolve. I think defining the white paper and people interested. I hope that the next meeting the white papers will be presented. Some people may have more interest in some topics than others; we need to announce the plans. We may need to have discussions between ETG meetings. Scarpas – I would hope that the FHWA could finance the efforts of a white paper, at least the travel. At the moment we have to be inventive to finance travel. We need both phone and physical interaction. Could travel expenses come out of part of the ARC? Masad – What is the interaction with the group? The ETG can make recommendations, but the FHWA makes the decisions, ARC is responsible to the FHWA.

Scarpas - The next meeting will pertain to issues relevant to modeling. From now on the work of the ETG should be dedicated to scrutinizing topics pertaining to models. Those who cannot participate in a particular topic can participate the next time because the topic will be different. Little – Next meeting we shall focus on models. Since we are going to focus on specific areas, do some of the ETG members peel off or do we save the time and effort to come to a meeting that pertains to us. Scarpas – As a voluntary ETG member, if an issue does not pertain to me I won't come. We shall focus on interaction and on substance. We should have a more scientific discussion and not an administrative meeting. Masad – I will do anything I am asked to, but I think focusing on a specific topic is not the purpose of this ETG. It is the purpose of workshops. Dallas – Is this going to be a superficial meeting or will it get into the details? I think some of the frustration is that the superficiality is just not working so maybe it would be better to just deal with the details. Masad – I think we will end up with an ETG that has a rotating membership. We are going to miss 90 percent of the project. Scarpas - The purpose is not to promote the ETG membership. At the end of the day we shall be able to tell the FHWA the plusses and minuses of the models.

Petros – I would hope that the entire ETG would contribute even if you are not an expert. There is a reason that the ETG has some diversity and I hope you would still choose to participate to bring in your varied perspectives. King – I worry that I would not contribute and there are others that are not a part of this ETG that could contribute. Maybe it would be beneficial to break into more specific task groups or have a workshop. That way everybody's not trying to do everything. R. Kim – Small group meetings may be more useful, maybe even break out from the larger ETG meeting. Scarpas – May not be realistic with parallel sessions in a group of fifteen. Bahia – The conversation could be more beneficial if key players could get together before the meeting and tell us (for example) what model is more effective.

Scarpas – I fully support this, the purpose of the white papers is to engage that smaller group and then to present the findings to a larger group.

Weaver – The issues identified at the last meeting and some people weren't there for some and for some there wasn't enough time. I asked the ARC to respond with a white paper, a specific topic may be something that we can bang out in the meeting. I don't foresee having face-to-face meetings of different groups because of expense involved. I but I do think we can review certain aspects of the next years work plan and then address one or two specific topics. Scarpas – Do you mean topics or specifics? Weaver - I am talking about specific technical things and we can talk in between that time to rough out what we are going to talk about. Scarpas - During the time that Eyad and Dallas are in Delft we will come up with an agenda for the next meeting.

Weaver - We need a chalkboard at the next meeting.

The meeting was adjourned at 12:04

Additional comments from Schwartz submitted after the meeting: Many arguments were raised by the ARC team at the ETG meeting on why APT sections cannot be used for model validation: APT emphasizes load rather than environmental influences, the tests are too short to develop sufficient aging (although FL has developed an accelerated aging APT), the time scale is wrong for diffusion processes, vehicle speeds are too slow, etc., etc. These are really arguments about how APT sections are not the same as real in-service sections, which no one would dispute. However, this does not imply that APT sections cannot be valuable tools for intermediate validation of models.

Moreover, the ARC has not proposed any credible alternative field validation plan that can be accomplished by the end of the project. This leaves comparisons with laboratory tests as the primary validation. We have been developing models and validating them against laboratory tests for a very long time—isn't it time to advance the state-of-the-art just a tiny bit?

No one pretends that prediction of APT performance will certify model validity. Neither does prediction of IDT or other laboratory test results. Realistic predictions of laboratory and field APT results are each necessary but not sufficient conditions for model validation. APT results clearly present a more challenging hurdle because they include behavior aspects that cannot be easily simulated in the laboratory—either in calibration or validation tests—such as long test durations, moving wheel loads with rotations and reversals of principal stresses, the potential for multiple distresses (rutting at surface, fatigue cracking at bottom), etc. Arguing that APT scenarios do not match actual field conditions and that therefore we should limit ourselves to laboratory "validation" does not represent the kind of forward-looking, risk-taking approach that I expect from a project of this magnitude.

I believe that there was another line of argument in the discussion that suggested it was premature to attempt to predict performance; the researchers should instead focus on fundamentals and hopefully develop the "perfect" model that can then be subsequently validated by others. Let's be real: We are engineers; we have a problem to solve, and it is not at all clear that we need a "perfect" model in order to solve it. Many second and third order model effects may be important when trying to predict laboratory behavior to high accuracy under extreme conditions, but how important will these be when attempting to predict field performance—particularly when mixed traffic loading, varying environmental conditions, and all manner of other messiness are now part of the scenario? I would argue that we should attempt to predict field performance (or, more realistically, APT performance as an intermediate step) even with

"imperfect" models so that we can assess how serious the imperfections are in the larger scheme of reality and perhaps draw better insights into what features are needed as improvements.

ATTACHMENT 1

May 21, 2008

To: FHWA Asphalt Mix, Binder and Modeling ETGs

From: Eric Weaver & Jack Youtcheff, FHWA Asphalt Research Consortium (ARC) Agreement Officer's Technical Representatives (AOTRs)

Re: FHWA Direction to the ARC Regarding Modifications to the Year 2 Work Plan

Dear ETG participants,

Since the February 2008 meetings in Tampa, we have been coordinating with our FHWA colleagues, the ARC members and some of you to ensure that we heard similar points raised in regard to year 2 work proposed by the ARC. On March 10, we had a meeting at FHWA with the federal staff who attended the ETG meetings to see if they agreed with the primary issues that were under discussion. Following that, we prepared a list of issues, their descriptions and specific recommendations on how they can be addressed by the ARC. This was communicated to the ARC key researchers via teleconferences on April 11 and April 18, in which the attached Part 1 and Part 2 documents were discussed respectively.

Many of these items enumerated in these documents will result in deliverables that necessitate modifications to the proposed year 2 work plans. The ARC is working diligently to produce the work plan changes by the end of May. In some cases, they are producing materials that will further describe work being proposed and these clarifications will be presented during the Asphalt Fundamental Properties and Advanced Modeling ETG in Chicago this June. The appropriate lead ARC researchers have also been participating in the RAP ETG and Pavement Preservation ETG to ensure their research efforts are well communicated and coordinated.

We appreciate your continued support in reviewing this important research program and providing your valuable expertise toward enhancement and overall success. Please take some time to review the material on the following pages to ensure that your input has been adequately captured. If there is anything on which you would like to provide feedback, or if there is anything significant that you feel we missed, please let us know through the ETG chairs or secretaries.

Thank you.

Requested Modifications to the ARC Year 2 Work Plan
Part 1

Eric Weaver & Jack Youtcheff (AOTRs)

March 27, 2008

1. Review and Reporting

In the future we anticipate changes in the review and reporting process. Specific subgroups within the binder and models ETGs have been identified to provide review on specific topics. As progress ensues, the FHWA and ARC should identify specific issues for them to consider and provide feedback. That feedback will be coordinated by the ETG co-chairs and secretary through the AOTRs, who will then consider it in terms of the direction of the agreement with the ARC. The agreed path forward will be communicated to the ETGs by the AOTRs with an explanation of deviations from recommended direction.

The finalized Year 2 Work Plan will become the basis reference document of the remainder of the program. Future work plans will not contain background and other supporting information that can be referenced to the Year 2 Work Plan. Rather, the future work plans will be reduced to the minimum information required to describe the details, purpose and anticipated outcome of the work to be done during the period of performance. This is intended to reduce the amount of material needed for preparation, distribution and review.

Similarly, future quarterly reports will be reduced to the minimum information needed to satisfy the reporting requirements of the agreement; the work done this quarter; significant results; significant problems, issues and potential impact on project progress and anticipated work for the next quarter. More detailed information about the research, such as approaches in test method development, data collection and analysis should continue to be documented for delivery in published research documents for deliverables and milestones.

2. Project Process Management Strategy and Critical Path

Issue: It is difficult to determine what the ultimate goals and products are for each research area, how the work elements and sub-elements lead toward that goal and what the recommended process to achieve the goal in the project time period.

Desired Action: For each research area, produce a Gantt chart that includes each element and sub-element and identifies the time period where effort will be applied and by whom. The chart will indicate milestones and deliverables, as well as elements in other categories to which it they are dependent. Critical decision points should be identified with a reference number to a part of the work plan that describes the factors affecting the decision and implications on the forward progress. The charts shall be provided for two time scales; the period covered by the work plan and the overall project.

3. Materials Selection and Management

Issue: The materials plan included in the draft Year 2 Work Plan is incomplete.

Desired Action: Provide a master table of materials indicating which research element or sub-element to which they will be applied; identify core materials; indicate who will be responsible for their acquisition and where they will be stored. Describe the process for central coordination that includes materials acquisition, quantity, labeling; shipping and tracking. Show the forms or online-equivalent that each member shall follow to maintain consistency. Provide separate sections to describe the management process for test method development materials and validation materials. Propose needed requirements for use of the MRL, including organization, inventory, material dissemination and the criteria necessary for environmental storage conditions.

4. Project Research and Resource References

Issue: References are contained in different areas of the work plan, making it difficult to find a particular reference easily. Some references are not generally available to the public, so a mechanism is needed to obtain the information contained in the reference.

Desired Action: Provide a master table of references, by research element and sub-element, along with the source from where they may be obtained, such as physical addresses, e-mail addressed or hotlinks for download. Include this as a bibliography at the end of the work plan and organize by research area to make it easier to find the section of the work plan to which it refers.

5. Validation Sites and Materials

Issue: Identify core materials for validation that have known performance.

Desired Action: Identify original material availability at the MRL. To verify existence, quantity and condition of materials at the MRL, this will require those in Reno to physically visit the warehouse and inspect the materials. For those sections that contain adequate original materials, work with the co-AOTRs to identify relevant material test data available in the LTPP database to support validation efforts. For sections with no original materials available, consider the applicability of early test results that may be contained in the LTPP database. For those sections and materials identified that meet this criteria, develop an appropriate extracted binder testing plan as recommended under subtask V3b-4. Work closely with the AOTRs to identify these sections, materials and testing plans. Eric Weaver has already begun this process via request to LTPP Customer Service.

6. Coordination with Related Research

Issue: For some research elements and sub-elements, there is a perceived duplication of effort with other ongoing research efforts. It is difficult to determine the similarities and differences between the ARC research and related research being funded elsewhere in terms of scope, objectives and deliverables.

Desired Action: For each research element, provide a table to compare and contrast ARC research with other ongoing research, such as NCHRP, FHWA and Transportation Pooled

Fund. The table should include coordination or collaboration efforts and primary contacts for each project through which the coordination is taking place.

Requested Modifications to the ARC Year 2 Work Plan
Part 2

Eric Weaver & Jack Youtcheff (AOTRs)

April 11, 2008

1. Missing Work Plans
Issue: For some research sub-elements, the year 2 work plan is to develop a work plan early in year 2.
Desired Action: Provide a detailed work plan for research sub-elements M1b-2, M2a-2, F1d-7 and F3a.

2. Engineered Materials
Issue 1: Task E1b-1 "Rutting of Asphalt Binders" binder and mix testing schedule.
Desired Action: Conduct mix and binder tests in parallel to the extent possible to save time.

Issue 3: E2a – Comparison of modification techniques. This appears to be an industry responsibility. Because the of the proprietary nature of the products and the changing technology, the results of the work will likely have limited long-term value to the states and will likely to be subject to scrutiny by the industry.
Desired Action: Work with the AOTR to bring some experts together from the industry and the states to discuss the issues to modify the work plan and come to an agreement. Otherwise, the modifier comparison should not be done and the ARC should propose where these resources should be re-directed.

7. Validation Sites
Issue 1: It is difficult to provide input or collaboration for in-service validation sites when the criteria are unknown.
Desired Action: Provide criteria for potential validation sites; climate; materials; traffic. Propose mechanism for long-term monitoring. Work with the AOTRs to identify potential state contacts who would like to participate and identify potential sites for candidacy.

Issue 2: The timeframe for in-service validation site performance monitoring is limited to the point that results by never be realized and objective will be left unmet.
Desired Action: Propose how validation objectives may be met using other methods, such as APT

Issue 3: APT plans are needed to be in place to ensure enough time to produce and analyze the results
Desired Action: Provide criteria for APT and proposed program plan, which includes Climate; loading conditions; materials; pavement structure.

8. Technology Development

The rankings are in, but they reflect differing methods of prioritization, such as overall importance to the pavements community or maturity of the test method, or both. We need to identify an approach for moving forward.

9. Moisture Damage

Issue: Unknowns related to transient moisture concentrations and non-uniform stress-strain states test conditions in the Moisture Damage research area cause risk in failure to meet stated objectives.
Desired Action: Prepare a written document to address the following concerns
A. How will the quality of moisture damage test data be determined if the tests are conducted on specimens with unknown moisture concentrations? How will the moisture concentration can be determined as a function of time? This has implications for non-linearity in the relationship between material strength and moisture concentration; choosing the appropriate conditioning time with relevance to realistic conditions for in-service pavements.

B. Torsional Tests – How will the uncertainties related to non-uniform stress conditions in the radial direction; moisture diffusion and chemical reaction rates through FAM and substrate be rectified to provide confidence in the validity of the results?
In the latest quarterly report you state that "*the use of G* as a performance related parameter is shown to be insensitive to effects of moisture (…), which raises some concern regarding the practice of using LVE rheology to evaluate moisture effects.*" How does this finding affect your recommendations for continued use of the DSR?

C. Adhesion/Cohesion tests – Given the uncertainties associated with diffusion in the materials under test and substrate, how will you be able to determine the difference in failure mode with one test?

D. Given the uncertainties with moisture concentration and differences in stress states imposed by the DSR and PATTI tests, how will the results be compared?

E. If the difference between thermodynamic and mechanical forces associated with adhesion and cohesion are orders of magnitude, how applicable are surface free energy inputs to the models?

F. During the ETG there was an important distinction made between the terms mastic and FAM. This should be clarified in the work plan as the two terms are often used interchangeably.

6. **Modeling Approaches**

Issue: There are several modeling approaches proposed throughout the study. We understand that different approaches will be pursued to achieve similar objectives. However it is unclear what the criteria are for success or failure of a particular approach.

Desired Action: Tabulate the strengths, assumptions and limitations of each modeling techniques in each research area. The merits and limitations of each modeling approach should be clearly stated in terms of meeting objectives, as well as the criteria for continuing or discontinuing further pursuit.

7. Aging

Issue: There are aging efforts spread across several research elements without complete discussion or their relationships or lack thereof

Desired Action: Provide a section on aging in the plan that includes overall program element associations and goals. Ensure same materials are being used in diverse aging investigations. Consult with appropriate experts in the field and the AOTRs to determine how an investigation of the mechanisms that cause block cracking may be included.