Morning Session 2

(Introduction of Maureen Corcoran)

Ben Carter: Thank you very much. We’re -- we’re now going to move onto a -- a smaller level or a lower level of -- of the vegetation challenge that we have, and we are going to hear about some of the research efforts that both the federal government and -- as well as locals that have -- have embarked on. This is the real beginning of the science. Dr. Maureen Corcoran joins us today from Vicksburg, Mississippi. And, she is very grateful for missing the wrath of Hurricane Isaac.

Dr. Corcoran spoke at our last symposium five years ago. And, she has experienced the eye of the storm and -- and served as Project Lead on the data collection efforts of the Inner Agency Performance Evaluation Team to support and -- the Hurricane Katrina research. Of particular interest today, Dr. Corcoran’s background is -- is in -- Dr. Corcoran’s background in levee vegetation research. She has been a -- a wonderful collaborator with the California Research Team.

She currently serves as the Project Manager with the U.S. Army Corps Engineering Research and Development Center and the lead in the multiple disciplinary Team that conducted an extensive literature review of vegetation on levees. In addition, she is the Associate Technical Director for the Water Resources Infrastructure Program. Let’s give Dr. Corcoran a warm and dry California welcome. There you go.

Maureen Corcoran:

Thank you and it’s a pleasure to be here. And, on behalf of the Army Corps of Engineers, I would like to thank the State of California for organizing this symposium. I know it was a lot of effort and we do appreciate it. We appreciate the opportunity to be able to present our research and to also learn to see what progress has been made on the California team and also on the international level. So, thanks, Peter, and your team for making this happen.

I would first like to recognize some participants from ERDC. We have Dr. Beth Fleming, who is our Director of the Environmental Lab and our Senior Executive Service. She also serves as our civil business area lead. On the vegetation side on the team, we have Dr. Chris Kees, who will -- you’ll hear later.

Bryant Robbins, who is replacing Johannes Wibowo. Johannes couldn’t make it. He had a -- Bryant was supposed to give a presentation at the Scour and Erosion Conference in France. Johannes was born in Indonesia and has changed his name twice and he got a visa approved and Bryant did
not, as I did not either. Also, Dr. Fred Tracy will talk to you about seepage. Dr. Joe Dunbar is on his way. Hopefully, he will be able to make it, given the conditions of the South.

Also, you all have probably figured out that I am from Mississippi, which is now known by the Weather Channel as the land mass between New Orleans and Mobile. So, the good news is that I speak very slowly so you’ll be able to follow whatever I say. The bad news is, I have a lot of information to cover in a short time. So, it will be a very fast overview and we’ll rely on the vegetation team later on in the presentations to fill in the gaps that I leave.

A little bit of background. It’s hard to believe I was telling Peter that I was here five years ago presenting on a literature review for vegetation. Little did I know where that would lead me today. So, we’ve been together five years. Happy anniversary, Peter. We worked very closely with the State of California. We’ve -- appreciate their input and it’s worked both ways and I think it’s been a very productive partnership.

To start off, we’ve heard about the -- the Vegetation Review. It didn’t take us long to find out that there was no much research that supported that issue. We actually increased our literature review and now we have a multidisciplinary, so to speak, literature review that acts as the foundation for our research. After this, we found out that the -- the science did not exist, so to speak, and so, our headquarters tasked ERDC with studying the vegetation issue.

Now, this was a very complex issue, so, we narrowed down and referred to this as our initial research to studying certain processes that are involved in seepage and slope stability, and we’ll get into those a little bit later. In 2011, we had completed our research and produced technical documents that are actually in four volumes and one appendices that are on the site, the email -- the Website that’s listed here. You’ll actually see this several times because I believe there was an error that was reported this week in the Sacramento Bee that this was not published, where, indeed, it has been available for the public for quite some time now.

Some of the data gaps that we found in the research is that sole mechanics are usually assumed when we’re looking at this -- this issue. Also, that the tensile strength of roots for different tree species was not well documented, as the root system, itself. Previous slope stability models did not account for different aspects of the root system. And, that being the morphology, the topology. Now, sometimes you can get on the Internet, you can type in, you know, “tree root species,” and you can get a database. But, we found that that varies, even among the same species. Different soil types affect this.

We also found that most of the models that deal with vegetation are based on vegetation -- vegetated banks, and not on levees, per se. So, that was another challenge. One thing that we definitely found is that you’re looking at so many different aspects that influence your levee stability. And, we found that there weren’t a lot of -- or any document that really took a lot of this into consideration. Basically, our research approach was divided into four separate tasks that interconnected.

The first one, as we mentioned, was to conduct this literature review. The second was to select our study sites: Where are we going to do our research? We relied very heavily on levee
stakeholders, agencies -- local agencies within the State, and also our districts and divisions, as well. This had to do with what information was already available in geotechnical reports, access to the site, which was a lot more difficult than you would think, or than I thought, I have to say. I was pretty naive going into this.

So, when I went into one of our study sites in Florida, this is a nationwide study, I had to point out. We went to Florida and I did a recon down there before the team went out and we had to discount one of the levees because of the alligators may eat the team members and -- I just kind of did not want that. So, we had to -- to consider quite a -- quite a bit of those that we -- aspects going into the field.

So, the third task was field data collection. As I mentioned, we relied on existing geotechnical reports. We also gathered quite a bit of field data, and I’ll go into that a little bit more detail later on. The fourth task was numerical model simulation for processes that were involved in slope stability and seepage, specifically. And, there are some pictures that you see here on the geophysical field methods that we won’t talk about today. And, I’ll have to point out that anything that we don’t cover today, get us to the site, any of the team members, and we’ll be happy to provide more details, or you can refer to the report.

I’ve been accused of being obsessed with the projects I work on, so there’s nothing that I like to talk about than our research. The root pull-out test was also a part of our field data collection. You’ll hear Bryant Robin speak about that later. Numerical model simulation -- we’ll have Dr. Chris Kees talking about the -- the 3D deformation analysis and Dr. Fred Tracy talking about the seepage analysis.

Approach -- I won’t go into that in more detail. I just covered that. But, I would like to point out - national wide study. So, we divided this into what we call “site characterization inside assessments.” And, that’s just really to divide the processes, the techniques, the methods that we use for each site. The site characterization included models. They included the seepage and slope stability models. The site assessments did not include the modeling aspects, but did include some field data collection. You notice, too, are close by to me are Vicksburg, Mississippi and Lake Providence, Louisiana. We use those a lot to test some of our methods before deployed out to other sites.

Some examples of the woody vegetation that we saw on these sites -- the first one you see of Danville, Pennsylvania. You could see the trees along the levees. Well, close to that, which is difficult to see, are some tree stumps that were left behind after they were removed. Those were silver maples that were already removed before we started our field study. Sacramento, of course, everybody here’s familiar with it.

Albuquerque, New Mexico -- the majority of the trees, in fact, probably 99% of the trees, are cottonwoods, much smaller than we’re used to see elsewhere, but cottonwoods, nonetheless. It gives you an example of how differences in species are across the nation. Now, in Albuquerque, that was another eye opener because we stood on -- on the levee, which I thought was a gravel road and it was pointed out it was a levee. Keep in mind, we’re used to dealing with the Mississippi River levee, so we were able to see quite a bit of different variations and that was greatly appreciated.
New Orleans, Louisiana, the trees that you see here, mostly hackberries, those were removed. We were able to do geophysical surveys and be there when they removed the trees to record certain parameters that we were interested in. I’d also like to take this opportunity to point out that, even though you saw these areas listed that we studied, we have had several of our districts called: Walla Walla District, and also their levee stakeholders called and they said, “Well, hey. Why didn’t you study us? You know, we have important places here.”

And, we definitely did not want to exclude everybody. So, we have sent teams. In fact, I was in Walla Walla District, myself, last year to look at these different sites. And, that has also helped us form our research. To get out in the field and what is there and the direction of our future research. So, we relied heavily on our input from -- from you all, really. So, that’s helped immensely.

I’ll get a little bit more into the field data collection. The tool selection, we’ve been asked, “How in the world did you select the models that you used or the tools that you went in the field with?” Like, our root pull-out test. Well, we have a lot of experience, obviously, in dealing with slope stability and seepage models, and in field data collection.

But, obviously, this is a topic that didn’t have a lot of work done so -- so, we looked to other people that had experience, such as the USDA and Oxford, Mississippi. I believe Andrew Simon is going to speak tomorrow on this. So, we did collaborate and get input from other organizations on the selection.

Some of the things we did under the field data collection: We recorded, obviously, the tree properties and identification. The root architecture we did in several ways. Not only we had our geophysics, we had in C2 root mapping, and that included LIDAR scans. Also included excavating different “cells,” we called them, to use a polhemus hand-held digitizer. One thing that were trying to improve on is -- is to develop noninvasive techniques and tools.

One thing that I heard, and I -- I was so glad to hear this this morning was that every speaker, I believe, stressed development of tools that we can use to be able to assess the effects of vegetation. And, I believe -- in fact, I know, that our research has accomplished that. Well, one thing that we looked at early on -- if we’re studying trees, we wanted to develop methods that didn’t include -- that weren’t invasive because, it seemed kind of counterintuitive -- excuse me -- if we’re studying the effects of trees on levees, and we remove them, then, really, what’s the point?

We also looked at -- it’s very hard having allergies when you’re allergic to carpet -- to get up and talk to people -- when there’s carpet in a room. So, bear with me. We also looked at the root reinforcements for slope stability through our root pull-out apparatus. That we actually coordinated this with Dr. John Greenwood in University of Nottingham Trent, and we adapted his tool, which you’ll hear about later.

So on properties, we relied on existing geotechnical reports. Also, an important field study that we conducted was that we looked at NC2 hydraulic conductivity. How exactly is that tree affecting the permeability of the soil? So, we looked at it around the tree, which, if you’ve ever tried
to put a soil probe around a tree, very difficult. That’s why we had some strong young men to help us with this. And, we compared that to a control site.

On the tree properties and identification, like I said, we did record what we could in the field. We relied on some previous publications. We did have some success with our geophysical techniques. As you can see in this photo, you can actually see the root ball. Still, what we need to work on is to calibrate this even better, because it was difficult to know what we were really looking at. Was it really this root ball where the roots? What was the diameter that could be detected using geophysical methods?

So, these were a lot of questions that we had. We used this information that defined our root system for our models. A little bit on how we calibrate our geophysical model. Like I talked about earlier, we’re trying to really improve our noninvasive tools. As you could see here on “A,” that’s the exaction of the cell that I mentioned. The -- the “B” is actual GPR with a model and “C.”

We correlated that and calibrated the geophysics using that to produce what you see in “F,” which was the model of the roots. We also used LIDAR scans. The only field site that we were able to do at this time was in Vicksburg, Mississippi. But we were successful in doing that. It provided a lot of information. But as you could see, that’s an invasive type of technique. On the field data, the root pull-out, I’ll let Bryant offer more detail on that. We did use that information in our slope stability model.

Now, why in the world are models necessary? We heard this early on that we can manipulate a model say anything we want it to say, and that was very true. Because of that, we’ve been very transparent with what we have put into these models. We relied on California to provide their geotechnical parameters on what we used in these models. We have received input, quite a bit of input from Dr. Les Harder. We are addressing that now and we appreciate that -- even though I may not act like I do all the time, Les.

So, to me, a model is a model. It depends on the variable of which are put into it. So, what to address the variables, we had to look to these models. Some of the primary tools that we used: GMS, C2D, UTEXAS4, and a 3D code that Chris Kees will mention earlier that was developed -- or, I should say, further develop for this project. Some of the roots -- type models that we used were, we looked at three different models in the seepage process, changes in hydraulic conductivity, defect in a levee blanket, and macropore heterogeneity.

A little bit more on how we did this. We took the rectangle block, more or less, that was identified through geophysics surveys. We used this to vary the hydraulic conductivity by different orders of magnitude, both increasing and decreasing. This is based on the premise of the roots influencing the hydraulic -- the permeability of the soil.

I’m going to run through this, like I said, a little quicker. I just got the 10-minute notice. A little bit on the macro pores. Okay. So, we had that rectangle block that was 100 hydraulic conductivity when compared to the surrounding soils. But, ideally, as we all know, a tree is not
going to be that uniform and it’s not going to have one block of -- of particular hydraulic conductivity.

So, what we did is that we rammed -- randomized it -- I think I just invented that word -- but, and we assigned different hydraulic conductivities for each triangular element that you see here. For the slope stability model, you’ll see of the inputs that we used. The phreatic zone in the port pressures -- we actually derived that from output from the seepage models. The deformation analysis -- Chris will get into that in more detail.

So, what did we get out of all of this? We have produced a report and we have developed an initial approach and tested this for looking at trees on levees -- the effect of woody vegetation on levees. We did modify the root pull-out device that we were able to pull more -- or, larger roots than have been pulled in previous field exercises. And, we also have developed the three dimensional models that -- that are very useful and -- in analyzing this.

So, that leads us to the research question. So, you say, “Maureen, you stood up here and you talk and you’re not making any sense and we’re bored. Get to the bottom line.” Okay, so here it is. Now, this is kind of -- I’m giving you the questions, and also, I’ll answer them before you get the opportunity to hear the research. So, you’ll have to bear with me and we’ll be happy to address these again after you’ve heard the research on the last day. What techniques are useful in identifying the spatial extent of root systems? Our field method’s successful in identifying these soil properties.

What are the parameters identified in numerical models that may be sensitive to the presence of a root system? And, what bearable are the most critical to the structural performance of the levee? And, do the tree positions even have anything to do with it? Now, you’ll see on the seepage model, that we actually moved the -- the placement of the tree. We did test those in the field, obviously. We could not be that lucky to find those trees to provide our research on. So, we moved those within the model.

And, so, the underlying question: Does woody vegetation affect the levee structure? First of all, we did find that the electrical resistivity imaging was the most successful when you want to determine the size and extent of the tree root system -- the “cohesive part,” is what we’re calling it, itself. Not so much, when you wanted to look at the individual roots. We found that our 3D ground-penetrating radar was most effective when locating individual roots. There again, shallow. Very difficult to look at anything deeper.

Are field methods successful in identifying these soil properties? We did have some luck, or some success with the hydraulic conductivity measurements. We compared those with what we used in the model. They did not always coincide with what we used in the model. There was a large range that we found even among one tree. So, that was very difficult to come to one conclusion on that -- on one input parameter.

On the parameters that are identified, these are some of them: major impact of the tree once it’s loading. That’s caused by the -- the weight. Nothing like getting an ice cube, there. That root strength was not a critical parameter when we’re dealing with the deep-seating slides. Hydraulic conductivity had little or no impact on seepage paths or flow or gradient.
What is most critical? These are the highlights: Please keep in mind that these conclusions are based on really specific sites. Those trees located on a slope above the phreatic zone have limited effect of seepage. Those beyond the levee toe, or at the dewatered drainage ditch, as we talked -- as we studied in Albuquerque, had any appreciable difference in the value of the exit gradient.

Trees in the upper part of the slope decreased the factor of safety because they added weight. Trees near the toe increased the factor of safety because of the reinforcing effects of the roots. We did find at -- through this focused study, that that reinforcing effect was limited to around the root mass.

Trees at midslope did seem to have a lesser effect on the factor of safety because they act as a load. Factor of safety decreased when wind load was considered. Keep this in mind, though: We do make that statement. The model did not accurately represent the wind load. That is something that -- that we worked with and that we’re still working with. The factor of safety decreased, like I said, when it was considered. The strengthening effect of the roots to deep-seated failure modes is insignificant because for the fact they are deep.

Does it affect -- does woody vegetation affect their levee structure? Very complex issue, as we all have already heard this morning. We cannot really provide definite answers, which is why we’re looking to develop tools and methods that better assess these effects. It is a case-by-case basis. The reductions in the factor of safety, and even then, creates -- reflects very specific conditions. If the flow field and pressure conditions are within the bounds of safety without woody vegetation, it will be equally safe if living -- living woody vegetation is present.

Factors, though, such as past performance of the levee, definitely need to be considered. The impact of trees on levees should be analyzed, as I said, on a case-by-case basis. This is just a summary slide to leave you with. I wanted to say, on the related activities, we will discuss, I believe, on Thursday, our path forward for FY13. Again, as I said, you would see that Website several times. Also, the literature review is located on this Website, as well.

I’ll leave you with a photo which is quite different than what we have this year. This was last year during record flood, right across the river. I live on a 300’ bluff. This is Louisiana. I won’t make any Louisiana, Mississippi jokes. But, this is -- as you can see, right off the Mississippi mainline levee. So, on that, I don’t know if I have time for questions. Ben?

Questions:

**Ben Carter:** You do, yes. We have time for a couple questions. And, just wanted to make an announcement. The presentations that you’re seeing today that are up on the -- on the screens, will be available on the -- the symposium Website, so you’ll be able to download those and review them at your leisure. Dr. Corcoran has covered a lot of ground very, very quickly. I’m sure there are some questions out there. Please -- let’s open it up. Yes, right here.

**Steve Greco:** Steve Greco, UC Davis. It seems like your conclusions point to a case-by-case basis. And, I’m wondering why the Army Corps policy is a one-size fits all.
Maureen Corcoran: Oh. That’s a good question. But, I will say that we are the researchers. We are the policy folks. I would also like to say that we are working with Headquarters to try to get our information -- present our information, in a language that can be easily understood by the policymakers, and we’re working toward that. So, I -- I know that doesn’t give you the answer you’re probably looking for, but as a research point of view, that’s what I can provide. Okay?

Ben Carter: Next question. I see none.

Maureen Corcoran: That’s amazing.

Ben Carter: I guess we are -

Maureen Corcoran: Oh, there’s Jonathan.

Ben Carter: I’m sorry. Sir.

Female Voice: Mike over here.

Jonathan Simm: Jonathan Simm from the United Kingdom. Maureen, to me, the conclusion that stood out most from what you said that was the -- the -- the significance of the tree roots on the lower slope, has been significant as to increase stability in those cases that you tested. And, you know, given the preceding session, that sounded quite interesting. And, I wondered whether you thought, based on the case studies that you’d examined, whether you thought that that might have more general scientific applicability.

Maureen Corcoran: There’s no easy answer to that question, Jonathan, but I -- I think you knew that when you asked that, thanks. But, one thing is, I need to point out here, and you gave me the opportunity to, that I forgot is that, we did not study clay levees. We didn’t really look at different soil types. We went where we could, more or less. That’s something that we need to look at.

So, we -- it’s still difficult to make a general statement. But, yes, you know, tree -- but, what we found on these levees with the soil conditions that we had, that the reinforcing effect was around the root mass. And, we didn’t find that it influenced -- if you had seepage, yes. But, really, we found that the progression, say, of internal erosion relied on the foundation, itself; not an initiator as a tree. The tree as an initiator. Okay?

Ben Carter:

Very good. Ladies and gentlemen, we’re going to have to move on. If you have additional questions, please jot them down on your -- your comment cards. Dr. Corcoran, thank you very much for -- for coming. Thank you, also, for your past collaboration and efforts on advancing our scientific knowledge and we look forward to collaborating much more with you in the future.
Moving on, ladies and gentlemen, we’re going to talk a little bit more about roots. Dr. Alison Berry comes to us from just down the road in Davis. She has been a participating research with the California Levee Vegetation Research Program. In addition to her topic today, her research interests include impacts of transportation infrastructure on plan communities, and biological nitrogen fixation.

And, Dr. Berry, I’d like to talk to you about that. I have some applications up in Colusa County area, with respect to nitrogen fixation. Dr. Berry and her colleague, Shih-Ming Chung, are here to inform us about tree root patterns in levees. With that -- good morning. Join me in welcoming Dr. Berry and her colleague.

**Alison Berry:**

Thank you. I got it right here, I think.

**Ben Carter:** Right up there, I think.

**Alison Berry:** Right next. Okay. Yeah. Okay. Well, good morning. I’m very happy to be here. Thank you, Ben for that very nice introduction. And, I’m joined by Shih-Ming Chung. Shih-Ming is a PhD student at -- at UC Davis and we’re going to do sort of a team presentation, maybe a tag team presentation. I’m going to just present some background on the project, and Shih-Ming, who has just been doing some fantastic work, will present some of the analytical -- the methodological and analytical information.

So, the topic of our study is on tree root architecture, as Dr. Corcoran has -- has been describing and her group has been working on, as well. And, we’re -- we’re specifically focused on the tree root architecture and the patterns of architecture, especially in relation to levees. And, potential geotechnical roles that tree root systems might play. We have some fantastic collaborators on the project. Gerald Baudin and Sandra Bond from USGS. Akira Keightly from UC Davis. John Lichter and Vick Claussen. They just contributed tremendously to the -- the overall project.

As we have heard of -- repeatedly during this morning’s discussion of policy issues, we -- we know that vegetated levees in California and elsewhere in the country and in the world provide critical flood protection. This is a -- a Google Earth view of the pocket levee in the Sacramento River. This is the -- the district that’s to the south of Sacramento that Congresswoman Matsui was discussing this morning as being highly urbanized. And, the levee there on the edge, you can see very nicely, on the river edge.

Across the river is -- is more agricultural land. There, too, is a highly vegetated levee with lots of trees along it. So, on the one hand, the safety -- you know, the concern and the protection that levees provide for -- is critical for safety and -- and especially in our highly urbanizing environments. Yet, as we have also heard, very poignantly discussed, riparian forests provide critical habitat and ecosystem serves this. In many cases, it is the very woody vegetation, itself, that provides
the strongest services, both to the aquatic populations and to riparian forests, other trophic levels and habitats and -- and communities.

So, how should levees be managed? This is really what’s drawing us all together here today. And, in this symposium, specifically, we’re focusing on what can science contribute to the discussion -- to help inform the discussion. And, as Dr. Corcoran has already mentioned, the central scientific question is: What is the impact of trees and tree roots on levee safety factors? Particularly, the key issues of slope stabilization and seepage, and these will be addressed by speakers later in their presentations.

During the planning, the California Levee Vegetation Research team tried to identify knowledge gaps in the science of levees back in -- starting in 2007, really, after following the first levee symposium here. And, one of the major gaps that was identified is: How do tree roots actually grow in levees? And, so, out of that identification, this project was created to focus on what are the architectural parameters of tree roots in the levees of California. So, our project objectives were twofold. First of all, to excavate and digitally map tree root systems in levees. And, secondly, from that information, to create 3D models of the tree root architecture that could help determine or help to inform modeling of potential risks and benefits of tree roots in levees.

So, what I’m going to do just in the beginning few minutes, and leave most of this to Shih-Ming, is to talk about some -- some of what we know. So, briefly on touch the key properties of tree root systems just in general. And, then, talk a little bit about some limits of the methodology and how that -- how our methodology evolved.

So, first of all, for those of us who -- whose memories of biology of trees might be a little dim or nonexistent, I thought I would just give you a few slides on what are the basic components of tree root architecture. First of all, where do they grow? It’s surprising, but tree roots tend to grow in the surface one to 3.5 or four -- one to four feet. So, because that provides the best conditions for growth. So, this is a typical -- what we might call, “structural root system,” of a tree root system. And, typically, about at least 80% of the total woody root system, biomass is in this surface zone -- one to four feet, or one meter deep.

So, that’s where they grow. How do they grow, or what is -- what are woody tree root systems composed of? Well, first of all, as you can see from this cartoon, contrary to our preconceptions, the tree root system is not a mirror of the aboveground part of the tree. Instead, tree roots tend to grow more horizontally than they grow vertically. So, that, you can again, in this upper zone of growth, it’s really where the major part of the woody root system and the -- the feeder roots are -- are located.

Secondly, you can compose tree root systems out of three or four major elements. And, then, those vary according to your soil conditions, your climate, and so forth. So, the four basic parts of a root system would be the structural roots -- those are in red or brown. Those are really what support the aboveground part of the tree. And, horizontal roots -- those are the -- in green. Those extend out radially and explore the -- the soils [iam] of the -- for water uptake and so forth. And, then, sinker roots -- there are vertical roots that -- that sink down into the soil subsurface to some extent.
What we have found in the levee system here in California, surprisingly, was that we also have tap roots. And, these -- Shih-Ming is going to talk about those in more detail. But those are very soil specific. They’re not in every soil. Certainly, we have here, highly sandy levees and -- and, so the soil texture is such that they’re -- that the biomechanics and probably the fact that the water table -- the location of the water table -- so, some combination of soil texture and water table determines the -- the fact that we have these tap roots. But, they can certainly modify pictures of tree stabilization.

So, that’s what, where, how. So, what are the key factors -- the key elements of -- of an environment? So, the actually architectural pattern that trees achieve, that root system achieves, will depend on the growth conditions. Soil moisture is a key factor. Aeration -- trees can’t grow without oxygen. And, mechanical impedance is a huge factor, too. So, if the soil is compacted beyond a certain threshold, tree roots can really grow there. So, these are the three -- three major determinants of what then becomes the tree architecture.

And, soil conditions, as I said, are usually best in the upper part of the soil profile. So, we started this project back in 2007 even, as a -- in relation to the levee conference then. I think it was Steve Cheney who emailed me and said, “Hey. Peter Buck and I would like to ask you some questions about tree roots and levees. Could you come and look at some levees in Sacramento with us?”

So, I said, “Well, sure, you know.” And, so, we went to the Garden Highway, which you may know is along the Natomas Levee. So, I got out. There were some restaurants there, some beautiful trees and greenery. And, so -- so, I said, “Okay. I’m ready to go. Where is the levee?” So, of course, the Garden Highway is the levee. So, this was my first introduction to -- to trees on levees. But from there, we went on and -- and organized a first effort on the Mayhew Levee in the American River to -- to do a sort of -- just a basic, what we call, “trench profile mapping.”

So, just do a backhoe trench, map the roots that you see in the profile. This is the method that Doug Shields and Don Gray used in their pioneering study of tree roots in levees in California. But, what we found was, and what you do then, of course, you have acetate sheets, you mark the roots, and -- and, then you can create this kind of a graph, where you can show where the roots are located. In this case, you can see there was not roots in this one zone, and that correlated very strongly with the high volt density of -- of that very compacted layer of the levee -- of the Mayhew Levee.

So, this method that we found had great limitations, as you can imagine. Tree root systems are very large and extensive. They extend out radially in three dimensions, not just in a single trench, in one direction. And, of course, as Dr. Corcoran has alluded to, one of the key problems is, where are the tree roots in the soil? We can’t see -- they’re in the soil. So, do -- you know, what kind of methods could we evolve to -- to overcome some of these difficulties?

So, one way, as you’ll hear in much more detail -- this is a picture of Shih-Ming out there in the field using compressed air in air spade excavation. So, you can see we’ve -- we’ve cut off the aboveground part for safety reasons, but excavating with strong compressed air leaves -- leaves the root system largely undisturbed. It’s not an -- an uninvasive technique, but we did find that all the
trees that we excavated -- when you cover them up with soil, they regrow again, sort of like a coppice -- coppice tree.

So, Step 1 -- Step 2, then, do some imaging of the tree root system. And, in order to -- to really take into account the 3D qualities of the root system, we use the laser imaging ground-based T-lidar. Again, this is collaboration with their expert here, Gerald [Bauda]. So, what that allows us to do is collect data in three dimensions and -- and then, we can go on with that. Digitized data enables very precise reconstruction, both of the aboveground and the slope surface and the belowground. And, then, these -- these data, because they’re digital, can be analyzed quantitatively and then 3D models can be developed showing the key parameters.

So, this method and its applications will go beyond just the measurement of these particular trees, because you can quantify aboveground canopy. You can use them for many different potential applications. I’m sure Gerald will show you many of these possibilities. The other aspect that I think Shih-Ming is going to talk about is, the relationship between aboveground measurements and what we can learn about belowground. So, some of the models allow you take below -- aboveground parameters and infer or extrapolate to what may be belowground architecture.

So, just to summarize my part and let Shih-Ming go on, as you will see when he presents and when other speakers today and in this conference presents, architectural patterns of trees growing in sandy levees in California have distinctive, quantifiable properties. These modeling methods that we’ve developed, that Shih-Ming in particular has developed and will present, can be widely applied, not just to California levees, but to any -- any of the systems you may be working with.

And, I would encourage -- I’ve been talking with at least one person and other, as well, to consider applying these methods, now that they’ve been worked out, in your own setting and -- and being able to carry out some comparative work. Be happy to talk with anybody about that. So, but, however, the -- what we found is particular for our levee systems in the Central Valley of California.

Specific configurations of tree root systems will vary much according to soil, climate, and levee properties. And, I think this will be the gist of Caroline Zanetti’s talk, or at least one of the major points that she’s able to -- to present to us. So it will be very interesting to hear.

So, as just in sort of pulling it together, this symposium is going to bring together many approaches and new sources of information to understand the behavior of tree root systems and levees. And -- and, we’ll hear this throughout the next three days. We are all contributing to a much-needed scientific knowledge base about the biomechanical and geotechnical properties of trees on levees.

We come in with insights from different angles and it’s much like -- as I can think about it -- the story of the blind man and the elephant. We all have a different piece of the elephant and we’re hoping that, through time, as we’re working in a coordinated fashion, we can reassemble this -- this beautiful beast. So, with that, I’ll -- I’ll let Shih-Ming take over.
Shih-Ming Chung:

Thank you, Alison. Okay, thanks, Alison. Good morning. Now, I’m going to talk about the method and the -- the model and the applications of our study. And, to help to -- to open the -- breadbox of the tree root system and to pull the elephant out to see what is it. Okay.

To open the breadbox, we should to get the break box first in the field. So, we have to develop a new field method for acquiring root system data. Then, we should bring the breadbox into a lab, then we process the data to open it and to see if there is any elephant in it. Then, we analyze our root system data along the levee. And, so we build quantitative models for root system. And, use these quantitative models and apply it to see some related studies about the geotechnical or other later studies.

First, we developed a systematic approach to acquire and to categorize in this root system data. We can see the root system complexity and the special attributes. And, we use critical variables of tree root architecture to determine the root system [wrench] which is the root system extent. And, the device resolution, which is the minimal unit of a root system. How small we want to detect, and how big we want to -- how we want to acquire it.

And, so, it’s included aboveground part, slope and the belowground compartments. Because we want to see aboveground slope, the environment, and the -- and the -- and, it’s relationship with the belowground compartment. And, we classify the data as a special point in 1D dataset. Linear connections in 2D dataset. And, the surface patterns in 3D dataset. Once we collect these 1D, 2D, 3D datasets, use them to create resulting thematic group of special – for specific, special compositions.

And, for acquiring the root system data in the field, we developed a new method. It’s called PEAL System. To acquire 3D and in situ systematical and hierarchical data, it comprised two parts, like just Dr. Berry said. The first part is numeric excavation. And, the second part is the T-Lidar scanning. We excavate at 15 Valley oak trees. Five cottonwoods, and 20 trees, in total. Most trees are on the waterside levee -- waterside levee slope. We also have two control trees on flat.

The first part of the PEAL System is the numeric excavation. We use air spray -- air knife with high volume compressed air to blur the dead out, to get the in situ root system data. First, we do the site survey and the clean up the surface. Then, we use the air knife to [blow] it out and -- and then we remove a huge volume of soil. And, finally, we get the in situ exposed through the system. Then, the elephant comes. Okay. The exposed new system is relatively low disturbed and the root still stay where they were.

The second part of the PEAL System need the ground-based T-lidar scanning. The scanning have five -- five steps. The first step is we scan -- or clean up the slope surface again. And, we scan the slope surface before excavation. Then we scan the aboveground part of the tree. For the safety issue, we cut the aboveground -- aboveground part out. And, then we excavate the tree root system. Then, we scan the exposed tree root system in many perspective. And, then we bring -- all the data back to the lab. Then we shoot the process the field data and acquire the resulting models.
In the bigger processing stage, we have two stages. The first stage is T-lidar pointed cloud. Process -- the T-lidar point of cloud is 3D. In the second stage, we need to convert these point cloud into the next step dataset. In our study, we want to develop two things. One is the [biomass]-- one is the [vector] things. And, I will talk more in the data slide.

At the stage one, first, we have prescanned -- we should assemble several perspective of the prescans. Then, we have the LIDAR scan after the root excavation. Of course, we need to assemble it again, then we assemble the slope aboveground and -- and the root system, like, as a whole. Then, we can see more clear the whole picture of the root system with the environment and aboveground.

And, the [left] pictures shows that we -- because we keep the special properties so we can assemble different root systems together in different location years, then we can extend one root system to become a group of trees system, and maybe more to landscape scale. Then, we can look at the row of tree root systems in one tree, several trees, and the whole watershed, maybe. And the second stage is the 2D – 2D dataset we developed.

The first is the root biomass model, which is a hierarchical nested dataset. By using the approach, we develop a called a thermographic slicing. And, the second dataset is the -- is the topological dataset. It can build [unintelligible] model, and by using pixilation of tree roots of the point cloud data to become [poly lines]. Okay. So, at stage one, we should process the LIDAR data like this. It is not a lot of noise and everything. And, so, we need to clean it up. And, then to use onsite experience -- some photos from the site.

And, finally, we got -- this is a point cloud and in XYZ format. So, we go millions of points. Each point, we call “XYZ data.” It has special properties. So, first things we should do, before we set two datasets, is to -- we have to set up the coordinate system, in relation to the environment, in our study -- in this study, is the levee. So, first, we set up the origin of the coordinate system and, the tree trunk center at the slope surface. Once we have the origin, then we set up the X -- X -- axis, which is the axis parallel to the levee. And, the Y-axis, which is the axis perpendicular to the levee. And, the Z-axis is the vertical axis.

Then we -- then we settle down the hollow system and we can understand where is the north, where is the south, where is the levee, where is the river, where has the higher water table, where is the lower water table? Okay. Then, we can do the root biomass model. We designed this model based on special patterns: root size, how root link each other, and their distribution, along which direction. And, we use root cross-section area and -- or diameter as the critical variable to build this model. Then, we send both the variables in virtual trench profile, into [2D sample]. And, the next step is we tomographically -- we construct this 3D hierarchical nested dataset.

Okay. This is the idea of virtual trench profile. Like the conventional trench profile, big change and map the roots on the real trench. The virtual trench profile is the -- is the idea that we cut several slices cross in our dataset, then we map the critical variables I just mentioned on the virtual trench profile -- on the profile. And, the advantage of the virtual trench profile is, we can cut as many as we want. And, also some impossible trench in real world. Like, the -- the red one. It is impossible to cut this trench in the field.
And, then -- so, we can cut any trench to fit in the need that other studies need to get the precise variable or parameters number that other studies precisely want. And, then -- a series -- a series of virtual trench profile, we can treat as the tomographic slices. Then, we -- the tomographic be construction can use linear already as slices. Radial slices.

Since tree roots grows radially from the tree -- tree trunk center to the extent. Of course, we can use any directions we want, like longitudinal direction, upslope, or down slope then -- which means -- which imply that we can see the distribution of the root biomass and vertical. And, also, the radial directions.

So, the tomographical reconstruction is like the [net cone] tomograms in MRI. It’s just a similar idea that we construct a whole dataset to become the root biomass model. Then each slice we can plot -- we can do the 2D plot. I do it in a statistical program because I want to do some statistical models. You can use any software that plotted XYZ data.

And, we -- I convert the 2D plot data to become a special analysis from it. Once we get a special -- special analysis from it, we can specially analyze it, then we can know -- we cannot not only how much or how many of it, we can also know where and how -- with how -- with what size it go. And, I use Arc-GIS to do that. And, also, once we have special analysis from it, we can use a lot of special analysis program to get the special data of the tree root system. I use [unintelligible] to get the special metrics.

And, finally, we got the data sheet for root biomass model. It will tell us a lot of patterns and I will talk later. The second model is the branching roots vector model that tell us the branching pattern and the root directionality, which is very important, as well. And the first, to build this model, is to visualize the point cloud data as poly lines. We use [unintelligible] angle to the North Pole. [Unintelligible] angle to sky. Root links, root orders is the critical variables. Then this model can construct the topological relationship of tree root.

The idea of the visualizing of the point cloud data, to make the [poly line] is, we have a bunch of XYZ points of one root. And, then, we cut cross-section of a -- of a root, and we got a point. We got a couple points in the root -- in the slice derivative, then we make a centroid of it. Then we connect several centroids to making the point lines. The final result like this. And, we build the tree root vector data and we also got the data sheet for the root [vector] model. So, we have directions angles, slice, where they goes. Special properties become 2D -- two datasets.

Okay. Once we prepare the lead two models, then we can analyze the root system now. And, for today, I’m going to talk about the root system information and also, the root system morphological plasticity in relation to the levee geometry. The root system information we got like is -- aboveground information is not good, itself. But, we also want to know the aboveground parameters: how it related to -- in relation to the root system. We have species, location, age, DBH, height, [unintelligible], and we have root systems and -- root systems and we called it a tree trunk center - TCS point. It’s a point.
Yeah. So, if we scale up our root system data to a [unintelligible] level, the tree becomes a point. Then, we can use that to be -- to do some georeference work. And, then to see more interesting things. And, we also have [unintelligible] spread, which is the root system extent. And, then the maximum looking depths. So, we can know how far they go, how deep they go. Okay. The first is, we use 17 [chase] a levee to see how far they go and how deep they go. The maximum root system extend was usually on the downslope side. In our case, which is around six meters. Six meters.

Like, 20 feet. The average maximum rooting depths equals 1.58 meter. It’s around five feet. It’s always the tap root. And, the interesting thing is, every tree on levee has a tap root. On all our sandy levee. Okay. Then, we found some interesting root morphological patterns in relation to levee geometry. The first is a root has asymmetrical root distribution along upslope versus downslope side. And, it also has -- it also has symmetric biomass distribution parallel to the levee.

And, then, it has [horizontal growth] pattern and the shallows of this gross pattern. By -- by using the vector data -- the vector model -- we also found that tree has a tap root as a first older root. Then, the second older root has a grown an alternating direction. So, the first is the upslope and the downslope symmetry. On the downslope side, we found more trees have further root extend great biomass and higher root number. Why are more roots on downslope side of the levee than upslope side?

We have some explanation. Like, we think bark density is one possibility because on our levee the upslope side of levee is higher bark density. Is more compact. And, on the downslope side, is lower bark density. And, of course, this is what we built it and compacted the top. And, also, another possibility is the -- maybe the soil moisture cause downslopes are close to the river. Okay. And, besides those two three symmetry. Also, more trees on downslope side has fertile sand or has more -- more roots. But, we -- we found one interesting things show a pattern that the upslope and downslope symmetry is more consistent.

Based on the root biomass model, and we’re using the tomographic approach. We want to know the root biomass distribution along upslope side and the downslope side. Their rate of decrease -- their rate of decrease to see they like levee or not. Okay. This is the result of the root biomass rate of decrease. The result in the right hand side to chart -- it shows that root biomass exponentially decrease cause I use a lock biomass versus the distance.

Root biomass exponentially decrease from tree center to the extent. And, I compare the upslope and downslope. And, we found that one upslope side, has higher rate of decrease except two trees. One tree is on the disturbed slope and the one tree is very, very small. It only have four major structural root. Okay.

Then, we see a root system symmetry. Symmetric distribution parallel versus perpendicular. We use second older root as the major structure root. The first older root is the tap root. And, we separate two groups. One group is the parallel group -- parallel to a levee. And, the one group is the perpendicular group -- perpendicular to the levee. Then we found that more second roots parallel to levee for every tree that we excavate. Okay.
The next pattern is the shallow and the higher on the root growth pattern. This picture is a radial slice of tree root system, and from zero to 300 in the 60 degree. The higher part is upslope and the lower part is downslope. And, we found the tree is like climb along the slope.

The every root -- root then is from one foot to three feet and there’s about 90 percentage of root biomass is from the depths of one feet to five feet. And, the more [horizontal] root than other type of root -- we classify the root into three categories, like [horizontal] root, oblique and vertical roots, and we found more horizontal root in other type of root in every tree root system.

Okay. And, by using the vector models, we can analyze the branching pattern. The general -- the general pattern, though, with root system can classified in these three types: plate, heart, and tap. And, we use root topological index to see the branching pattern of root system. It’s developed from oh, in 2001. And, the root topological index is competitively illustrating the branching pattern of the root system. So, the RT index is from zero to one and the branching pattern is from [dichotomous] branching -- branching to [unintelligible] branching.

Okay. And, then we -- we use -- we want to see the branching pattern, the RT index, versus aboveground parameter like DBH. We found a very interesting result. We found that bigger tree -- bigger trees have lower RT index. And, the small trees tend to be more [unintelligible] branching. And, this result is very -- has high R² variable -- is close to 0.9. It’s quite -- quite high. So, we found that higher RT index may represent mechanically tree stable.

Okay. Now, we have other to control trees on flat. The tree growing for the ground. The general pattern of root system on the flat plain may be more symmetrical on the previous study. Our result: one cottonwood and the one valley oak in Vernalis, California, cross bound with the previous study. It’s symmetrical. And, they don’t have tap root. And, another result is, the root biomass, the tree on the flat, also radial distribute with an exponential equation change. Those two chart on the bottom are the result.

Okay. So, review two datasets, and we have some patterns in relation to the levee -- geometry. And, then, we want to show some applications -- how our data in the models can it apply to other studies? The first is belowground biomass estimation, and levee slope stability modeling and levee slope surface erosion mapping and also to assess the vulnerability -- the vulnerability of levee. The first that the belowground biomass estimates: We found that root biomass has a linear trend with DBH. And, it has an R² of 0.8 -- that’s pretty high. And -- but we need more data of levee of big trees in our dataset. And, that would be better.

And, the second is the -- the second application is we -- we -- the root system may be useful if the levee stops the root stability model. And, on the -- on the levee is a potential [varial plan]. We can use a virtual change profile to locate a root system with a potential [varial plan], and we can cut a virtual change size -- put it in the profile, slice it -- of potential [varial plan] and we can use [IR] root -- root area ratio or cross section area and to determine the factor of safety in levee slope stability model.

And, the third application is the root slope surface erosion mapping. We can map first -- we can map the length use and we can have general geomorphology map and then we can map the soil
and the roots, soil [seeping] dynamics. Then we overlap it to become -- to generate the soil process along the levee.

And, the last application I want to introduce is the levee vulnerability assessment. First, we can map surface -- we can evaluate the surface process to thicken and we can have a subsurface connectivity and the slope effect of study to become the second map. Then, we can use root system to create a potential root system map. A different color means different possibility of the root system. Then we overlap and to evaluate or assess the vulnerability of levee. Okay. That’s pretty for today I want to introduce. Thanks, everyone. Any questions?

Questions:

**Ben Carter:** So, ladies and gentlemen, we have questions. That was quite a mouthful. Yes, here in front.

**Alison Shilling:** Hi. Alison Shilling from Sacramento Valley. I know that the sample was very small but you did have oaks and cottonwood and I wonder if there were any distinguishing features in the root systems of those two species.

**Shih-Ming Chung:** Yes, versus cottonwoods. That’s a good question. We found that root system biomass distribution -- the biomass distribution of indeed, different species have different decreasing change and oak has higher rate of decrease than cottonwood, which means cottonwood extend longer. They can go longer. Yeah. Further.

**Alison Shilling:** How about branching patterns?

**Shih-Ming Chung:** The branching pattern -- and, in our result, the root topological index of cottonwood is lower than oak. Lower means more spread out [unintelligible], yeah. But, we -- we may need more trees cause we have five cottonwood and we have 15 oaks. Yeah.

**Ben Carter:** Another question? Yes, here in the center.

**Doug Shields:** Doug Shields. Two questions: The first question is, I hate to be dense, but I don’t know what your last two slides showed. The -- the colored bands with the four panels -- I don’t know what that is. Could you explain what that is? The second thing is, if you wanted to prohibit tree roots from growing into a levee embankment, how far from the levee embankment would you prohibit trees? I believe the ETL calls for 15 feet. What distance is required to make sure there are no tree roots growing in the embankment? So, two questions.

**Alison Berry:** Go back to the -- go back to these. What is that showing?

**Shih-Ming Chung:** Okay.

**Alison Berry:** These are sort of hypothetical models of a landscape scale, scaling up from the -- from the modeling there that we’re able to do in -- with single trees. So, these are just some hypothetical applications.
**Doug Shields:** What’s the colored line?

**Shih-Ming Chung:** Different color -- I just want to represent different color shows different level of factor of safety or different possibility of -- of -- of the root number based on for instance the third on our studies, we can predict the root distribution. So, we have different potential distribution of tree root system, then we overlap them. We can give them the index to evaluate -- build models. But, of course, after building the model, we have to do the sensitivity analysis. But this is just a very -- very beginning ideas, like, how can we apply our models?

**Alison Berry:** So, imagine that this is the -- the pocket levee --

**Shih-Ming Chung:** Yeah.

**Alison Berry:** Something like that.

**Shih-Ming Chung:** This is one levee and the dark grade is the -- the river.

**Alison Berry:** And, the second question, Doug was --

**Doug Shields:** How far from the levee toe do you need to prohibit trees and add no good to the environment?

**Ben Carter:** So, the question again, repeated was: How far from the levee or the levee toe do you have to prohibit tree growth so that roots do not penetrate the levee section?

**Shih-Ming Chung:** Penetrate the levee section. Based on our study, we believe that the tree root will climb the levee, not penetrate levee. And, how far? It’s out of our study scope. Yeah.

**Alison Berry:** There are a lot of variables.

**Shih-Ming Chung:** Too many of variables.

**Alison Berry:** As I’m sure you appreciate.

**Doug Shields:** Having growth into -- having grown into [unintelligible].

**Alison Berry:** I think there are a lot of variables, again, depending on moisture, you know, water table, moisture relations, the soil texture, and so forth, that are going to affect that -- that number. Are you trying to say that it’s not possible to say an absolute number? I think you’re correct that that’s true.

**Doug Shields:** I didn’t say it.

**Shih-Ming Chung:** And, also, different types of levee, like sandy levee were very different from the -- from the clay levee. Other types, so -- it’s really hard to say. Our study is only for sand -- sandy levee.
Alison Berry: I have one more. Can we get out of this? Can you help me?

Ben Carter: Next -- next question? Here in the center?

Male Voice: Yeah, it’s not really a question, it’s a comment. It was interesting results you found that on -- on the flat -- on horizontal surfaces, you had a nice distribution of roots all around the tree. And, an incline surface, you saw more down -- downslope. Is that correct?

Shih-Ming Chung: More -- yeah, more.

Male Voice: Yeah. And, I suspect the difference maybe not due -- be due to bulk density, but simply due to gravity. Because, generally, you’re going to have greater densities at -- at depth and water. Thank you.

Ben Carter: Interesting hypothesis. Perhaps a subject of -- of future research.

Alison Berry: Yeah. Let’s have lunch.

Ben Carter: Any -- any other questions?

Ron Stewart: Just to follow up again. This is Ron Stewart. ETL does call for any trees that are planted or allowed to grow, there is, of course, vegetation or even California poppy-free zone, that you’re -- that’s fairly obvious to measure. But the other part of the ETL is: No root shall enter a critical part of a levee system which begins either the profile or -- or no seepage firm or cut-off wall, or a drainage structure.

In other words, if you actually mean to comply with ETL, there’s seems to be a research need to understand, indeed, how far back the woody vegetation-free zone would have to be. And -- and, I think you’re probably correct in your -- in your initial reaction, but is there -- is there any either core or California research planned to try and comply with that aspect of ETL that is -- essentially guarantying that no root will enter a critical feature of the levee?

Alison Berry: I think Les Harder is going to address that with his presentation that you’ll be able to see how root behavior is quite unruly and unmanageable, in that sense. So, I think -- yeah, that it’s -- it’s not -- it’s not possible to exclude roots from growing into the -- onto the levee. What we can say is, it’s -- the growth is -- is going to be relatively superficial on the levee. So, yeah.

Ben Carter: One -- one last question, we have time for.

Maureen Corcoran: Maureen with ERDC. I have several questions but I’ll try to keep them brief, cause I know we have limited time. I appreciate all this information that you’ve gathered because there’s really no database that exists that has the level of details that you provided. So, I think that is great. I think an issue, though -

Shih-Ming Chung: Thanks.
Maureen Corcoran: - sure. I think an issue, though, is, to use this an assessment tool would be quite difficult. First of all, you’re removing the canopy of the tree, which, based on what we heard this morning is critical habitat. So, 1) I want to know if that’s been addressed, looked at.

And, also, if you’re saying the tree will live, and it does, because ours did the same thing 'til we dug it up and laid it -- then it didn’t stand a chance -- but, you’re still altering the permeability of the soil. So, are you looking at -- at those things. And, also, the second part is, will we see, later on, how you’ve used this and some of the methods that you briefly discussed today, such as slope stability models?

Shih-Ming Chung: Yeah. Actually, based on our database, if we have more -- if we have more trees, then we can get more significant results, then we can have different fieldwork methods. For instance, we can only think of one change because we know tree [unintelligible] in levee, exponentially decreased. Then, we can pick -- we can pick only one or two changes. It’s much, much less disturbed, like the whole system. And, we don’t have to cut it aboveground.

And, we also developed another way to see that every root biomass, and that the extent, by using another, more compact studies model to see it. Then, we don’t have to do -- we can measure the aboveground parameter. That’s why we need it aboveground: not only [excavate] tree root system, itself. So, if we have the aboveground parameters correlated to the root system, then we can use the aboveground parameters. That’s easier. Then, we can get -- we can use LIDAR scan aboveground as a way to get -- use the same thing -- tomographic slicing -- to do it again. Yeah. So, I think that’s possible. Yeah.

Maureen Corcoran: My second question was: Will we see later on some of the -- the techniques and methods that you talked about? Will we see that in later presentations today? Such as, slope stability models? Will we see your work incorporated into some of that?

Shih-Ming Chung: We want to do --

Maureen Corcoran: Or, is that planned?

Shih-Ming Chung: Yeah, that’s a plan. Actually, I want to do -- I want to do a breach.

Ben Carter: The question was the part of Dr. Corcoran’s question, which was, “Will we see the results of this being used in future presentations here in the symposium, such as slope -- slope stability studies, and so forth?

Shih-Ming Chung: We hope but I -- when I studied tree root system and others -- others geotechnical models, I found there is a bridge lost. How to use root system data. So, I try to understand those geotechnical model and to build their base -- how to build database, also very important to connect to other studies. So, this is my main focus. I want to build several bridges to other studies because geotechnical expert must be much, much better than I, but I can build a -- I can convey -- convey the data and to talk in the same language. Yeah. In different disciplines.
Maureen Corcoran: Great. Thanks.

Ben Carter: Thank you very much, Dr. Berry. Shih-Ming, thank you very much for sharing your - - your information.

Alison Berry: And, just an acknowledgement -- acknowledgement of all of all those who have really contributed greatly to -- to the success of the study. SAFCA, of course, and DWR, our collaborators and these other folks who really helped us on the levees -- the particular levees that we worked on to make it possible for us to do our work. And, a whole ton of people from UC Davis who have contributed over these several years to the study. Thanks.

Ben Carter: Thank you very much. As we see, we’re one piece of the puzzle, which, when it works in -- in concert with other pieces, hopefully, we’ll be able to see a -- a picture coming together at some point.

(Introduction to Bryant Robbins)

We’re going to talk a little bit more about roots. We have a -- a gentleman, Mr. Robbins, who is a geotechnical engineer in the Geotechnical Structures Laboratory at the -- at the U.S. Army Corps’ ERDC Laboratories. His current research interests include erosion measurement and modeling -- centrifuge modeling of embankments and discrete element modeling of coupled embankment erosion stability problems. Prior to working for the Corps, Mr. Bryant worked in the Montana Department of Transportation performing bridge scour analysis, hydraulic studies, and hydraulic analysis of culvers. So, please join me in welcoming Mr. Bryant Robbins.

Bryant Robbins:

Good morning. That was awful. Everyone’s asleep. Good morning!

Audience: Good morning.

Bryant Robbins: That’s better. As Maureen mentioned, my colleague, Dr. Wibowo, was originally going to come and give this presentation. So, I’ll do the best I can to answer any of your questions. But, before I get into the presentation, I’d like to just acknowledge that I think the speakers this morning in the first session did an exceptional job of given an overall view of this problem and how it all fits together. So, if you would, just give them a round of applause for our three speakers this morning, if you will.

Part of why I think they did such a good job is they all commented on how complex the issue is and how multidisciplinary it is. They commented on the severe financial constraints that face us in addressing the issues. They acknowledged that we’re all very aware of the environmental concerns and implications that decisions in this area have. A couple of them acknowledged that there are social benefits to the decisions we make, such as recreational areas. And, they all mentioned that we have to be concerned with public safety.
All these issues, and how multidisciplinary and complex it is, require that a team be used to assess the risks in each area. And, that term was thrown around this morning. The term, “risk,” gets used a lot in different fields, and in my limited experience, I have found that many people have different understanding so the term, “risk.” So, I’d just like to briefly talk about it. I know Dr. C’s going to address it in greater detail, but what I’m about to talk to you about, you can see how it applies to the problem, if you really understand risk.

The formal definition of “risk” is that it’s a quantitative value that is equal to the probability of an event happening times the financial consequences of that event. The idea behind risk is that it lets you optimize your resources and minimize your consequences. The problem then becomes, in this issue, how you do assess probability of occurrence, and how do you look at the consequences? To do both of these things, you have to understand the problem well enough that you can analyze it. But, you also have to understand it well enough that you can assess the uncertainty in the answers of your analysis, and that’s often overlooked.

To me, this is where the greatest problem lies. We’ve heard over and over again this morning that the data doesn’t exist, or we don’t know the answer. And, without data, as Dr. Berry said so elegantly, a knowledge database, that includes data, case histories, and successful examples, we’ll never be able to answer those questions. So, it’s exciting to be here and see this knowledge database be built.

I wanted to preface this talk after hearing these talks this morning because that’s exactly what this is about -- creating this database. I’m going to talk to you about field tests that were conducted -- pulling roots out of the ground -- for the sole purpose of creating a dataset. So, we’ll quickly go through objectives and the equipment that was used, and then, the test procedure. And, side-by-side, I’ll talk through the results that were obtained and the different variables at each site.

The sole purpose of this study was to measure the in situ root strength. And, so what I mean by that is the tensile pull-out capacity of a root. As part of this, we recognize that roots fail in different ways, and I will talk about the different mechanisms that were observed. The equipment that was constructed for this was a modified version of equipment that was originally built by [Norison Greenwood].

The modifications include, rather than use a lever system, we constructed a T-frame, that you can see here. And, there was a hydraulic actuator and cable system that allowed for direct pulling of the roots. There was also a string pot that was used to measure deformation and a load cell to measure the load in the cable, so that we could get a real time record of load deformation during the test.

Here’s a picture of the equipment out in the field. You can see that there’s a hydraulic pump to supply the actuator, and the root is down here in the bottom of the picture. So, when we arrived at a site, the first thing we had to do was find roots. Being researchers, we looked for the closest free labor that we could get. Don’t worry; we didn’t use three year olds. This is my son, digging my tree in my backyard up, just like that. In all actuality, when we got to a site, we brought in heavy equipment and gradually excavated from the top down until we encountered roots in the vicinity of a tree.
Once we encountered roots, we would use shovels and uncover more of the root to ensure that we got to a portion of the root that would have not been hit by the heavy equipment. We made sure they were virgin, untouched roots. We, then, removed the bark of the root to allow the apparatus to get a strong hold on the root, itself. And, we recorded the diameter, before and after embarking, the position of the root relative to the tree, and the dip, direction, and angle.

The next step was to secure the root in a clamp. Here, you see a photo of the apparatus around a root. It’s hard to tell from the picture, but the individual pieces have teeth in them so that the harder you pull on this root, or, the harder you pull on the cable, the tighter it grabs the root. It’s similar to an apparatus you use for testing tension cables. Then, this picture again, you set the apparatus up about six feet from the root, and anchor it in with fence posts. We, then, begin logging measurements and obtain a force displacement curve with the pull-out capacity corresponding to the peak value.

So, we did this at three different sites: Burlington, Washington; Portland, Oregon; and Albuquerque, New Mexico. At the first site, there were six trees tested, and they were tested in two separate areas. The first area, there was a cedar and two maples. In the second area, a cottonwood, another cedar, and an alder tree. The tests were conducted in March of 2010. The soil in the area was a sandy or silty clay, as you can see by the picture, and, during testing, the site was dry. Here’s a topo map of the area. You see the town of Burlington, Washington near the top. The study area is along the Skagit River.

Here’s an aerial photo of that site. Area 1 is, as shown there -- it was actually between the levee and the river. And, Area 2 is near the top, a little bit farther upstream. Here’s an aerial photo of Area 1, showing the three trees that were tested. To give you a little more perspective of a site, here’s the picture of the cedar tree. This tree was 28 feet tall and had a DBH of 22 inches. And, here’s a picture of one of the maples. Note the close proximity of this tree to the river. Site 2 was outside the levee, and it was in a much more forested area. There was close tree spacing. We recognized that that could impact the pull-out resistance, but that wasn’t specifically addressed.

So, during the pull-out tests, there were failure modes observed. One, a root break, where the root carries all of the load and snaps, instantaneously unloading the load cell. There is a pull-out type failure, where the bond between the root and the soil actually fails and it just slips out of the ground. And, these typically had larger deformations. And, then, a combination, where the root loads up and fails, but it fails far enough in the soil that there’s still a residual load.

Here are the results from Burlington: There is quite a bit of scattering the data, but if you ignore -- let me back up for a second. There’s -- there’s three datasets broken out by the failure mechanism. So, the black circles are root breaks; the green diamonds are the pull-out, or bond failures; and, the red crosses were a combination. If we look at just the root break mechanism, because it’s hard to make inferences across different failure mechanisms, and ignore an outlier, there’s an extremely strong trend showing an increase in force with diameter, which is what you would intuitively expect and is what other authors have also found.
The second site was in Portland, Oregon. There were only two trees tested at this site: one cottonwood, and an Oregon ash. The testing was also conducted in March of 2010, however, this site had a loose sand as a soil, and the conditions were dry. The red star indicates the test location. It’s along the Columbia River, north of Portland. And, in this aerial photo, you can’t see the river. The river’s just a little bit up from the photo, out of the field of view. But, you can see the Oregon ash and the cottonwood tree, and that they’re out in the open.

The cottonwood was a rather large tree. It was 81 feet tall, with a DBH of 42 inches. And, the Oregon ash was 48 feet tall, with a DBH of approximately 12 inches. There were fewer tests done but, again, you see the same trend. There’s an increase in pull-out force for root diameter. Note, though, that there are some significant variances. So, around 1.2 inches in diameter, you see these points at approximately 500 pounds. And, at almost the same diameter, there is a root that developed almost 3,000 pounds.

Site 3 was in Albuquerque, New Mexico, and this was a unique site because all of the trees were the same species and in almost the same exact environment. There were nine cottonwoods that were tested in two separate areas. The testing was conducted in April of 2010. There was a really fine, silty sand, as you can see from the photo. And, again, it was dry during testing. Here’s a map from Google of Albuquerque. And, the test area was just north of downtown Albuquerque, along the Rio Grande River. Here’s an -- you can see an aerial photo of the site. There’s Area 1. And, Area 2 was about a mile further upstream. Both areas were between the levees and the river.

You can see from the Aerial photo that it is a pretty forested area. To give you a little more idea of how closely spaced these trees are, here’s a picture of some of the permeability testing that was also conducted there, as part of a different study. Area 2 was also heavily forested, where the trees are very close together. And, all of these trees were alive, by the way, just wanted to make sure I hadn’t said that before. The results from Albuquerque exhibited a lot more scatter even than the other two sites, which was surprising, considering they were all the same species. But, again, there is a trend showing an increase in pull-out force with increasing root diameter.

So, this all of the data from all of the sites plotted together. It’s interesting to note that the bond failure datapoints are all around the same strength. And, this is possibly due to the roots being at a given depth in a frictional media so that, if they’re going to pull out, it’s the soil strength that is the limiting factor. But, if we look at the root breaks, there is a trend. This is all of the data, ignoring failure mechanism, because we weren’t sure exactly how to address it - and I’ll talk about one way we tried later -- with a median best fit linear line and 95% confidence intervals on the mean. And, there’s quite a spread.

We wanted to see how this compared to other data, so here is a best fit line from a study conducted by Norris in 2005. If we extrapolate that, it aligns well with our mean, but doesn’t mean anything due to the scatter, is the question that needs to be answered. We also compared it to another study conducted by [Evan Zemer] in 1991, and it didn’t compare favorably at all. And, their -- their study was on conifers. So, a few concluding remarks out of observations during the study. Out of all of the different species that were tested, cottonwood trees, had the largest root dimensions and grew the furthest.
There were three distinct failure modes encountered: the root break, pull-out, or a combination. And, the pull-out strength can vary significantly. To try and assess some of the variants, an analysis of covariance was conducted on the dataset. And, in an attempt to account for the different failure mechanisms, the dependent variable in this analysis was work. We used the force displacement curves to calculate the work that was applied to the root. At a significance interval of, I believe, 1%, the location and diameter were determined to be statistically significant, however, the species was not, in this study.

As you can see from the study, there wasn’t a lot of analysis done to the data, so, there are more things that can definitely be done with the study. For instance, we can look at the modulus of elasticity in the roots as a function of the DBH. There should be further comparisons conducted on this data with other datasets that are in the published literature. And, more rigorous statistical analysis, to try and explain some of the variation of the data need to be done. So, time and resource permitting, I hope to be able to address some of these.

One last thing I’d like to say is that, all of this data is available. If you are interested in obtaining this data for your own research or you think it will help you in any way, please contact me or come up and give me your contact information, and I will be more than happy to email all of the data from this study. With that, are there any questions?

Questions:

Male Voice: Maybe I missed this, but when -- when you were pulling those roots, were they still attached to the tree?

Bryant Robbins: No.

Male Voice: Okay. So, you did -- so, it wasn’t a direct kind of correlation --

Bryant Robbins: No.

Male Voice: - the larger the root, the stronger it would be attached to the -- to the tree, itself, then.

Bryant Robbins: No. I forgot to mention, our apparatus could only pull a root up to two inches in diameter. So, we had to dig far enough away from the tree that we would encounter roots of that size. And, then, when we did, we cut them and pulled them --

Male Voice: Thank you.

Bryant Robbins: - the portion away from the tree. Next.

Female Voice: Hi. I noticed on the X axis that the smallest roots you measured were about .7 inches. Can you explain why you neglected the smaller roots, and whether you think that’s important -- bearing in mind that, when you pull out tensile strength of roots against diameter, the smaller roots are actually stronger per unit area. Sorry.
And, also, just a comment: I think the large scatter that you’re probably seeing could be a result of -- of the methodology you’re using where you’re pulling on these roots and other smaller roots are attached to those roots. As you’re not really testing individual roots. You’re testing a bundle of roots, and you’re not really isolating those -- that individual root that you’re pulling on. Just a thought.

Bryant Robbins: I agree with that comment. The -- the idea was, with a root -- if you encounter a root of a given diameter, we wanted to know what force you would end up being able to implement in numerical models. So, that was the goal with that. I’m sorry -- I didn’t catch the question, though. What was your question?

Female Voice: [Unintelligible] inches diameter?

Bryant Robbins: Oh, that was just a limitation on the equipment.

Female Voice: But, do you not think the smaller roots are very important?

Bryant Robbins: No, absolutely. They are. There’s a lot -- tons of research that shows that the strength of the smaller roots goes up exponentially as the diameter decreases.

Female Voice: Right.

Bryant Robbins: We just didn’t have the equipment with us to test those roots.

Female Voice: Okay.

Bryant Robbins: And, we were indirectly testing them as -- by pulling the larger roots, because you’re testing that entire root system beyond that point.

Female Voice: Okay.

Ben Carter: Next question? Here in front. We’re -- we’re giving our folks a little exercise.

Male Voice: Could -- could you compare the pull down forces you observed to the kind of wind shear force you might expect to see -- that would pull the tree down?

Bryant Robbins: There’s quite a bit of research looking into modeling [wind throw] right now. The models that I’ve seen have been complex enough that I feel you can manipulate it to make it match. And, I haven’t seen a wind throw model yet that could be extended in that manner to all cases. That being said, I think that’s the direction that things are going. And, no, we have not done that, ourselves.

Ben Carter: Here in the back.

Male Voice: The aboveground biomass of many of these trees, especially cottonwoods, is not uniformly distributed over the root mass. Trees are growing toward the sun. There may be effectual
wind. Are any of that taken into account by any of the researchers, whether it’s Dr. Berry or yourself, in -- in how the roots may be responding to different stresses.

**Bryant Robbins:** I think there is quite a bit of research that’s being done on how biomass is distributed. There is a lot -- Dr. Peterson, I believe, is going to talk about wind throw later and may touch on some of these topics. But, you have to recognize that this is extremely complex, especially considering we can’t see what’s in the ground. And, to try to say that we can model this with confidence at this point in the time - I don’t we can make that statement. But, I do believe that that’s the direction research is going. I know there’s a lot of forestry models that take an empirical approach to trying to do that.

**Ben Carter:** Questions? Right here in front. There’s one right here.

**Male Voice:** Just a very quick question about your methodology. Were the tree’s roots that you were looking at in the levees or in ground adjacent to the levees?

**Bryant Robbins:** They were not in the levees. They were -- it was flat areas off to the side of the levees. So, these were not roots in the levee maintenance.

**Male Voice:** Okay. Cause, I -- cause, from the previous presentation, I understood that the distribution of root systems might be different between levees growing on flat -- trees growing on flat ground, and those growing on levee slopes. And I just wondered whether you had any thoughts about how that might influence your results.

**Bryant Robbins:** I think that there -- there are definitely differences on the slopes. And, I was actually very excited to see that research, and I’d love to talk to you more about it. I’m looking at wind throw when trees do uproot and have to be root play. I’m looking at a study right now to try to characterize those dimensions. And, there is existing research that shows the dimensions are altered by slopes. So, I think that is entirely accurate and there’s lots of research to support that.

**Maureen Corcoran:** Jonathan, I’d like to add just one thing on that. Some cases, we were restricted to how much we could pull from the tree. Albuquerque, for instance, would not let us any more than four roots per tree, because they didn’t want to damage the tree in any way. So, that was restrictive of -- of some of the data that we collected.

**Bryant Robbins:** But, I think to answer your question, I don’t have any reason to say that the slope would influence the pull-out capacity, just the root distribution.

**Ben Carter:** Alright. Right over here, and then we’ll -- we’ll come back.

**Anthony Wright:** Tony Wright, Puget Sound Partnership. The -- the -- you showed one line there and said that was a study of conifers. I’m -- I’m curious: Is that something -- is that -- do they use similar enough study methods to say that the conifers have that profound differing characteristics, or do you have an opinion on that?
**Bryant Robbins:** I don’t actually have an answer to that question. I haven’t had a chance to look at that in great detail. But, if you would like an answer, I can have Dr. Wibowo give you -- shoot you an email.

**Anthony Wright:** That would be great.

**Ben Carter:** Okay here -- back here in the center.

**George Sills:** George Sills. I’m just curious: Will we see later in some other presentations of how you took this pull-out strength and incorporated that into your stability models?

**Bryant Robbins:** I don’t believe anybody from ERDC is going to be talking about that. But, I think some of the presentations appear like they will touch on that topic.

**Ben Carter:** Okay. Dr. Berry, here in front.

**Alison Berry:** I just wanted to comment on a previous question, if you’re all set.

**Bryant Robbins:** No, go ahead.

**Alison Berry:** So, about the aboveground part of the tree and how that relates to root -- you know, the root architecture, and, certainly, using their -- these methods, we’ve -- we can look at that question and we have done some looking at it. We’ve -- we can say, for example, that, as Shih-Ming presented that, there are these symmetries and asymmetries that are characteristic and consistent, regardless of directionality of the sun or the levee, and so forth -- the wind -- you know, prevailing wind. We haven’t really put that together, but that’s certainly part of the data. And, we can at that -- at those kinds of relationships using these kinds of methods. I hope that’s helpful.

**Ben Carter:** Okay, I saw one other question here in the center, yeah.

**Andrew Simon:** Yes, Andrew Simon. I’d like to make a couple of comments regarding your talk and one previous. You know, we’ve heard several times that there’s no data out there on -- on tensile strength of tree roots of various species. There’s a lot of data out there. It’s been published in the -- in the peer review literature. It’s been incorporated into root reinforcement models, and it’s been incorporated into -- into bank stability models. We’ve also heard that we can’t model these things, in terms of root reinforcement. And, that’s really not true, either. Natasha Bankhead, as part of her Ph.D., developed a fiber bundle model which is being used all across the globe, in terms of modeling root reinforcement.

The third comment I wanted to make regards the idea of the variability that you’re seeing in some of your root pull-out experiments. And, one thing that Natasha just mentioned with this whole idea, if you’re trying to relate that pull-out force just to a root diameter, but that there are other roots of varying diameter and varying roots that -- numbers that might be attached to that root, that might explain some of -- of the difference.
So, I guess my comment, in general, is that, to make sure that when we’re presenting these things, that we present a -- a full picture of the research that is out there and available.

**Bryant Robbins:** Thank you, Dr. Simon. I’m actually very familiar with the [B Stem Model] and [Rip Root Model], and I’ve looked extensively into a lot of the data that’s been collected. The issue I have with a lot of the data is that the objectives behind studies varies so much that a lot of it is very hard to compare directly.

Also, with your comment on modeling, having used B Stem and Rip Root, and seeing it applied, I know that you’ve had some very successful case histories with it. But, I’ve seen cases, actually here in Sacramento, where it’s given really aggressive rates of lateral channel migration. So, I just want to caution people to use modeling as a tool, but recognize that it doesn’t give you an answer. And, I agree entirely with your third comment.

**Ben Carter:** Any other questions?

**Bryant Robbins:** Excellent.

**Ben Carter:**

Thank you very much, Mr. Robbins. So, this concludes our morning session, first day. We’ll go ahead and break for lunch. I wanted to, first of all though -- want everyone to give a big round of applause to the folks who dedicated countless hours of pulling the logistics of these three days together. A complete list of those folks is in your program. Let’s give them a big round of applause.

But, I did want to mention a few special folks who did much of the heavy lifting for the -- the symposium. And, in particular, there are eight people: Gary Estes, from the American River Watershed Institute; Kristin Jacobs, from California DWR; KC Sorgen, from SAFCA; Jessica Ma, from SAFCA; Cassandra Musto, from DWR; Mick Klasson, who was an independent consultant; Laura Kaplan, from the Center of Collaborative Policy, who you’ve seen running around with the mike; and, finally, Peter Buck, from SAFCA. These folk dedicated much, much time, met all -- weekly since -- since January, to make this happen. And, we all owe them a great round of -- of applause and gratitude.

So, I understand there are box lunches available. They are in a room behind this wall here. So, to get there, you can exit the side doors or out the back, and go around and collect your -- your box lunches. Please, carnivores: You guys eat the meat and let the vegetarians get the -- the vegetarian boxes that they did order. So, please leave those -- those to them. And, please enjoy lunch. We will reconvene as scheduled back here at -- what time is it? 1:00 -- 1:10. So, we have one hour for lunch. Enjoy.