PUBLIC

BEFORE THE
SURFACE TRANSPORTATION BOARD

STB Docket No. 35305

PETITION OF ARKANSAS ELECTRIC COOPERATIVE CORPORATION FOR A DECLARATORY ORDER

BNSF RAILWAY COMPANY'S OPENING EVIDENCE AND ARGUMENT

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Confidential Exhibits, Volume I, filed under seal

Confidential Exhibits, Volume II, filed under seal

Highly Confidential Exhibits, filed under seal

BEFORE THE
SURFACE TRANSPORTATION BOARD

STB Finance Docket No. 35305

PETITION OF ARKANSAS ELECTRIC COOPERATIVE CORPORATION FOR A DECLARATORY ORDER

BNSF RAILWAY COMPANY'S OPENING EVIDENCE AND ARGUMENT

In accordance with the Board's decision served on December 1, 2009, BNSF Railway Company submits its opening evidence and argument in this declaratory order proceeding. Petitioner Arkansas Electric Cooperative Corporation ("AECC") has asked the Board to declare BNSF's coal dust emissions standards set out in BNSF's Rules Publication 6041-B, Items 100 and 101, to be an unreasonable rule or practice and an unlawful refusal to provide service. For the reasons set out in detail below and in the attached Verified Statements, BNSF urges the Board to find that BNSF is entitled to establish operating rules that limit the amount of coal dust that can be emitted from loaded coal cars in transit over rail lines in the Powder River Basin ("PRB") and to find that the specific coal dust emissions standards set out in BNSF's Rules Publication 6041-B, Items 100 and 101 are not unreasonable.

COUNSEL'S SUMMARY OF EVIDENCE AND LEGAL ARGUMENT

Coal dust emitted from moving coal trains is pervasive along the rail lines in the PRB. Coal dust deposits are visible between the rails, between the sets of tracks, along bridge abutments and in creek beds.


New Track Construction – Fall 2006
M3 Mile Post 52 – Orin Subdivision
Photograph May 2007
5
2


FROG

Additional photographs of coal dust deposits are included in Counsel's Exhibit 1. Even in areas that appear to be free of coal dust, coal accumulations are found just beneath the surface.

See additional photographs in Counsel's Exhibit 2. Maintenance work uncovers vast amounts of coal dust deep in the rail ballast under the track structure.

See additional photographs in Counsel's Exhibit 3. It is undeniable that coal dust is emitted in large quantities off of the top of loaded coal cars in transit along the PRB lines, and anyone who has spent time in the PRB is aware of the problem.

Short videos of coal dust episodes are contained on the CD at Counsel's Exhibit 4. When a coal train passes, it is usually necessary to avert your face or roll up your car window to avoid being pelted with coal dust flying off the coal cars. A parked car left near the rail lines will be covered with black coal dust by the end of the day.

Coal dust is a serious contaminant of rail ballast and therefore presents a serious problem for railroad operations, as rail ballast is critical to the integrity of a railroad's track structure. Ballast provides structural support for the heavy loads applied by trains moving over the tracks and provides for the drainage of water from under the tracks. When ballast becomes fouled, its ability to support heavy loads is compromised, as illustrated in the following figure:

(a) Clean ballast (b) Partially fouled ballast (c) Heavily fouled ballast

See the attached Verified Statement of Professor Tutumluer. In 2005, two derailments occurred on the Joint Line, the rail line in the PRB owned jointly by BNSF and Union Pacific Railroad Company ("UP") that extends from Coal Creek Junction, WY in the North to Shawnee Junction, WY in the South. The presence of coal dust in the ballast was a contributing factor to the derailments. Since 2005, several studies have shown that the physical properties of coal dust make it one of the worst possible contaminants of ballast.

The coal dust falling onto the railroad right of way and fouling the railroad ballast belongs to the coal shippers who take ownership of their coal at PRB coal mines. The coal is the shippers' freight and therefore it is their responsibility to keep their coal in the loaded railcars. Unsurprisingly, BNSF does not allow the freight of any other shipper to escape from the railcars and damage the rail property. While BNSF has dramatically expanded its maintenance and inspection of the PRB rail lines to deal with the increasing problem of coal dust, BNSF should not be required to clean up after the shippers' freight has fallen out of the loaded cars. Moreover, expanded maintenance is not an acceptable solution to a problem that has the potential for disrupting the PRB coal supply chain. The risk of service interruptions from coal dust and the impact of expanded maintenance on limited PRB rail capacity mean that the only responsible solution to this problem is to take measures to keep the coal in the loaded cars.

Since the 2005 derailments, BNSF has paid over $4 million to consultants to set up an extensive data gathering network and it has collected a considerable amount of data on the sources of coal dust and the alternatives for curtailing coal dust emissions. BNSF has measured the coal dust emissions from thousands of trains passing Milepost 90.7 on the Joint Line and Milepost 558 on BNSF's Black Hills Subdivisions. The data show that it is possible to identify specific trains that are emitting excessive levels of coal dust as they pass a particular location. Using the data, BNSF calculated limits on coal dust emissions at those two locations that would, if met by all passing trains, substantially eliminate coal dust. BNSF set these standards only after it concluded that it had done enough testing and data collection to support the standards. The standards, set out in the BNSF operating rules at issue in this proceeding, are conservative and achievable.

It is possible that other environmental scientists and statisticians would take different approaches to setting a limit on coal dust emissions than the approach that BNSF has taken. But the question here is not whether BNSF's standards are the only defensible standards. Rather, the question here is whether BNSF's standards are a reasonable response to a problem that could have a serious impact on the reliability of PRB coal transportation. New monitoring equipment might become available and new coal dust detection techniques might be developed in the future. But it has been almost five years since the 2005 derailments, and BNSF's studies and experience since then have confirmed the need to act now to curtail coal dust emissions. It would be highly imprudent to put off further action until the perfect solution—if it even exists—can be found.

BNSF has not dictated what measures PRB shippers and their mine agents must adopt to meet the coal dust emissions limits. Under BNSF's approach, individual shippers and their mine agents have the leeway to determine the most efficient and cost-effective method of coal dust suppression. BNSF has actively assisted shippers and mines in identifying effective dust suppression approaches. Through extensive laboratory and field testing, BNSF has shown that it is possible to substantially eliminate coal dust emissions and has collected data that will allow shippers and mines to choose optimal solutions. By leaving the solution to individual shippers and mines, BNSF believes that a market will emerge in which suppliers of coal dust suppression methods and products will have the incentive to innovate and develop the least costly and most effective dust suppression measures.

BNSF explains in this opening evidence and argument why the Board should reject the claim of petitioner Arkansas Electric Cooperative Corporation that the coal dust emissions standards in BNSF's Rules Publication 6041-B Items 100 and 101 are unreasonable. BNSF's submission in this opening evidence and argument has two components: (1) Counsel's Summary of Evidence and Legal Argument, and (2) Verified Statements of seven witnesses and accompanying exhibits.

The witnesses submitting Verified Statements on behalf of BNSF and the subject matter of their testimony are identified below.

Gregory C. Fox: Mr. Fox is BNSF's Vice President, Transportation. Mr. Fox led BNSF's efforts to restore operations on the Joint Line after the 2005 derailments and subsequently to rehabilitate the track structure. He initiated a proactive coal dust study to ensure that the service dislocations experienced in the aftermath of the 2005 derailments would not recur. Mr. Fox explains that the coal dust emissions standards that resulted from that coal dust study are necessary and appropriate operating rules that are intended to ensure safe, efficient and reliable PRB coal transportation service.

Stevan B. Bobb: Mr. Bobb is Group Vice President, Coal Marketing for BNSF. Since taking that position in 2006, Mr. Bobb has been extensively involved in outreach to PRB coal shippers and mines to keep them informed about BNSF's ongoing study of coal dust and to help explore dust suppression alternatives. Mr. Bobb describes his efforts to promote a consensual solution to the problem of coal dust in which shippers will voluntarily accept responsibility for curtailing coal dust emissions.

William VanHook: Mr. VanHook is Assistant Vice-President and Chief Engineer-Systems Maintenance and Planning for BNSF. He is the BNSF employee who has had primary responsibility for investigating the causes and the scope of the coal dust problem that BNSF has encountered on its PRB coal lines and for overseeing the development of standards intended to limit the emissions of coal dust from loaded coal cars. Mr. VanHook provides an overview of the steps BNSF has taken to understand and address the coal dust problem.

Craig Sloggett: Mr. Sloggett is General Director Maintenance for BNSF with responsibility for maintenance and maintenance planning on BNSF's Powder River Division. Mr. Sloggett describes the unprecedented maintenance challenges presented by coal dust accumulations in the PRB and explains why expanded maintenance is not a responsible solution to the problem of coal dust in the PRB. He explains why coal dust emissions must be substantially curtailed to ensure reliable coal transportation service.

Charles Sultana: Mr. Sultana is a Six Sigma Specialist in BNSF's Mechanical Department. Mr. Sultana is responsible for bringing an advanced level of analytical and problem solving skills to bear on important problems identified by BNSF's management. Mr. Sultana was asked in 2006 to work with BNSF's coal dust study group to help understand and evaluate the extensive data being gathered on coal dust emissions and to develop a conservative and achievable limit on coal dust emissions based on the data. Mr. Sultana describes the process by which the standards at issue here were developed and explains the logic underlying the standards.

G. David Emmitt: Dr. Emmitt is the President and Senior Scientist of Simpson Weather Associates ("SWA"), a scientific research and development firm that BNSF hired in 2005 to assist in BNSF's coal dust study. Dr. Emmitt, who had worked with Norfolk Southern Railway Company in the 1980s to address coal dust issues, describes the extensive data gathering network that SWA helped BNSF set up. Dr. Emmitt also explains how SWA helped BNSF identify changes in the loading profile of coal cars to reduce coal dust emissions and how SWA has assisted BNSF and its shippers to evaluate coal dust suppression measures, particularly the application of surfactants.

Erol Tutumluer: Dr. Tutumluer is Professor of Civil and Environmental Engineering at University of Illinois at Urbana-Champaign. He has done extensive research on issues relating to railroad track structure and has studied in detail the impact of coal dust on rail ballast integrity. Dr. Tutumluer explains that based on the physical and mechanical properties of coal dust, it is one of the worst possible ballast fouling agents. When rail ballast is fouled by coal dust, the load bearing capacity of the track structure is significantly reduced, which can lead to unstable track conditions and, potentially, to derailments.

FACTUAL BACKGROUND

The facts relevant to the issues in this proceeding are discussed in detail in the Verified Statements of BNSF's witnesses. The most salient facts are summarized briefly below.

The PRB rail lines are among the highest volume rail lines in the world. Coal originated in the PRB moves primarily to electrical utilities located throughout the western United States and is interchanged with eastern railroads for delivery to utilities in the east as well. Two carrier operations over the Joint Line began in 1984, and in that year approximately 76 million tons of coal were originated by BNSF and UP predecessors on the Joint Line. By 1997, Joint Line originated tonnage had increased to 212 million tons, and by 2008, the Joint Line traffic had increased another 53 percent to 375 million tons of coal. Thousands of loaded coal cars move each day out of the PRB on the Joint Line and on BNSF's Black Hills Subdivision lines. PRB coal transportation is a critical component of the U.S. energy supply chain.

A 1983 Joint Line Agreement between BNSF and UP predecessors governs rail operations over the Joint Line. This Agreement, which was approved by the Interstate Commerce Commission, establishes BNSF as the operator of the Joint Line, makes BNSF responsible for the maintenance of the Joint Line, and gives BNSF the right to establish rules for Joint Line operations without discrimination in favor of either party.

On May 14 and 15, 2005, two derailments occurred on the Joint Line within a few miles of one another. These derailments and the work required to repair the affected lines severely disrupted coal operations in the PRB. BNSF, in consultation with UP, took immediate short-term measures to address the derailments and to rehabilitate track and roadbed conditions. But the remedial track maintenance reduced available track capacity and required slow orders because of safety concerns. As a result, coal loadings at PRB mines served by the Joint Line were briefly halted after the derailments and were substantially reduced during the rest of 2005. Congestion and reduced loadings on the Joint Line depleted some utilities' coal stockpiles just as they were about to experience high demand for electricity during the hot summer months.

BNSF studied the causes of the derailments and concluded that the derailments had resulted from a confluence of events. An extraordinary amount of rain and snow had fallen at the same time that the frozen ground was thawing and additional sub-surface moisture was rising up through the roadbed. Coal dust accumulations in the rail ballast had exacerbated the drainage problems caused by the excessive moisture in the roadbed. The mixture of coal dust and water caused the ballast to weaken to the point that the roadbed no longer provided adequate support for the rails.

BNSF concluded that it had to take measures to prevent a recurrence of the derailments and the severe service disruption caused by these outages. BNSF had been studying the problem of coal dust and possible dust suppression measures before the derailments, but BNSF substantially expanded its efforts to understand the scope and causes of the coal dust problem in the PRB and to investigate possible ways to address the problem of coal dust emissions. BNSF gave the highest priority to the study. BNSF retained an environmental and energy research and development firm, SWA, to assist in setting up a data gathering network so that there would be a solid factual record for understanding the coal dust problem and developing possible solutions. SWA had worked extensively with Norfolk Southern Railway Company in the 1980s on coal dust issues in the East. SWA worked with BNSF and an environmental engineering firm, Conestoga-Rovers Associates ("CRA"), to implement the data gathering network and to set up protocols for conducting field and laboratory tests and data analyses.

The data gathering network set up after the derailments consisted of three basic parts. First, an extensive network of dustfall collectors was set up at several different locations along the PRB rail lines. Coal accumulating in the dustfall collectors is gathered at 30-day intervals and measured. These instruments allow BNSF to keep track of overall coal dust deposition rates along the PRB lines and at varying distances from the track. However, these dust collectors cannot be used to measure dust emissions from individual trains.

Second, SWA set up Trackside Monitors ("TSMs") at Milepost 90.7 on the Joint Line and at Milepost 558 on BNSF's Black Hills Subdivision lines. The TSMs consist of a tower on which is mounted a weather system and a sophisticated electronic dust monitor referred to as an e-sampler. The dust monitor measures the number of dust units in the air at five-second intervals. It is therefore able to measure the total amount of coal dust emitted by a passing train as the train moves past the TSM location. Dust monitors are mounted on both sides of the track so that dust levels can be measured on the downwind monitor for each train. Equipment installed on and near the tracks allows BNSF to identify each train and therefore to produce reliable train-specific coal dust measurements.

Third, SWA assisted BNSF in monitoring coal dust emissions from certain instrumented trains so as to test the effectiveness of various dust suppression measures. The instruments include mobile weather stations (called Rail Transport Emission Profiling Systems or "RTEPS") and Passive Collectors ("PCs") that are attached to the cars in a test train. The passive collectors are mounted on the rear sill of cars at specified intervals within the train and the coal captured in the PCs over the course of a train trip can be measured and compared to determine the impact of various suppression alternatives being tested. For example, since 2005, SWA and BNSF have run several instrumented trains testing the effectiveness of different surfactants on limiting the amount of coal dust released in transit. Surfactants are chemical solutions that are sprayed onto the top of loaded coal to keep the coal from being blown out of a car during transit.

BNSF worked closely with its shippers and their mine agents to inform them of the results of BNSF's extensive data gathering efforts. BNSF regularly attended meetings of the National Coal Transportation Association ("NCTA"), whose members include numerous coal shippers and mines, and made extensive presentations on the results of the ongoing tests and analyses. BNSF also undertook numerous studies at the request of NCTA members to investigate various issues of concern to shippers and the mines and presented the results of those studies to the NCTA.

In addition to these data gathering efforts, BNSF sought to understand better the physical impact of coal dust on rail infrastructure. Since 2006, BNSF has worked with Dr. Erol Tutumluer, a Professor of Civil and Environmental Engineering at University of Illinois at Urbana-Champaign, who has done extensive studies of railroad track structure and the causes of track failures. Dr. Tutumluer advised that while coal dust had not previously been identified as a significant ballast contaminant, it actually has characteristics that make it one of the worst possible fouling agents. He found that coal dust has a very high water holding capacity which limits drainage in ballast fouled by coal dust. His tests also showed that ballast contaminated by coal dust has a much lower load bearing capacity than ballast fouled with other contaminants, which is an obvious problem for PRB lines that carry a greater volume and annual tonnage of freight than any other rail lines in the United States. Particularly when it gets wet, coal dust can have a highly destabilizing effect on rail ballast.

BNSF concluded that coal dust emissions had to be substantially eliminated. During BNSF's study of the coal dust problem, BNSF was surprised to see how quickly coal dust accumulated in the ballast. In one area of new track construction, BNSF discovered a few months after the new track had been installed that the ballast had already become fouled. BNSF carried out a coal dust cleaning effort in 2008, focused on gathering visible deposits of coal dust along the right of way, in creek beds next to tracks, and along bridge abutments, and filled over 300 railcars with coal dust for disposal at a landfill.

Expanded maintenance, while necessary to deal with the rapid accumulation of coal dust, is clearly not an adequate or responsible solution to a problem that has the potential for disrupting the supply of PRB coal. It is often difficult to detect coal dust before it becomes a problem because the coal dust quickly makes its way down into the ballast. Visual inspection of the rail bed cannot be relied on to locate areas where fouling has occurred. More widespread maintenance activity must be carried out to make sure problems do not develop, but such extraordinary maintenance of way activities are intrusive and disrupt train operations. Tracks must be taken out of service and slow orders issued to allow maintenance work to proceed. Maintenance effectively consumes capacity on the railroad, and on the heavily traveled PRB lines, the capacity available for maintenance activities is limited. Eventually, new track would need to be added just to be able to maintain the existing rail infrastructure.

BNSF therefore set out to determine whether there were ways to meaningfully limit coal dust emissions from loaded railcars. BNSF determined that coal dust emissions could be reduced by changing the load profile of loaded coal cars. SWA had previously studied the aerodynamics of loaded coal cars for Norfolk Southern. SWA provided BNSF with an idealized load profile which, if achieved during the loading process, would reduce the impact of wind and air currents on the loaded coal and thereby reduce coal dust emissions during transit. PRB mines adopted a modified loading chute that makes it possible, if sufficient care is given during the loading process, to achieve the ideal load profile. The load profile and modified loading chute design are described in Appendix A to BNSF's Rules Publication 6041-B. Subsequent monitoring of loading practices indicates that additional care needs to be taken in the loading process to achieve the load profile.

Even if coal cars are loaded to the ideal load profile, substantial dust emissions still occur. Therefore, BNSF set out to identify a coal dust emission limit that could be established as an operating rule applicable to the Joint Line and BNSF's Black Hills Subdivision. BNSF concluded that the data gathered at the TSMs set up with the assistance of SWA could be used to set a limit on coal dust emissions at the location of the TSMs which, if met by all trains passing the TSMs, would effectively eliminate coal dust at those locations. The data gathered by BNSF on test trains and in the dustfall collectors showed that coal trains emit dust sporadically throughout a trip. However, BNSF concluded that if shippers pursued methods sufficient to limit coal dust emissions to levels permitted at the TSM location, e.g., the application of a surfactant to the loaded coal car, those same measures would effectively limit coal dust emissions along the entire length of the movement and the problem of dusting on coal lines would be effectively eliminated. The TSM dust monitors would act like a "traffic cop" at a fixed location to ensure that coal dust emissions had been successfully curtailed along the PRB rail lines.

BNSF carried out extensive field and laboratory tests on the electronic dust monitors and concluded that the readings taken from these monitors between September 2005 and August 2007 could be used to set a coal dust emission standard that could be applied to individual trains and used to identify specific trains emitting unacceptable amounts of coal dust. The dust monitors measure in real time the number of dust units emitted by a train passing the TSM. The dust units for a particular train can be summed up while the train passes the TSM location to produce an Integrated Dust Value ("IDV.2") for the train. Mr. Sultana identified a maximum IDV.2 value for each TSM location which, if met by all trains at that location, would give BNSF a very high degree of confidence that at least 85% (and possibly as much as 95%) of the coal dust emissions historically measured at that TSM location would be eliminated. The emissions limits are set out in the BNSF's Rules Publication 6041-B. Mr. Sultana explains his methodology in detail in his Verified Statement.

BNSF has given individual shippers the flexibility to choose a dust suppression method that ensures compliance with BNSF's coal dust emissions standards. One promising way to ensure compliance is to apply a surfactant to the top of a loaded coal car. BNSF and its consultants carried out numerous laboratory and field tests beginning in 2005 on the effectiveness of various surfactants in reducing coal dust emissions. As noted above, several instrumented trains were run to determine the relative effectiveness of different chemical surfactants. BNSF found that the use of surfactants, particularly with properly groomed coal cars, can substantially eliminate coal dust emissions. BNSF is in the process of carrying out at the request of several PRB shippers a large scale trial of dust suppression alternatives, and BNSF has expanded its use of instrumented trains to assist in developing data through the current trial that will enable shippers to choose effective dust suppression measures.

BNSF first established its coal dust emissions standard as an operating rule under the Joint Line Agreement and communicated the new rule to UP on November 7, 2008. BNSF subsequently published its coal dust emissions standards in BNSF's Rules Publication 6041-B on April 30, 2009 and expanded the rule to cover BNSF's Black Hills Subdivision on May 27, 2009. The coal dust emissions standards in BNSF's Rules Publication had an effective date of November 1, 2009. On October 2, 2009, AECC filed a petition for a declaratory order seeking a declaration from the Board that BNSF's coal dust emissions standards set out in BNSF's Rules Publication constitute an unreasonable rule or practice and an illegal refusal to provide service. AECC also sought a stay of the effective date of BNSF's emissions standards to give the Board an opportunity to address AECC's declaratory order petition. BNSF responded on October 21, 2009, indicating that it had suspended the effective date of the emissions standards in BNSF's Rules Publication 6041-B until August 1, 2010 and further stating that it welcomed the opportunity to have the Board examine the reasonableness of BNSF's measures to address the problem of coal dust in the PRB. On December 1, 2009, the Board initiated this proceeding.

ARGUMENT

I. The Board Should Declare that BNSF May Establish Rules Designed to Limit the Emission of Coal Dust from Coal Trains Operating Over its Lines.

In this declaratory order proceeding, BNSF seeks confirmation from the Board that it is pursuing a legally permissible course of action in establishing rules that are designed to limit the emission of coal dust from coal trains operating over its lines. BNSF believes that the standards that have been challenged here are needed to assure safe, efficient and reliable operations on BNSF's coal lines. The goal of these standards is not simply to protect BNSF's physical plant from being degraded by coal dust but also to guard against the risks of disruption in the provision of coal transportation service.

Long-established judicial and agency decisions compel the conclusion that BNSF can regulate coal dust emissions from trains operating over its lines. These decisions establish that rail carriers have broad authority to adopt operating rules to promote safe, efficient, and reliable operation of their railroads. *See Platt v. LeCocq*, 158 F. 723, 730-31 (8th Cir. 1907) ("A common carrier has the right to conduct its business in its own way in accordance with the rules of the common and statutory law. . . . It has the right to make and enforce reasonable regulations which may lawfully fix the times, the places, the methods, and the forms in which it will receive the various commodities it undertakes to carry, and the rules which it thus adopts are presumptively right and reasonable."); *M. Longo Fruit Co. v. Ill. Traction Sys.*, 38 I.C.C. 487, 489 (1916) ("Both this Commission and the courts have held that carriers have the right to make reasonable and appropriate rules respecting the acceptance and transportation of traffic."). Unsurprisingly, rail carriers' power to set reasonable operating rules is accompanied by the power to modify existing operating rules and practices. *See Robinson v. Baltimore & O.R. Co.*, 129 F. 753, 755 (4th Cir. 1904) (noting the established rule that "the power to make reasonable regulations as to the manner and place where the railroad would receive coal for shipment implied the power to change and modify such regulations from time to time upon reasonable notice to the public").

A rail carrier's broad authority to establish operating rules that promote safety and efficiency was recently affirmed by the Board's decision in *N. Am. Freight Car Ass'n v. BNSF Railway Co.*, STB Dkt. 42060 (Sub-No. 1) ("*Freight Car*") at 6 (Jan. 24, 2007), which rejected an unreasonable-practices challenge to BNSF's charges for holding empty private cars on its system. The Board recognized that BNSF's charges "encourage shippers to utilize their private cars more efficiently" and that BNSF's past practice of not imposing such charges "does not mean that [the new charges are] unlawful . . . under today's conditions." *Id.* Under the logic of the *Freight Car* decision, the fact that BNSF had not taken steps prior to the issuance of the challenged standards to restrict coal dust emissions is not a valid reason for questioning the standards. The growth in coal volumes over the Joint Line and other lines have made it necessary to restrict coal dust emissions "under today's conditions."

Long-standing case law supports the authority of BNSF to adopt the very sort of operating rule that is at issue in this proceeding. Rail carriers' broad authority to establish operating rules includes the power to set reasonable standards for packing and loading freight in railcars. *See, e.g.*, *In re Suspension of W. Classification No. 51, I.C.C. No. 9*, 25 I.C.C. 442, 486 (1912) ("Carriers have an undoubted right to demand and insist upon secure packages for the protection of the commodities contained in them, as well as for the protection of other freight."). Moreover, the ICC long ago held that railroads could require shippers to bear the expense of special measures necessary to prevent cargo such as grain and flaxseed from leaking from railcars. *See Chicago Bd. of Trade v. Abilene & S. Ry. Co.*, 220 I.C.C. 753, 761 (1937) ("We find that, as the installation of grain doors is an incident of loading bulk grain, it is not unreasonable to require that the shipper should, at his own expense, install the doors furnished by the carriers and made available to him . . . ."); *In re W. Trunk Line Rules, Regulations, and Exceptions to Classifications*, 34 I.C.C. 554, 578 (1915) (allowing rail carrier to issue rule "that shipments of flaxseed in bulk will not be accepted for transportation unless loaded in cars which have been properly lined at shipper's expense to prevent loss by leakage").

It follows from rail carriers' broad authority to set packing and loading standards designed to prevent leakage that BNSF may set reasonable standards designed to minimize the emission of coal dust. Similar authority is regularly exercised through a range of rules intended to ensure safe and efficient carrier operations. In the context of loading railcars, these rules recognize the commonsense principle that the best way to ensure safe, efficient, and reliable rail operations is for shippers to load freight in a manner that does not allow the freight to escape from railcars. This commonsense principle is reflected in BNSF's general loading rule, which provides that the "[s]hipper is responsible for loading railcar . . . so that lading will not be released, discharged or inadvertently removed from railcar during rail carrier handling . . . ." *See* Fox Verified Statement ("V.S."), Exhibit 4. BNSF has numerous rules that apply this general rule in particular contexts. For example, there are rules governing the manner in which heavy equipment is loaded and secured in railcars to ensure safe operations and avoid service disruptions. *See* Fox V.S., Exhibit 5. Other rules govern the loading of scrap metal into open top cars so that the scrap metal does not escape from the cars in transit. *See* Fox V.S., Exhibit 6. Additionally, there are operating rules governing the leakage of materials in transit. *See* Fox V.S., Exhibit 7.

Like all of these rules, BNSF's coal dust emissions standards fit within rail carriers' broad authority to adopt operating rules that promote safe, efficient, and reliable operations by requiring shippers to keep their freight in railcars. The coal dust emissions standards are entirely consistent with BNSF's common carrier obligation because they are intended to assure that the transportation that BNSF is required to provide as a common carrier is operationally sound and consistently reliable.[1]

Importantly, the Board's predecessor, the Interstate Commerce Commission, has previously recognized BNSF's authority to promulgate reasonable rules governing rail

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[1] Apart from promoting reliable common carriage, the coal dust emissions standards at issue here are an appropriate means of protecting BNSF's interest in preventing its property from being degraded by coal dust contamination. It would clearly be a trespass if a party, without permission, entered BNSF's right of way and dumped coal dust on the tracks. *See* Restatement (Second) of Torts § 158(a) ("One is subject to liability for trespass, irrespective of whether he thereby causes harm to any legally protected interest of the other, if he intentionally enters land in the possession of the other, or causes a thing . . . to do so."). The heavy emissions of coal dust that BNSF has experienced are the effective equivalent of having coal dumped on BNSF's right of way without its permission. BNSF has a legitimate interest in acting to protect its interest in its property. Indeed, a regular feature of railroad operating rules is that, in addition to promoting safe and efficient transportation, they have the effect of protecting a rail carrier's interest in its real property and tangible assets. For example, there are rules that set specific standards so that rail cars do not damage BNSF's property beyond normal wear and tear. *See* Fox V.S., Exhibit 8.

operations over the PRB Joint Line. Under the Joint Line Agreement between BNSF and UP predecessors, BNSF is entrusted with maintaining safe and efficient operations over the Joint Line. Section 2.7 of the Agreement provides that operations over the Joint Line shall be "in strict accordance with the Consolidated Code of Operating Rules and such other rules and regulations as promulgated by [BNSF], as modified and amended from time to time. . . ." The Joint Line Agreement was approved by the ICC in connection with its approval of the construction and operation of the Joint Line. *See Chicago & N. W. Transp. Co. Approval of Terms of Construction, Ownership & Operation of a Line of R.R. in Campbell & Converse Counties, Wyo.*, ICC Finance Docket No. 29066 (served Oct. 22, 1982).

II. BNSF's Coal Dust Emissions Standards Are Not Unreasonable.

A. The Reasonableness Inquiry

Because Congress has not defined in 49 U.S.C. § 10702 what constitutes a reasonable rule or practice, "[t]he [Board] has been given broad discretion to conduct case-by-case fact-specific inquiries to give meaning to these terms, which are not self-defining, in the wide variety of factual circumstances encountered." *Granite State Concrete Co. v. STB*, 417 F.3d 85, 92 (1st Cir. 2005) (rejecting challenge to STB's conclusion that railroad operating restrictions were reasonable). In performing this inquiry, the Board should not substitute its judgment for BNSF's judgment. Instead, the focus of the inquiry is whether BNSF's coal dust tariff is reasonable. The issue, in other words, is not whether the coal dust emissions standard that BNSF has adopted is the standard that the Board would have adopted if the Board were in the business of imposing railroad operating rules, but whether there is a rational basis for the approach BNSF has taken to dealing with the coal dust problem and whether the standard that BNSF adopted is rationally related to the problem it seeks to address.

B. It Was Rational for BNSF to Conclude that Coal Dust Emissions Need to Be Curtailed Rather than Dealt with Exclusively through Maintenance.

There can be no serious dispute that the accumulation of coal dust on BNSF's coal lines poses a risk to safe and efficient operations on the Joint Line and BNSF's other PRB coal lines. The combination of coal dust accumulation and heavy flooding in 2005 led to serious disruptions in coal transportation service that must be avoided in the future. BNSF is committed to preserving the integrity of the coal supply chain.

In its initial Petition for a Declaratory Order, AECC contended that the adverse effects of coal dust emissions should be addressed exclusively through "normal maintenance." AECC's Petition for Decl. Order at 3. Based on BNSF's experience, that suggestion is simply not realistic. BNSF has determined that not even the enhanced levels of maintenance that BNSF has been pursuing are sufficient to eliminate all the risk inherent in coal dust accumulation. As explained in the Verified Statement of Craig Sloggett, who has responsibility for maintenance and maintenance planning on BNSF's Powder River Division, BNSF has been pursuing extraordinary maintenance efforts on the Joint Line and Black Hills Subdivision. Sloggett V.S. at 6-9. Even with these efforts, it has not been possible to keep up with the rapid accumulation of coal dust. Sloggett V.S. at 5-6.

Gregory C. Fox, Vice President of Transportation for BNSF, explains that "[f]rom a maintenance of way perspective, it is better to keep coal dust out of the ballast in the first place, rather than to undertake extraordinary measures to maintain a railroad that is compromised by coal dust." Fox V.S. at 8. This is the case because, as Messrs. Fox and Sloggett explain, there are limitations on what even vigilant maintenance can accomplish. One limitation stems from the difficulty of identifying all areas where ballast has been fouled by the accumulation of coal dust. While many areas potentially compromised by coal dust accumulation are visible to the naked eye, there are other areas where the surface of the roadbed or shoulder ballast reveals no visible accumulation of dust, and yet the ballast beneath the surface has been fouled. If the sub-surface dust has built up rapidly, the areas of undetected dust buildup may not be addressed in a timely manner, even under a regime of enhanced maintenance.

A second drawback in relying exclusively on maintenance to address the coal dust problem, is that maintenance activities impinge upon rail operations, and the more intensive the maintenance is, the greater the impingement. Fox V.S. at 8-9; Sloggett V.S. at 9. Maintenance requires that tracks be taken out of service and that slow orders be issued. The effect is to reduce line-haul capacity. As Mr. Fox explains, "it is not a question of simply expanding maintenance to deal with coal dust. Eventually, new track would need to be added just to be able to maintain the existing rail infrastructure." Fox V.S. at 8.

BNSF believes that addressing the problem of coal dust solely through enhanced maintenance is not a responsible way to address the risk of potential disruption in the supply of PRB coal to coal-fired electric utilities. The Board itself has stated that it "views the reliability of the nation's energy supply as crucial to this nation's economic and national security, and the transportation by rail of coal and other energy resources as a vital link in the energy supply chain." *Establishment of a Rail Energy Transportation Advisory Committee*, STB Ex Parte No. 670, at 2 (served July 17, 2007). Given the vital public interest in assuring the reliable transportation of coal, BNSF has concluded that it must act to limit coal dust emissions rather than merely dealing with them after the fact.

C. BNSF Acted Rationally in Adopting a Performance Based-Emissions Standard.

The IDV.2 coal dust emissions standards at issue in this proceeding are performance-based standards in that they measure whether individual coal trains emit quantities of dust that exceed or fall below a specified dust emissions level. As an alternative approach, BNSF could have prescribed an activity-based standard for limiting coal dust emissions. That is, BNSF could have required shippers to put tops on their coal cars, or it could have required them to spray the coal loaded in cars with surfactants. BNSF elected to adopt a performance-based standard because it believed that that approach would give shippers the leeway to determine on an individual basis the method of complying with the standard that best suits each shipper's needs.

The performance based approach not only allows shippers to choose how they will comply with the emissions standards, but it should also encourage market-based innovations in coal dust emission control techniques that will result over time in reduced costs and improved methods of dust suppression. As BNSF's witnesses Messrs. Bobb and VanHook note, various suppliers of coal dust suppression products are already competing to supply shippers with products that will allow them to achieve compliance with the emissions standards. Given the size of the potential market – over 300 millions tons per year of PRB coal – one would expect vigorous competition to supply shippers with effective surfactants and alternative dust suppression products. The likely result of such competition is the availability of improved dust suppression products at lower cost.

The Board has been a strong proponent of market-based, private sector solutions to a wide variety of problems that arise in the rail transportation sector. By adopting a performance based standard, BNSF has sought to create an environment in which market based solutions to the coal dust problem are most likely to emerge. There is no reason to conclude that BNSF's approach is anything other than reasonable.

D. BNSF's IDV.2 Standards Are Practical and Conservative.

BNSF's witnesses explain in detail the steps that BNSF took to develop the IDV.2 emissions standards at issue in this proceeding. In fashioning its standards, BNSF relied upon (1) extensive data collection,[2] (2) extensive analysis of the data,[3] and (3) statistically sophisticated methods to formulate an emissions standard that is practical given the limited options for measuring dust emitted from moving coal trains.[4]

BNSF applies its coal dust emissions standards to loaded coal trains moving past track-side dust monitors at specific locations on BNSF's coal lines. This approach is practical because it allows the dusting from individual trains to be monitored without disrupting mine loading or train operations. Given the episodic nature of coal dusting and the large geographic territory covered by moving coal trains, the "traffic cop" approach to the monitoring of coal dust emissions is a logical way to apply the IDV.2 standards to individual trains.

The IDV.2 standards themselves are conservative, as Mr. Sultana explains. The standards were devised specifically by identifying a desired level of reduction in coal dust emissions and by taking into account the variability in the e-samplers used to monitor coal dust emissions. By establishing a dust level of 300 IDV.2 on the Joint Line, Mr. Sultana identified a dust emissions level that any shipper should be able to achieve if it makes a good faith effort to comply with BNSF's standard. The same is true for the standard that Mr. Sultana developed for the Black Hills Subdivision.

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[2] *See* VanHook V.S. at 4-8; Emmitt V.S. at 4-12.

[3] *See* VanHook V.S. at 4-8; Emmitt V.S. at 4-12.

[4] *See* Sultana V.S. at 6-11.

It may be that the specific IDV.2 levels that BNSF calculated will be the target of second guessing in this proceeding. But those levels are not "arbitrary" as AECC contended in its Petition for Declaratory Order. The standards are the product of careful investigation and analysis by highly trained professionals. BNSF has been thorough and rigorous in its search for a solution to the coal dust problem, and this includes the development of the specific IDV.2 standards by Mr. Sultana. It is certainly possible that a more refined IDV.2 standard may be developed in the future as more sophisticated dust measurement equipment becomes available. But it would be irrational to deem the existing standards unreasonable simply because they do not meet some illusory ideal of accuracy.

III. BNSF's Position Regarding Compliance with its Coal Dust Emissions Standard

A. The Board's Review of Any Compliance Provisions that BNSF Might Adopt Would Be Limited to the Application of those Provisions to BNSF Common Carrier Shippers.

One of the many unfounded claims in AECC's Petition for a Declaratory Order was the assertion that BNSF's rules publication setting forth its coal dust emissions standard constitutes "a refusal to provide service." Declaratory Order Petition at 1. As BNSF explained in its reply to AECC's petition, BNSF has not adopted any particular measures to ensure compliance with its coal dust emissions standards. Consideration of specific enforcement measures is therefore premature. However, BNSF understands that there is an interest in what approach to compliance it would pursue if it became necessary to implement enforcement measures, so BNSF offers a framework for its likely approach to enforcement.

As a threshold matter it is important to recognize that the Board has authority to assess the reasonableness of the challenged emissions standards only as they apply to BNSF's common carrier transportation. Thus, the only question that could arise before the Board regarding enforcement is whether BNSF could require its common carrier shippers to comply with the coal dust emissions standards set forth in BNSF's Rules Publication. BNSF intends to apply the coal dust standards to its contract shippers in accordance with the terms of privately negotiated coal transportation contracts, but BNSF may not disclose or discuss specific terms of those confidential agreements in this proceeding.

The coal dust standards set out in BNSF's Rules Publication do not apply to UP's Joint Line coal shippers unless and only to the extent that they are also BNSF coal shippers. However, BNSF is responsible for operating the Joint Line and, as BNSF's witness Stevan Bobb explains, BNSF has issued an operating rule under the Joint Line Agreement with UP that adopts the same coal dust emission standard set out in the Rules Publication at issue here. The operating rule requires that the coal dust emissions standard must be met as soon as practicable for all movements on the Joint Line. BNSF expects that UP will comply with the operating rule.

B. A Proposed Framework For Addressing Enforcement of the Challenged Rule

BNSF expects that shippers will voluntarily comply with the coal dust standards at issue here if the Board finds that they are not unreasonable. If any enforcement measures were necessary, they would be set out in separate notices and they would be limited to circumstances of inadvertent or intentional non-compliance. BNSF's enforcement approach would turn on individual shippers' good faith intention to comply with the coal dust emissions standards. Shippers' intent to comply would be presumed unless or until there is a failure by a shipper's train to meet the IDV.2 level. At that point, BNSF would consider requiring that the shipper execute a certificate indicating its intent to comply with BNSF's coal dust standards.

Where a shipper has executed a certificate indicating its intent to comply with the standards but is not immediately able to implement its proposed method of compliance or the compliance method adopted is ineffective and the standard is not met, BNSF might consider publishing a new operating item that would provide for some type of special handling charge for the non-compliant coal trains. BNSF would hope that instances of willful non-compliance with the emissions standards would be non-existent. Were such a circumstance to arise, BNSF would reserve the right to decline to provide service until the shipper had manifested a good faith intention to comply with the standards.

Respectfully submitted,

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March 16, 2010

CERTIFICATE OF SERVICE

I hereby certify that on this 16th day of March, 2010, I caused a copy of the foregoing, along with the Confidential and Highly Confidential Exhibit Volumes, to be served on the following Parties of Record by hand delivery or by Federal Express:

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Counsel's Exhibits

COUNSEL'S EXHIBITS

EXHIBIT 1


New Track Construction – Fall 2006
M3 Mile Post 52 – Orin Subdivision
Photograph May 2007
52

Orin Subdivision MP 45.7

2009
Note coal dust
Accumulation
Alongside track

BNSF


04/29/2009

Orin Subdivision 90.5 - 97

2009
What you end up
With when ballast
Contaminated with
Coal dust and it
rains

BNSF

BNSF_COALDUST_0022334

EXHIBIT 2


05/05/2008 14:10

New Track Construction – Fall 2006
M3 Mile Post 52 – Orin Subdivision
Photograph May 2007

Nacco Bridge

EXHIBIT 3


CATERPILLAR
PASSER AMERICAN
09/11/2008 13:19

Reno Subdivision - UC01

2009
Undercutter work
Note normal ballast
Is not "black".

BNSF

Reno Subdivision - UC01

2009
Undercutter work

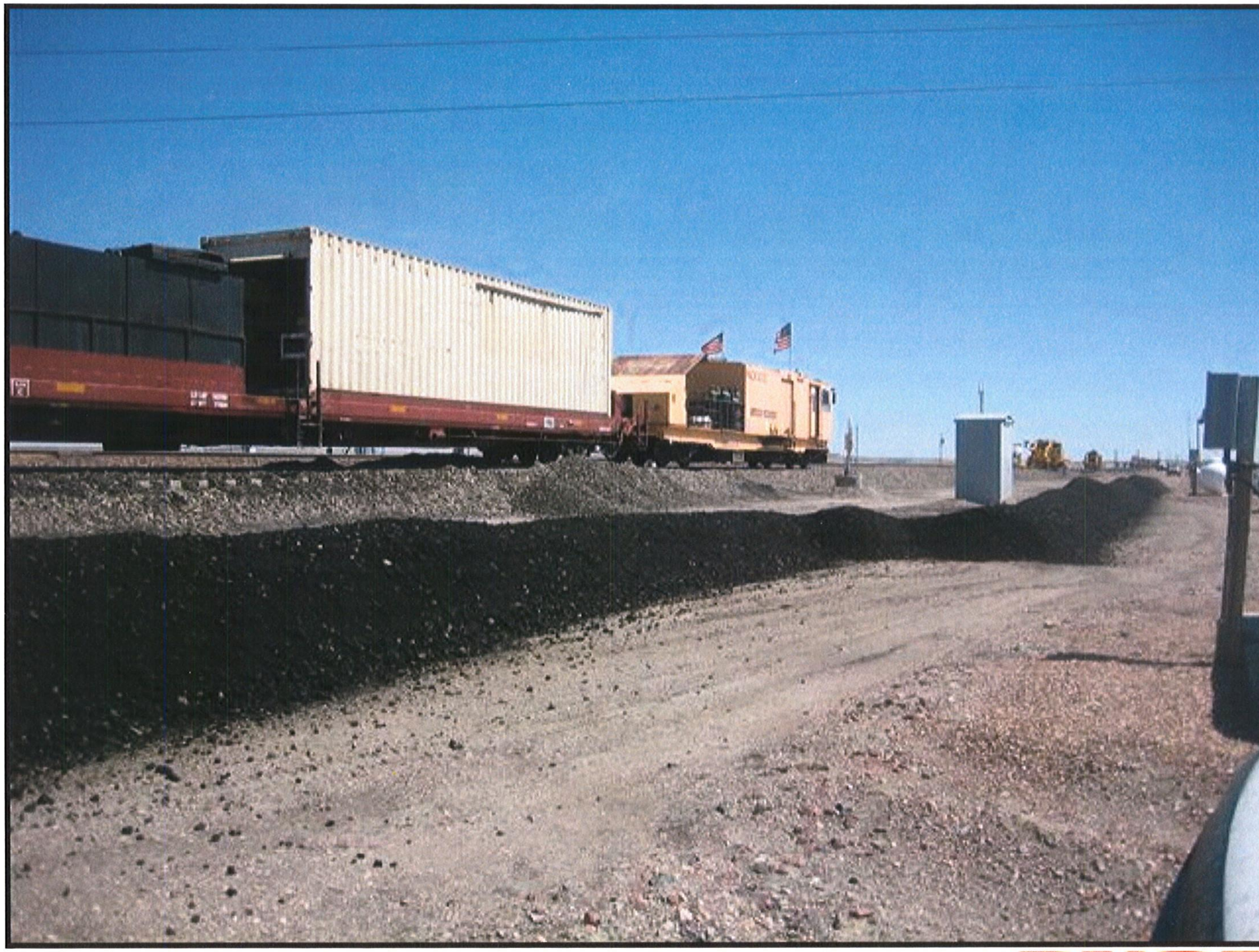

EXHIBIT 4

Counsel's Exhibit #4 (On CD)

BNSF-0023002.mpg


BNSF-0022999.wmv

BNSF-0023003.mpg

BNSF-0022995.mpg

VERIFIED STATEMENT OF GREGORY C. FOX

BEFORE THE
SURFACE TRANSPORTATION BOARD

STB Finance Docket No. 35305

PETITION OF ARKANSAS ELECTRIC COOPERATIVE
FOR A DECLARATORY ORDER

VERIFIED STATEMENT OF GREGORY C. FOX IN SUPPORT OF
BNSF RAILWAY COMPANY'S OPENING EVIDENCE

My name is Gregory C. Fox. I am Vice President, Transportation of the BNSF Railway Company, a position I have held since May 2007. In this position, I have responsibility for leading BNSF's transportation team, which includes Field and Network Operations, Locomotive Distribution, and Crew Management. The team includes almost 20,000 employees and has an annual budget that exceeds $2.2 billion.

The purpose of my verified statement is to explain to the Board that coal dust emissions from rail cars must be substantially eliminated to ensure the safe, efficient, and reliable operation of rail lines in the Powder River Basin ("PRB"). Coal fired electric utilities throughout the United States rely upon an assured supply of Powder River Basin coal. BNSF is not willing to incur the risk of supply disruptions that could occur if coal dust accumulates in the roadbed, fouls the ballast that supports our track structure and thereby compromises the integrity of that track structure. BNSF must be able to limit coal dust emissions in the interest of providing reliable coal transportation service. I urge the Board to find that BNSF's coal dust emissions standards at issue in this proceeding are a reasonable means of addressing the coal dust problem that we have encountered on our railroad.

Work Experience and Education

I began my railroad career in 1984 as a corporate management trainee for the former Burlington Northern Railroad. During my early years I held operations positions such as trainmaster, terminal trainmaster, and terminal superintendent. In 1988, I became Manager, Finance and Strategic Planning, and I subsequently held a series of positions in Finance until 1992, when I was promoted to Director, Information Technology, Information Systems Services. Over the next ten years, I held a series of technology-related positions including Assistant Vice President, ISS; Vice President, eBusiness; Vice President, Technology Services; and Chief Information Officer.

In September 2002, I was named Vice President, Engineering, a position I held until I was named to my present position in May 2007. As Vice President, Engineering, I oversaw BNSF's efforts to provide safe, efficient, and reliable physical infrastructure, tracks, signal systems, bridges, tunnels, and buildings. From 2006 to 2007, I also served on the Board of Governors of the American Railway Engineering and Maintenance Association, which recommends standards for various engineering aspects of railroad infrastructure.

I have a B.S. in Finance and Transportation Management from the University of Colorado and a Masters of Business Administration in Corporate Finance from Avila College.

Concerns About the Impact of Coal Dust on PRB Lines Predated the 2005 Derailments.

Since the 1970s, BNSF and its predecessor Burlington Northern has had to deal with coal dust accumulations on the right of way. When I became Vice President, Engineering, in September 2002, BNSF understood that accumulated coal dust affected the reliability of rail switches and contaminated the ballast, but we did not fully appreciate the magnitude of the impact that coal dust could have on the integrity of the roadbed. We thought the problems caused by coal dust were mainly limited to the reliability of switches, the risk of the coal dust catching fire, and the burdens of increased maintenance requirements. The increased maintenance included undercutting and switch undercutting, other surfacing requirements, and increased switch maintenance. This additional maintenance activity affected operations on the Joint Line since maintenance work reduces track capacity and causes slow orders as trains on adjacent track must travel below maximum speed to ensure the safety of the maintenance operations.

Although we were generally aware that coal dust caused problems, we had not intensively studied coal dust, we were not aware of the magnitude of the adverse impact to the track structure, nor had we adopted specialized programs to deal with the coal dust problem. However, by late 2002, coal dust became a source of heightened concern regarding the long term stability of the roadbed. With steadily increasing traffic volumes on the Joint Line, coal dust deposits on the right of way far surpassed BNSF's historical experience. As a result, in December 2003, BNSF undertook a study to quantify the magnitude of the problems associated with coal dust on the roadbed.

Throughout 2004, BNSF continued to monitor and study the rate of coal dust accumulation, the magnitude of the deposits, and the seasonal and locational impacts of coal dust accumulation on Joint Line operations and maintenance. This review was intended to form the basis of a long term plan that would address the increasing amounts and rate of coal dust deposits on the roadbed while ensuring that BNSF could accommodate the increasing volumes of coal traffic on the Joint Line.

In late 2004, preliminary findings from the coal dust study were reviewed internally within BNSF's engineering department. *See* Ex. 1. In the first quarter of 2005, a crossfunctional team within BNSF was formed to develop and coordinate a long term strategy for dealing with coal dust deposits along the Joint Line that would allow BNSF to meet the need for rising demand for coal shipments. By early May 2005, we believed that we had sufficiently quantified the coal dust problem to present our findings to BNSF's CEO. *See* Ex. 2.

While we were concerned about the increasing accumulations of coal dust, rail operations on our coal lines were satisfactory through the early spring of 2005. The Joint Line had accommodated record volumes in 2004 and the first four months of 2005. BNSF had increased its inspection and maintenance activities to deal with coal dust and we were confident that this expanded maintenance activity would be adequate to support Joint Line operations until long-term solutions could be implemented to address the problem of coal dust accumulations. However, subsequent events demonstrated that we had underestimated the risks posed by coal dust.

<u>The May 2005 Derailments on the Joint Line Made it Clear that Coal Dust Presents a Serious and Unacceptable Risk to Reliable Service.</u>

On May 14, 2005, a BNSF coal unit train derailed on the Joint Line. On May 15, 2005, less than eighteen hours later, a UP coal unit train derailed on the Joint Line a few miles away from the first derailment. These derailments and the work required to repair the affected lines severely disrupted coal operations in the PRB. BNSF, in consultation with our Joint Line co-owner Union Pacific, took immediate short-term measures to address the derailments and to rehabilitate track and roadbed conditions. As Vice President, Engineering, I led BNSF's efforts to restore operations on the Joint Line as quickly as possible. We immediately cleaned the site and rebuilt the track so that train operations could be resumed within a matter of days, although at a reduced level. Over the next few months, we undertook comprehensive rehabilitation measures such as undercutting substantial portions of the Joint Line, putting in new ballast, and cleaning turnouts.

Although we tried to minimize the disruption to the around-the-clock service that Joint Line shippers rely upon, the remedial track maintenance unavoidably reduced available track capacity and required slow orders because of safety concerns. As a result, coal loadings at PRB mines served by the Joint Line were briefly halted after the derailments and were substantially reduced during the rest of 2005. Congestion and reduced loadings on the Joint Line depleted some utilities' coal stockpiles just as they were about to experience high demand for electricity during the hot summer months. It was widely reported that some coal shippers sought alternate supplies of power on the open market.

As in all cases of derailments, BNSF investigated the causes of the May 2005 derailments. We concluded that the derailments were attributable to a confluence of events. First, an extraordinary amount of rain and snow had fallen over a short time period in late April and early May. Drying cycles were not long enough to allow moisture to drain from the roadbed. Second, temperatures were warm enough by mid-May that the frozen ground was thawing and additional sub-surface moisture was rising up through the roadbed. Third, the coal dust accumulations in the rail ballast had exacerbated the drainage problems caused by the excessive moisture in the roadbed. The mixture of coal dust and water caused the ballast to weaken to the point that the roadbed no longer provided adequate support for the rails.

Some coal shippers have claimed that the 2005 derailments on the Joint Line were the result of inadequate maintenance. In fact, we had been maintaining the Joint Line and our other coal lines to a high standard. Our ability to accommodate record volumes of coal up to the point of the derailments confirmed our belief that the coal lines were well maintained. In retrospect, if we had understood the full impact coal dust has on the track structure or if we had been able to anticipate the extraordinary weather events of late April/early May, we would have undertaken additional, extraordinary maintenance measures that might have prevented the derailments. But viewing our maintenance of the coal lines based on how we were performing and what we knew up to the time of the derailments, I do not believe our maintenance practices can be faulted. And it certainly makes no sense to say that inadequate maintenance caused the derailments because our pre-derailment maintenance was not in any way sub-standard.

BNSF Must Be Able to Establish Operating Rules to Ensure Efficient and Reliable Service.

The May 2005 derailments caused BNSF to focus on the problem of coal dust with a heightened sense of urgency. While we have never claimed that coal dust was the sole cause of the derailments, it was absolutely clear that the presence of coal dust in the ballast had contributed to the derailments and that coal dust was a ballast fouling agent that could be expected to weaken the track structure. While BNSF expanded its inspection and maintenance activities to prevent the recurrence of another derailment, the risk of serious operating problems would remain as long as substantial quantities of coal dust were being emitted from loaded cars and being deposited on the right of way. Therefore, immediately following the May 2005 derailments, BNSF initiated a high priority study to understand the full extent of the coal dust problem and to identify ways of eliminating or substantially reducing coal dust emissions from loaded coal cars. I put William VanHook, Assistant Vice President of Engineering in charge of the coal dust project. I asked him to keep our coal shippers and the coal mines informed of our progress in the study and, in particular, to work with the National Coal Transportation Association ("NCTA"), as NCTA had acknowledged the importance of addressing the problem of coal dust. *See* Ex. 3.

Under Mr. VanHook's supervision, BNSF and its consultants collected a large amount of data on the sources of coal dust in the PRB and the alternatives for curtailing coal dust emissions. As described in other witness statements, BNSF collected a large amount of data on coal dust emissions over a period of two years. We determined that the best way to deal with the coal dust problem would be to adopt a performance standard that would require coal shippers to limit emissions of coal dust from loaded cars. Using the data we had collected, BNSF established a limit on coal dust emissions which, if met by all coal trains moving on the Joint Line and on BNSF's Black Hills Subdivision, would substantially eliminate coal dust from the railroad right of way. The development of those emissions standards is addressed by other witnesses in this proceeding. BNSF adopted its Joint Line coal dust emissions standards first as an operating rule that applies to coal trains moving on the Joint Line, including Union Pacific trains. The Joint Line emissions standard, as well as the Black Hills Subdivision standard, was subsequently made applicable to BNSF common carrier shippers through BNSF's rules publication. As described by other BNSF witnesses, the standards are readily achievable by shippers that make a good faith effort to meet them.

It is standard practice in the rail industry for rail carriers to adopt operating rules designed to ensure safe, efficient, and reliable rail operations. Numerous operating rules govern the way freight is loaded and secured in railcars to ensure safe operations and avoid operating disruptions. Under BNSF's general loading rule, shippers are responsible for securely loading their freight so that the freight stays in rail cars. *See* Ex. 4 at BNSF_COAL_DUST_0082736. Other rules apply this general rule in particular contexts. For example, operating rules govern the manner in which heavy equipment and scrap metal are loaded and secured in railcars to ensure safe operations and avoid service disruptions. *See* Exs. 5-6. Additionally, there are operating rules that govern leakage of freight in transit. *See* Ex. 7. Other rules set specific standards for railcars so that the cars do not damage BNSF's property beyond normal wear and tear. *See* Ex. 8.

BNSF's coal dust emissions standards are like numerous other operating rules that require rail shippers to take actions with respect to the freight they load into railcars to ensure the safe and efficient movement of trains. Some coal shippers contend that BNSF should not be permitted to address coal dust through an operating rule designed to limit coal dust emissions. These shippers claim that BNSF should be required to deal with coal dust after it has fallen onto the right of way through expanded maintenance. But shippers of other commodities are not allowed to contaminate BNSF's right of way and compromise the integrity of our track structure simply because BNSF can fix the damage after the fact. The coal that falls onto the railroad right of way belongs to the shippers and it is their responsibility to keep it in the cars.

From a maintenance of way perspective, it is better to keep coal dust out of the ballast in the first place, rather than to undertake extraordinary measures to maintain a railroad that is compromised by coal dust. The challenges of detecting coal dust deposits that are not readily apparent on the surface but have worked their way into the ballast means that we cannot be certain that enhanced maintenance will always address the problem before it manifests itself. Moreover, maintenance of way activities are intrusive and disrupt train operations. Tracks must be taken out of service and slow orders issued to allow maintenance work to proceed. Maintenance effectively consumes capacity on the railroad, and on a very heavily traveled line like the Joint Line, the capacity available for maintenance activities is limited. Therefore, it is not a question of simply expanding maintenance to deal with coal dust. Eventually, new track would need to be added just to be able to maintain the existing rail infrastructure.

Finally, addressing the problem of coal dust through expanded maintenance is not a responsible way to deal with a problem that has the potential for disrupting the supply of PRB coal. The risk of service interruptions on PRB coal lines, including the Joint Line, requires that coal dust be kept from falling out of the loaded cars onto the right of way. Balancing the burdens of coal dust emissions restrictions against the risk of service disruption resulting from compromised track structure, leads to a very clear answer – we must take the steps necessary to avoid the risk of service disruption. There is no reason for the Board to second guess this conclusion.

The solution to the coal dust problem is to require that shippers take measures necessary to keep their coal in the coal cars. BNSF's coal dust emissions standards represent a reasonable limit on coal dust that shippers should be required to meet.

I declare under penalty of perjury that the foregoing is true and correct. Further, I certify that I am qualified and authorized to file this Verified Statement.

Executed on March 15, 2010

Gregory C. Fox

Gregory C. Fox

VERIFIED STATEMENT OF STEVAN B. BOBB

BEFORE THE
SURFACE TRANSPORTATION BOARD

STB Finance Docket No. 35305

PETITION OF ARKANSAS ELECTRIC COOPERATIVE CORPORATION FOR A DECLARATORY ORDER

VERIFIED STATEMENT OF STEVAN B. BOBB IN SUPPORT OF BNSF RAILWAY COMPANY'S OPENING EVIDENCE

My name is Stevan B. Bobb. I am Group Vice President, Coal Marketing for BNSF Railway Company ("BNSF"), a position I have held since the spring of 2006. In this position I have responsibility for the sales and marketing of BNSF's coal transportation services. Coal transportation is one of BNSF's four principal lines of business. In 2009, we transported 283 million tons of coal. The vast majority of this coal originates at mines located in the Powder River Basin ("PRB") of Wyoming. Coal originated in the PRB moves primarily to electrical utilities located throughout the western United States and is interchanged with eastern railroads for delivery to utilities located in the East as well. Coal transportation is a critical component of the domestic U.S. energy supply chain, and BNSF transports the largest volume of coal to domestic receivers of any U.S. railroad.

The purpose of my verified statement is to address from the marketing perspective both the problems created by coal dust emissions and potential ways to prevent those problems. As past events demonstrate, the accumulation of coal dust on densely traveled coal lines creates the risk of significant disruption to our rail operations, and also to the operations of our competitor the Union Pacific Railroad Company ("UP") who is a joint owner of the PRB Joint Line with us. Disruption of rail operations threatens the coal supply chain and creates serious risks of curtailed energy generation. BNSF has concluded that those risks can best be controlled by limiting coal dust emissions from rail cars while in transit. We believe that effective measures exist to control coal dust emissions and that the shippers who own the coal that falls onto our railroad line have the ability and responsibility to adopt such measures. BNSF has established coal dust emissions standards in the interest of maintaining the integrity of the coal supply chain, and we are optimistic that coal shippers will recognize that it is in their own larger interest to take voluntary measures to limit coal dust emissions.

Education and Work Experience

I have a B.S. in Agriculture from North Dakota State University. I joined BNSF's predecessor, the Burlington Northern Railroad, in 1987 and have been employed continuously by the railroad since that date. Following some early work in information systems and marketing support, my career has been spent primarily in line marketing positions. This has included extensive work in Minerals and Chemicals Marketing, where I eventually rose to the level of Vice President Minerals Marketing in June 1996. I subsequently became Vice President Chemicals Marketing in October 1996, Vice President of Agricultural Commodities Marketing and then Group Vice President, Agricultural Products Marketing. I became Group Vice President, Coal Marketing, which is my current position, in the spring of 2006. In addition to these marketing positions, I spent one year in an operations job as General Manager of BNSF's Texas Division in 2005 and a year as Vice President Business Unit Operations in 2004.

Operation of and Volume Growth over the PRB Joint Line

The Powder River Basin in northeastern Wyoming produces the largest volume of coal of any producing region in the United States and provides approximately 40 percent of the coal consumed in the country. Both BNSF and UP have access to the PRB. A critical artery for accessing the PRB mines that produce the majority of PRB coal is the 103 mile segment of railroad owned jointly by BNSF and UP that extends from Coal Creek Junction, WY in the North to Shawnee Junction, WY in the South.

A 1983 Joint Line Agreement between BNSF and UP predecessors governs rail operations over the Joint Line. This Agreement, which was approved by the Interstate Commerce Commission, establishes BNSF as the operator of the Joint Line, makes BNSF responsible for the maintenance of the Joint Line, and gives BNSF the right to establish rules for Joint Line operations without discrimination in favor of either party. The Joint Line Agreement is attached to this statement as Exhibit 1.

The Joint Line began operating as a joint facility in 1984. Traffic levels and Joint Line capacity have both increased tremendously over the intervening period. Combined BNSF/UP coal tonnage originated on the Joint Line increased from approximately 76 million tons in 1984 to 212 million tons in 1997. Over the eight year period from 1997 to 2005, Joint Line coal tonnage originations increased another 113 million tons (or 53 percent) to 325 million tons. Joint Line coal tonnage reached a high of 375 million tons in 2008, but has dropped off somewhat from that level due to the recession.

The capacity of the Joint Line has steadily increased over the 26-year period of Joint Line operations. What began as a single track railroad with limited passing sidings has grown to a triple track railroad, with sections that are quadruple tracked. The Joint Line has sufficient capacity to accommodate over 60 loaded coal trains per day, and an equal number of empties. The maximum capacity of the existing Joint Line plant is estimated to be over 400 million tons.

The growth in Joint Line coal traffic and capacity is significant for two related reasons. First, this growth underscores the increasingly critical role that the Joint Line plays in the energy supply chain. Second, this growth in coal volumes originating on the Joint Line is a primary reason why coal dust has emerged as a major problem on our railroad. Greater volumes transported over the rails means more coal dust emissions and the faster build-up of coal dust along the right of way.

Awareness of the Coal Dust Problem

In May 2005 while I was working as General Manager of BNSF's Texas Division, I became aware that two derailments had occurred on the PRB Joint Line and that those derailments, coupled with the need to repair the affected lines, caused serious disruption to coal operations in the PRB. I also learned indirectly that while heavy precipitation coupled with spring thaws was a triggering cause of the derailments, the accumulation of coal dust in the ballast underlying the track structure had been a significant contributing cause of the derailments. While anyone who was employed with the company at the time would have been aware of the derailments and the challenges to our operations and our shippers' operations, I did not have any personal involvement with the derailments or issues associated with coal dust in 2005.

I began to learn in detail about the coal dust problem in the spring of 2006 when I took over the job of Group Vice President, Coal Marketing. I learned about coal dust from my predecessor, Tom Kraemer, and I learned about it in greater detail from Bill VanHook, a BNSF Assistant Vice President & Chief Engineer Systems Maintenance and Planning, who had been tasked by our senior management with the job of understanding and addressing the coal dust problem. Over time, as I had occasion to travel to the PRB, I also learned about the coal dust problem from my own first hand observations, as the presence of dusting was and continues to be readily apparent from the observation of coal dust blowing out of loaded coal cars and visibly accumulating along the right of way.

In my transition to coal marketing, I learned that BNSF engineering personnel, including Mr. VanHook, had engaged in considerable study and concluded that unacceptable quantities of coal dust were accumulating along the right of way of portions of BNSF's coal network, including the Joint Line and other lines in and adjacent to the PRB, and that these accumulations posed risks to the integrity of the track structure, which in turn posed risks to the coal supply chain. I learned that Mr. VanHook and others at BNSF were in the process of trying to understand the science of coal dust in various different dimensions, including (1) the monitoring and measurement of coal dust levels; (2) the effect of coal dust on ballast and track structure; and (3) the identification of effective measures for limiting coal dust emissions. Work in each of these areas was already underway when I joined the Coal Marketing Department in the spring of 2006, a year after the PRB derailments. This work has continued without interruption over the last four years and progressed to the point that BNSF believes that we will be able to solve the coal dust problem. Doing so will require a collective, affirmative effort on the part of the shippers that own the coal and the coal mines that sell it to them, as well as the railroads that haul PRB coal.

Continuing Outreach to Coal Mines and BNSF Coal Shippers

BNSF's approach to the coal dust problem has involved continuing outreach to PRB coal mines and to the electrical utilities that are the principal shippers of PRB coal. The mines must be part of the solution to the coal dust problem because they are the shippers' agents and they are the entities that load the coal dust into coal cars. The nature of the loading affects the level of the dusting. The shippers must participate in the solution to the coal dust problem because the shippers own the coal and they bear responsibility for the commodities that they ask us to transport. The concept of shipper responsibility for controlling spillage of commodities shipped over the railroad is an established one in our industry. Just as the railroad cannot accept leakage of toxic chemicals from defective valves on tank cars, it should not be expected to accept emissions of coal from coal cars that foul the ballast and compromise the integrity of the track structure. It is particularly appropriate that coal shippers participate in the solution to the coal dust problem because a principal objective of that solution is to avoid disruptions to the coal supply chain that could result from compromised track structure.

When I first took over as head of Coal Marketing, BNSF outreach on coal dust was focused on a coal shipper and producer trade association, the National Coal Transportation Association. That is, we were performing a joint coal dust study with various sub-committees working on different facets of the issue. At this time our communications and position explanations regarding coal dust issues were primarily with the NCTA coal dust working group. We understood that NCTA was communicating directly with its broader membership. Eventually our focus shifted from interactions primarily with NCTA to direct interactions with BNSF coal shippers, individually and through a variety of public forums.

We have not interacted with UP shippers unless they happen also to be BNSF shippers, in which case we deal with them on coal dust, as on other matters, solely in their role as BNSF shippers. However, because UP operates over the Joint Line and because coal dust emitted from trains operated by UP to transport its customers' coal is a source of the coal dust problem, we have issued a Joint Line operating rule, applicable both to BNSF and UP, that incorporates the coal dust emissions standard set forth in BNSF's rules publication. That rule was communicated to UP's Executive Vice President – Operations from BNSF's Chief Operating Officer on November 7, 2008, and is attached hereto as Exhibit 2.

A significant amount of my personal attention over the past four years has been devoted to meeting with coal mines and BNSF shippers on issues related to coal dust. We have found the attitude of the mines to be generally constructive and have made tangible progress towards reducing coal dust emissions through efforts focused on the loading of coal trains. Specifically, our consultants from Simpson Weather Associates performed studies indicating that coal dust emissions could be reduced by shaping the profile of the coal loaded into coal cars. The proper profile of the loaded coal can be achieved by using a modified coal loading chute and by careful attention to the loading process by the individuals overseeing that process. This portion of our mitigation program has been a success, as all coal mines have installed the modified loading chutes that allow the proper profile to be achieved. They have also been generally receptive to our proposals to provide real-time feedback on the loading of coal cars through the use of laser monitoring devices so that their loading operators are able to achieve optimal loading profiles. This implementation of improved loading techniques has been a positive, although somewhat modest, step in reducing coal dust emissions.

I personally have attended dozens of meetings with individual coal shippers on coal dust issues over the past several years, as well as numerous meetings and conferences attended by multiple shippers at which the topic of coal dust was addressed. Throughout these discussions, whether in private or otherwise, my efforts have focused on promoting a consensual solution to the coal dust problem whereby shippers will voluntarily accept responsibility for curtailing emissions of coal dust. We have sought to do this through an approach designed to be deliberate, fact-based and transparent. We have shared the coal dust science with our shippers. We have shared our test results. We are now involved in an extensive trial of measures that can be used by shippers to limit coal dust emissions. We undertook the facilitation of this trial at the request of several customers. To date, we have been encouraged by the level of mine and shipper participation in the trial. Our hope and expectation is that when shippers have seen first-hand that there are effective methods available to limit coal dust emissions to acceptable levels, they will voluntarily adopt those methods.

Adoption of a Performance Based Standard

Mr. VanHook describes in his Verified Statement the process that BNSF went through to develop the coal dust emissions standards at issue in this proceeding. After consultation with senior BNSF management, those standards were first placed in BNSF's rules publication on April 30, 2009 for the Joint Line and May 27, 2009 for the Black Hills Subdivision. BNSF established the emissions standards only once we believed that we had done enough testing and analysis to justify imposing the standards. As explained by others, we believe that the standards we have adopted are conservative in the sense that any shipper that makes a good faith effort to comply with the standard will be able to achieve compliance. And we believe that widespread acceptance of the standard will solve the coal dust problem.

The IDV.2 standards set out in our rules publication are performance based in that they establish a level of dusting that should not be exceeded. The standards do not specify behavior that must be pursued to comply with the standards. By adopting a performance based standard rather than prescribing a particular method of controlling coal dust emissions, BNSF sought to allow individual industry members to determine the most efficient and cost effective method of coal dust containment. As shippers will have the incentive to select cost effective suppression methods, vendors of various coal dust emission suppression methods and products will have the incentive to continue to innovate to come up with less costly and more effective suppression measures. We are already seeing this process unfold, as multiple vendors of dust suppression products have sought to participate in the ongoing trial.

We believe that the adoption of our emissions standards will have benefits for the mines and shippers beyond maintaining the integrity of the coal route that they rely on. Coal dust suppression at the mine origin and the utility destination is one set of additional benefits that we anticipate. We also understand that other beneficial treatments are now available (such as suppressing spontaneous combustion) that utilize some of the same application infrastructure used to curtail dust emissions. Another useful byproduct of the coal dust standard is the dissemination of testing information from our monitoring devices that will allow shippers to observe the level of dust reduction being achieved. By providing individual train performance data of the shippers' trains as they pass the TSM sites, they will be able to see over time the effectiveness of their efforts in mitigating the loss of coal off of the rail cars using whichever method they desire to use.

We are hopeful that voluntary compliance with our standard by the shipping community will eliminate any need to adopt enforcement measures. However, if it should be necessary to adopt enforcement measures at some time in the future, we will provide sufficient advance notice to give interested parties an opportunity to raise any issues related to those measures before they are implemented.

I declare under penalty of perjury that the foregoing is true and correct. Further, I certify that I am qualified and authorized to file this Verified Statement.

Executed on March 15, 2010

Stevan B. Bobb

VERIFIED STATEMENT OF WILLIAM VANHOOK

BEFORE THE
SURFACE TRANSPORTATION BOARD

STB Finance Docket No. 35305

PETITION OF ARKANSAS ELECTRIC COOPERATIVE CORPORATION FOR A DECLARATORY ORDER

VERIFIED STATEMENT OF WILLIAM VANHOOK IN SUPPORT OF BNSF RAILWAY COMPANY'S OPENING EVIDENCE

My name is William VanHook. I am Assistant Vice-President and Chief Engineer-Systems Maintenance and Planning for BNSF Railway. Since 2005, I have been responsible for coordinating and overseeing BNSF's efforts to study the scope of the coal dust problem in the Powder River Basin ("PRB") and to investigate measures to curtail coal dust emissions. The purpose of my Verified Statement is to describe for the Board the extensive measures that BNSF has taken since 2005 to address the problem of coal dust in the PRB. As I explain below, the emission of coal dust from loaded coal cars presents a serious challenge in maintaining the structural integrity of one of the most important portions of the rail network in the United States. I urge the Board to affirm BNSF's authority to address this problem and to affirm the reasonableness of BNSF's requirement that there be limits on the emission of coal dust from coal cars in transit.

As AVP Engineering at BNSF, I have responsibility for ensuring that the BNSF rail network is built and maintained to a level that permits efficient and reliable transportation for BNSF's shippers. Among other things, I oversee the development and implementation of a $1.5 billion annual capital maintenance budget and a $900m operating budget for the engineering department. I support BNSF's engineering field personnel and make sure they have the information and resources necessary to maintain BNSF's physical plant. I oversee the Engineering Information Technology Group, which is responsible for the collection of a vast amount of engineering information and for making that information available in a usable and accessible form to BNSF's field personnel. I facilitate BNSF's inspection of tracks and track structure through end user programs and interfaces. I am responsible for BNSF's large fleet of test and rail maintenance cars, including its track geometry cars, rail detection cars, and rail and switch grinders. I interact with the Federal Railroad Administration and other government regulatory agencies on matters relating to track conditions and formulation of new regulations through various Railroad Safety Advisory Committee meetings.

I have been employed by BNSF for 16 years. Since 1995, I have been responsible for the construction of new track, signal, bridge and facilities initially for one region of BNSF, then subsequently for the entire BNSF system, as director construction, AVP Construction Santa Fe Lines and AVP Engineering Services. In 2001, I was appointed to my current position with system maintenance responsibilities. I have over 30 years of railroad experience. Prior to joining BNSF, I was employed by the Norfolk & Western Railway, the Southern Pacific Railroad, the Atchison, Topeka & Santa Fe Railroad, the Chicago, Missouri & Western Railroad and the Norfolk Southern Corporation. At each of these railroads, I was in the engineering department and my responsibilities were varied, including track maintenance, building maintenance, expansion of the physical plant, establishment of and maintaining track standards, oversight of signal and bridge maintenance, and planning and scheduling of overall company capital maintenance programs and operating budgets. I have a bachelors and masters degree from the State University of New York, Buffalo, in civil engineering.

The 2005 Joint Line Derailments Led to a Concerted and High Priority Effort to Understand and Address the Problem of Coal Dust.

In 2004, I became aware of the persistent and difficult problems that were caused by coal dust that was being blown out of loaded coal cars in transit from PRB coal mines. Spontaneous fires were occurring along the right of way on the PRB lines from the large volumes of accumulated coal dust. Rail switches were being fouled by the coal dust. Coal dust was piling up along bridge abutments and creek beds. Slow orders on the heavily traveled PRB lines were increasing as BNSF carried out increased maintenance activity to deal with the coal accumulations. I also became aware of complaints from local ranchers in Wyoming about coal dust deposits on their property.

I did not have primary responsibility for dealing with coal dust issues in 2004 but I participated in several presentations and discussions of the issue. Indeed, just a few days before the derailments occurred in 2005, I participated in a high level internal meeting that addressed BNSF's on-going study of the coal dust problem. *See* Exhibit 1. At the meeting, we were informed about the efforts of BNSF's division managers to understand the sources and amount of coal dust accumulating on the right of way and BNSF's preliminary views regarding alternatives to deal with the problem. BNSF had already conducted field measurements of coal dust and analyses of ballast contaminated by coal dust.

On May 14 and 15, 2005, two derailments occurred on the Joint Line within a few miles of one another. Gregory Fox, who was BNSF's Vice President, Engineering at the time, took the lead in dealing with the immediate consequences of the derailments. The sites were cleaned and the track was put back into service. Over the next several months, BNSF undertook a comprehensive rehabilitation of the Joint Line which reduced track availability and coal shipments. BNSF studied the causes of the derailments and concluded that the derailments had resulted from a combination of unusual weather conditions – an extraordinary amount of rain and snow had fallen during the spring thaw – and high levels of coal dust in the ballast which had weakened the track structure due to the lack of proper ballast support.

While Greg Fox focused on the short-term engineering and maintenance responses to the derailments, he asked me to take the lead on dealing proactively with the coal dust problem from a long-term standpoint. It was clear that BNSF had to take measures to prevent a recurrence of the derailments and the severe adverse service impact to our customers caused by these outages. The widespread presence of such large quantities of coal dust along the right of way and in our track structure was not acceptable on high volume rail lines like those in the PRB that were of such critical importance to the rail network and to the nation's economy. BNSF decided to expand substantially its prior efforts to understand the scope and causes of the coal dust problem in the PRB and to investigate possible ways to curtail coal dust emissions. I took the lead on this new project.

BNSF has given the highest priority to these efforts. Throughout my work on this project I have consulted with senior management at BNSF, informed them of my progress and obtained approval for the actions we have taken. It was widely agreed among senior BNSF management that the presence of large quantities of coal dust on the right of way presented unacceptable risks to the reliability of coal transportation in the PRB. We also believe that over time coal dust deposits on BNSF's track and right of way will grow outside of the PRB. Unless measures are taken to curtail coal dust emissions, service to other shippers could be adversely affected.

BNSF Immediately Set Up an Expanded Data Collection Network so that the Coal Dust Problem Could Be Addressed on a Scientific Basis.

The fact that large quantities of coal dust escape from loaded coal cars in transit is undeniable. Accumulations of coal dust are obvious in many areas along the right of way in the

PRB. *See* Exhibit 2. Plumes of coal dust can often be seen from passing coal trains. *See* Exhibit 3. When standing near the rail lines, I have often had to avert my face when a loaded coal train passes to avoid being pelted with coal particles. I have even heard the impact from coal on my hard hat after turning my face away from the coal pieces coming off the top of the rail cars. As we expanded our investigation, we have also observed coal deposits on our track structure outside of the PRB, although to a lesser degree than is seen on the PRB trackage. This is particularly evident on certain subdivisions where our coal traffic was and is a fairly significant part of our overall traffic.

While the problem of coal dust is obvious, BNSF wanted to make sure that any efforts it took to deal with the problem were based on a solid factual and scientific basis. So BNSF undertook to develop facts and data that would support any actions it took to address the problem. To help BNSF collect the necessary data, BNSF retained Simpson Weather Associates ("SWA"), an environmental firm that had substantial experience in addressing the problem of coal dust emitted from moving coal trains. SWA had worked extensively with the Norfolk Southern in the late 1970s and 1980s to address the problem of coal dust emissions from loaded rail cars of export coal moving from West Virginia to Norfolk and I believed that SWA could help BNSF expand and improve its data collection efforts. Before the derailments, BNSF had been working with an environmental engineering firm, Conestoga-Rovers and Associates ("CRA"), to conduct preliminary studies of coal dust accumulations. I concluded that it would help to bring SWA into this effort to work with CRA and take advantage of SWA's particular expertise in the area of coal dust. SWA began working extensively with BNSF in the summer of 2005 and has worked with BNSF since then. The President of SWA, G. David Emmitt, is submitting a Verified Statement in this proceeding that describes the data collection efforts and protocols initiated by SWA from 2005 until the present.

To summarize briefly those efforts, SWA first set up an expanded network of dustfall collectors. Prior to the derailments, CRA had set up dust traps that collected dust accumulating on the ground next to the tracks. BNSF estimated that an average of about 80 pounds of coal dust accumulated each year in the coal traps. *See* Exhibit 1 at BNSF_COALDUST_0035071. SWA recommended that BNSF use a somewhat more sophisticated dustfall collector that was mounted slightly above the ground to estimate dust fall rates. SWA also recommended that several dustfall collectors be set up perpendicular to the tracks to measure the rate at which dust falls onto the right of way at different distances from the track and that the network of dustfall collectors be expanded along the Joint Line. *See* Exhibit 4. BNSF implemented these recommendations.

SWA also provided us with information on the use of surfactants and grooming of the coal loads in rail cars as was being done for Norfolk Southern export coal at the mines in West Virginia. Surfactants are chemicals sprayed onto the loaded coal to form a protective crust or an adhesive layer that holds the coal inside the car. I discuss in more detail below the use of surfactants on loaded railcars and the benefits that can be obtained by grooming loaded cars or by changing the load profile of the coal loaded into coal cars.

SWA also recommended that BNSF establish a Track Side Monitor ("TSM") station that would gather data on coal dust emissions from individual coal trains and collect additional information to help put the dust emission data in context. A TSM consists of a weather station and an electronic dust monitoring device mounted on a tower. *See* Exhibit 5 at BNSF_COALDUST_0079694. Based on designs SWA had used with NS, SWA provided

BNSF with a TSM that we set up at Milepost 90.7 on the Joint Line. We looked at several different sites for the TSM and chose Milepost 90.7 because that was a location where significant dust had accumulated in the past and because power was available nearby to support the TSM instruments. A tower was set up initially on one side of the track and later expanded to both sides of the track so that the dust monitor on the eastside tower could measure coal dust emissions from passing trains when the wind was blowing from the west and the westside monitor could measure coal dust when the wind was blowing from the east. The TSMs collect data on the ambient conditions and dust readings for each train passing the TSM and transmit the data directly to SWA. BNSF began collecting data on all passing trains in September 2005.

An important part of the TSM is the dust monitor, referred to as an e-sampler. The e-sampler measures the amount of dust emitted by individual trains passing the location of the TSM tower on which the e-sampler is mounted. *See* Exhibit 6. The e-samplers used in our TSMs are the best equipment available for measuring dust emissions in the field in part because they take measurements often enough to determine accurately the coal dust levels during the entire period that a train is passing by the TSM. I insisted that BNSF use state of the art equipment and I am confident from the research performed by SWA that no other equipment available today would provide the same level of detail and reliability as the instruments used in the TSMs. Of course, the environmental monitoring technology is evolving and it is possible that new or more sophisticated generations of dust monitoring devices will become available in the future. BNSF will remain open to using superior dust monitoring equipment as it becomes available. But the problem of coal dust must be addressed now, and BNSF is therefore relying on the best dust monitoring equipment that is available today.

The third data gathering approach recommended by SWA was also based on work that SWA had done for NS. SWA developed a set of instruments that could be mounted on individual coal trains and used to collect data along the entire route of movement of the train. The instruments consist of (1) a Rail Transport Emission Profiling System ("RTEPS") device, which is essentially a combination of a mobile weather station and an airborne dust monitor similar to the e-samplers used at the TSMs, and (2) Passive Collectors ("PCs"), which are metal boxes attached to the sill of coal cars that collect coal dust particles that are blown off of the loaded cars. *See* Exhibit 7. These instrumented trains are the best and quickest way of determining whether a particular coal dust containment technique is effective. For example, as discussed further below, it was possible to use the RTEPS/PCs to determine the relative effectiveness of different chemical surfactants without testing a large number of trains, which would have been necessary if we relied only on data gathered by the TSMs. With the permission of individual shippers, BNSF, CRA and SWA were able to set up RTEPS/PCs on trains where some cars were treated with a surfactant and other cars were left untreated. The relative effectiveness of a particular surfactant could be determined by comparing the amount of dust collected in the PCs attached to treated and untreated cars. I discuss in more detail below the tests that BNSF, CRA and SWA conducted on surfactants and the conclusions that we reached based on these tests.

BNSF Kept Its Coal Shippers Closely Informed of These Efforts and Responded to Numerous Questions and Data Requests from the Shippers.

From 2005, shortly after the derailments, and continuing through most of 2007, BNSF worked intensively with the National Coal Transportation Association ("NCTA") to provide results of tests and data analyses on coal dust issues and to respond to questions from NCTA members. NCTA is an association of coal producers, rail car owners and coal consumers that deals with issues relating to coal transportation. We participated in quarterly meetings of NCTA and worked with a number of NCTA committees to collect, analyze, and distribute data and other information that BNSF was developing as it studied the problem of coal dust. We provided NCTA with regular updates on the studies that were being carried out. To give the Board an understanding of the high level of interaction with NCTA and the detailed presentations that BNSF was making to coal shippers during this time period, I attach to this statement some representative presentations that BNSF made to NCTA from November 2005 through August 2007. *See* Exhibit 6; *see also* Exhibit 8. BNSF employees and consultants attended the NCTA meetings and engaged in extensive dialog with NCTA members regarding coal dust issues. Employees of Union Pacific Railroad Company ("UP") also participated extensively in the NCTA presentations.

BNSF did far more than just keep NCTA members informed of the results of its data collection and analysis. From 2005 through 2007, BNSF also performed numerous studies at the request of NCTA members. During this time period, BNSF spent nearly $2 million on efforts to respond to NCTA members' questions. As we continued our studies in 2008 and 2009, we spent an additional $2.2 million. These expenses do not include the costs incurred by UP for its portion of the coal dust study efforts under the Joint Line Agreement. I describe below some of the studies we performed.

One of the mines suggested that the size of coal loaded into coal cars might affect the amount of dust that is emitted from the loaded cars in transit. Specifically, the mine was interested in knowing whether coal dust emissions could be substantially reduced by crushing coal to 3 inch pieces instead of 2 inch pieces. BNSF used several trains equipped with RTEPS/PCs over 5 days to test the relative dust emissions from coal that had been crushed to 2 inches versus 3 inches. We found that there was a notable reduction in coal dust emissions, about 30%, from the use of 3 inch coal. *See* Exhibit 5 at BNSF_COALDUST_0079736-42. We provided NCTA with the results of our study. I am not aware that the mines made any changes in their practices or that the shippers requested any changes in mine processes based on these study results.

BNSF advised NCTA members that its primary concern was that coal dust was contaminating the track structure, most importantly the track ballast, which could lead to an unstable track structure under circumstances similar to those in 2005. Some NCTA members speculated that the contaminants BNSF was finding in the rail ballast were attributable to brake dust released from rail car brake shoes rather than coal escaping from the coal cars. BNSF collected samples of contaminated ballast and samples of brake dust and carried out several analyses, including x-ray diffraction tests and infrared spectra analyses, to determine whether brake shoe dust was present in the ballast in significant quantities. These tests showed that the contamination in the ballast was attributable to coal dust and not brake shoe dust. *See* Exhibit 5 at BNSF_COALDUST_0079792-808. We presented the results of these studies to NCTA members.

Some NCTA members expressed skepticism that the coal that was accumulating on the right of way had come off of the top of loaded coal cars and they speculated that the problem of coal dust accumulation might instead be primarily attributable to coal leaking out of the bottom of bottom dump coal cars. Some coal cars used in the PRB are cars that are loaded from the top but release the coal at the utility destinations through outlet doors on the bottom of the car. If the bottom doors on these cars are not tightly closed when the cars are loaded, coal can escape through the bottom doors onto the right of way. To determine the relative amount of coal that is lost through bottom dump cars we equipped several cars with fiberglass bins that collected the coal dust lost through the bottom of the car. *See* Exhibit 9. We concluded that on average, these cars lost about 12 pounds per 100 miles per car per trip. *See* Exhibit 5 at BNSF_COALDUST_0079788-89 (average of all values). BNSF and UPRR both took action by repairing their steel bottom dump rail cars to ensure adherence to maintenance standards for bottom dump cars and to minimize any losses of coal through the bottom of cars. BNSF also issued Coal Car Bottom Outlet Door System Validation Procedures to our mechanical rail car inspection teams to check bottom outlet door latches, to view outlet doors for gaps, to verify that the secondary lock is properly engaged, and to check primary lock indicators to see if they are damaged or need adjustment. If a defective door is identified, the car would be taken out of service and sent to the mechanical shop for repairs. *See* Exhibit 10; *see also* Exhibit 11.

We then compared the bottom dump losses with the loss of coal from the top of loaded cars. The amount of coal lost off of the top of a car could not be collected and measured directly, but we were able to make rough estimates of the coal losses from the top of loaded cars using lasers to measure the volume of coal in a car at the beginning of a trip and the volume of coal in the car at the end of the trip. This analysis basically measured the difference in the elevation of the coal in the car before and after the train moves a certain distance. Based on these analyses, we estimated that somewhere between 250 and 750 pounds per car are lost in transit. *See* Exhibit 8 at BNSF_COALDUST_0034962-66. We also found research carried out in Canada that concluded that as much as 2% of the total volume of coal in the rail car (2 tons from a 100 ton car) can be lost in transit. These are only rough estimates and more precise measurements could be made in the future of the amount of coal lost out of the top of cars as they move from the mines to the utilities. But the analyses on which these estimates are based make it clear that substantial volumes of coal are blown out of coal cars in transit and that the volume of coal emitted from the top of coal cars substantially exceeds the amount of coal escaping from the bottom of the cars. We also presented the results of these analyses to NCTA.

Another issue raised by NCTA members was the availability of water near the mines for use in applying surfactants to loaded coal cars. Surfactants are usually delivered to the mines in a concentrated form and they need to be combined with water before being applied to the coal. There was a concern that inadequate supplies of water existed in the PRB to support widespread use of surfactants. Mark Murphy of CRA did a study of potential water sources. He found that while surface water resources were relatively scarce in the region, there were adequate sources of well water to support the use of surfacants. *See* Exhibit 5 at BNSF_COALDUST_0079809; *see also* Exhibit 12.

BNSF Determined That Coal Dust Emissions From Loaded Coal Cars Have To Be Curtailed.

As our analysis of the coal dust problem progressed, it became clear that the only effective and responsible way to deal with the problem was to substantially reduce coal dust emissions from loaded coal cars. The derailments and our further studies confirmed that coal dust emissions had to be substantially eliminated. Coal dust is a particularly serious contaminant of track ballast and poses serious challenges when it accumulates along rail lines such as those in the PRB that handle extraordinarily large volumes of coal traffic. Ballast is the layer of coarse granite aggregate on which the rails and ties rest. The track structure relies on ballast as the foundation of its structural integrity, very similar to a bridge span relying on the bridge abutments for its foundation. The purpose of railroad ballast is to provide drainage and structural support for the heavy loads that are transmitted to the ballast from the wheels of a heavy train on the rail, the rail on the tie plates or pads, the tie plates or pads on the ties and then ultimately to the ballast. When the ballast is fouled by contaminants, its load bearing properties are adversely affected and the track structure integrity can become severely compromised. These problems are especially acute with coal dust which acts like clay and becomes "slimy" or slippery when wet, thereby compromising the interlocking capabilities of the individual granite rocks in the ballast. Wet coal dust further prevents the drainage of water out of the ballast section.

In 2006, BNSF commissioned a study by Professor Erol Tutumluer at the University of Illinois at Urbana-Champagne to examine the properties of fouled ballast. Professor Tutumluer had conducted preliminary tests on ballast collected at a derailment location in Nebraska and he proposed to expand his tests to include different types of ballast and different types of ballast contaminants, including coal dust. *See* Exhibit 13. Professor Tutumluer carried out his study and reported to BNSF his conclusion that coal dust was a particularly severe source of ballast fouling. He noted that while coal dust had not previously been identified as a significant ballast contaminant, in fact, it has characteristics that make it one of the worst fouling agents. He found that coal dust has a very high water holding capacity which limits drainage in ballast fouled by coal dust. His tests also showed that ballast contaminated by coal dust has a much lower load bearing capacity, which is an obvious problem for PRB lines that carry a greater volume and annual tonnage of freight than any other rail lines in the United States. Particularly when it gets wet, coal dust can have a highly destabilizing effect on rail ballast. *See* Exhibit 14. Since providing BNSF with the results of his study, Professor Tutmuluer has continued to examine the properties of coal dust and is submitting a Verified Statement to the Board in this proceeding on the character of coal dust as a ballast fouling agent.

Coal dust accumulates rapidly and in large quantities along the PRB rail lines. We have been surprised at the rate of accumulation. As explained by Craig Sloggett, BNSF's General

Director of Maintenance & Planning in his Verified Statement, we have found significant accumulations of coal dust on PRB lines to occur within as short a period as six months. In one area, we found that brand new track installed with clean materials from the native ground up to the track level had been contaminated with coal dust in a few months. On one bridge, we replaced the ballast materials in 2007 down to the concrete structure or tub that the ballast and track sits in, and we found in 2009 that the entire process needed to be repeated because of coal dust contamination all the way down to the bottom of the concrete tub. There were at least 12 inches of compacted ballast contaminated by coal dust all the way to the bottom of the tub. In 2008, we carried out a large coal dust clean-up exercise, focusing on coal that had accumulated above ground in creek beds, next to the tracks and along bridge abutments. We filled over 300 rail cars with the dust that had been collected and transported the coal to a landfill.

While the coal dust accumulates rapidly and visibly in some areas, it is often difficult to detect because it quickly makes its way down into the ballast. As Mr. Sloggett explains, on some sections of track that appear to be clean, coal dust can be right below the top rocks and further down below the surface. *See* Exhibit 15. This makes it difficult to carry out surgical maintenance of fouled ballast. Visual inspection of the rail bed cannot be relied on to locate areas where fouling has occurred. As a result, more widespread maintenance activity must be carried out to make sure problems do not develop. For example, on high volume rail lines, BNSF would expect to undercut the track structure generally on 10-year cycles. Undercutting involves removal and replacement of the ballast and locations are prioritized based upon condition. We are finding that in some areas on the Joint Line, undercutting may be needed as often as every two or three years.

This increased maintenance activity is not only costly, it also substantially reduces the capacity of the rail lines. Traffic must be slowed down to allow the maintenance activity to be safely carried out. In addition, BNSF is forced to carry out extraordinary inspection and track monitoring activity, particularly during rainy months, in an effort to detect problems caused by coal-fouled ballast before service is affected. While the additional inspection and monitoring activity is being carried out, the tracks cannot be used to provide service. With the severe winter weather in Wyoming, we are limited to performing our capital maintenance work in the summer or mild weather months, putting great pressure on capacity that is already strained.

It is not acceptable to operate the high volume PRB lines while constantly trying to play catch-up with the coal dust emitted from loaded rail cars. BNSF's approach is to proactively operate a safe and efficient railroad. The problem of coal dust is not one that can or should be dealt with through maintenance but has to be addressed by substantially eliminating the dust that is emitted onto the rail lines from loaded coal cars.

BNSF Has Taken the Steps Within Its Control To Curtail Coal Dust Emissions.

One of the first things that Dr. Emmitt noticed when he started working with BNSF in 2005 was that the profile of loaded coal in the coal cars had steep angles and irregular surfaces that made the coal susceptible to being blown off during transit. He had done studies for NS on the benefits of loading coal cars with a more aerodynamic profile and he recommended that the load profile of coal cars loaded at PRB mines also be changed. He provided us with an ideal load profile design for a rounded breadloaf shape. *See* Exhibit 16. This breadloaf shape took into account the natural angle of repose of the PRB coal, which is the slope that a coal pile would naturally take from the effect of vibration and wind through a train's movement. When the breadloaf angles match the natural angle of repose at the beginning of the trip, the coal is less likely to blow off of the top of the car during the trip, since the coal is already in its natural angle of repose.

Some NCTA members were concerned that modifying the load profile would reduce the amount of coal that could be loaded into the coal cars. They were also concerned that the load profiling would increase the time to load a train. SWA did laser analyses of loaded coal cars and showed that use of a more aerodynamic load profile would simply redistribute the coal within a car without reducing coal volumes. It was evident that in poorly loaded cars there were air pockets in the back and front of the rail car where coal could be redistributed without reducing the loading volumes. We determined that a modified loading chute design could be used by the mines to produce a more aerodynamic load profile. *See* Exhibit 17. We starting working with one mine to test the new loading chute and we found that it improved the load profile without impeding the loading process. This mine also confirmed that it could load the coal into the train without adversely increasing loading time. We then worked with the other PRB mines to persuade them to use the improved loading chutes. *See* Exhibit 18.

Changing the load profile reduces coal dust emissions, but the precise extent of the reduction is uncertain. Data from the dustfall collectors suggests that the reduction in coal dust that has resulted from modified loading profiles has been in the range of 15% to 20%. *See* Exhibit 19 at BNSF_COALDUST_0064122. One reason for the limited benefits we have seen is that the use of a modified loading chute alone does not guarantee that the ideal load profile is achieved. The loading operator plays an important role in loading cars with the proper profile, and we have found that sufficient care is not always given to the loading process. In an effort to improve loading practices, SWA has established a Coal Car Load Profiling System ("CCLPS"), which uses lasers to read the loading profile of a car shortly after it has been loaded and allows us to give immediate and reliable feedback to mines on the profile of the loaded cars. *See* Exhibit 20. Even if loading practices were perfect, improved loading would not eliminate the majority of coal dust emissions.

Another early and effective step that BNSF has taken to reduce coal dust was the overhaul and enhanced maintenance of bottom dump coal cars in BNSF's car fleet to reduce dusting from the bottom. As noted above, our analyses showed that substantially more coal was being lost from the top of loaded coal cars than from the bottom of bottom dump cars. However, coal losses from those bottom dump cars were significant and cannot be ignored. Therefore we instituted a multi-year program to expand the inspection and repair of the older fleet of bottom dump steel cars. Car doors have been tightened and adjusted and gaps or holes in the bottom of the cars have been caulked shut. New maintenance practices have been instituted to ensure proper operation of the bottom dump doors as described previously.

Further Reductions In Coal Dust Emissions Can Only Be Achieved Through Shipper Compliance With the Coal Dust Emissions Standards that Are the Subject of this Proceeding.

The improved loading of loaded coal cars and the enhanced repair and maintenance of bottom dump rail cars addresses only a small part of the coal dust problem. Effective curtailment of coal dust must include strict limits on the emission of coal from the top of loaded coal cars. BNSF does not load coal cars and the freight loaded into the cars does not belong to BNSF. The steps necessary to limit coal dust emissions from the top of loaded coal cars must be taken by the shippers and the mines. No shipper of any other commodity is allowed to release their commodity onto BNSF's rail lines or property and to create the risk of serious service disruptions by contaminating the rail ballast. BNSF has no interest in dictating how the shippers and the mines choose to limit coal dust emissions. BNSF's only interest is in substantially eliminating the coal dust emissions. Indeed, by leaving to the shippers and mines the flexibility to address the issue of coal dust emissions as they see fit, BNSF believes that competition and market forces will lead to the adoption of the most efficient and cost-effective remediation approaches for the shippers and the mines.

The most obvious way to eliminate coal dust emissions from loaded cars would be to cover the loaded cars with tops. If the shippers and their mine agents were currently covering all loaded coal cars, no coal dust emission standard would be needed. The use of car tops would effectively eliminate the coal dust problem. But BNSF realizes that significant costs might be involved in converting to the use of car tops. Moreover, other technologies may become available that could generate the same benefits as car tops with less cost. Therefore, BNSF chose to adopt an emissions limit instead of prescribing any particular coal dust suppression approach. This gives shippers and their mines the freedom to adopt the measures they believe will be the most efficient and cost effective in meeting the emissions limit.

The coal dust emissions standards at issue in this proceeding and the process of adopting them are described in detail in the Verified Statement of Charles Sultana. Mr. Sultana is an expert in the Six Sigma methodology, which is a process for solving business problems that relies heavily on facts and data. As explained above, BNSF had been collecting massive amounts of data on coal dust emissions since 2005. In particular, since September 2005, the TSM set up at Milepost 90.7 had been collecting train-specific data on coal dust emissions on all trains passing that milepost. When Mr. Sultana joined BNSF in 2006, Mr. Sultana was asked to help understand and evaluate the data being collected. I subsequently asked Mr. Sultana to bring his data analysis skills to bear on identifying a coal dust emissions standard which, if met by all trains passing Milepost 90.7, would substantially eliminate coal dust emissions at that point on the Joint Line.

The adoption of a coal dust emission standard applicable to trains passing a particular milepost flows from the practical requirements of measuring coal dust from moving trains at a fixed location. It is analogous to the use of a traffic policeman to enforce speed limits on a long stretch of highway. As a practical matter, the traffic policeman must choose a spot and measure speed from that spot only. There can be no assurance that a car exceeding the speed limit at the measurement location actually was speeding on other sections of the highway or that a car below the speed limit at that location had never exceeded the speed limit on other sections of the highway. But the practical limits on enforcement require that enforcement efforts be limited to a single location. Those same practical factors required that we develop a standard applicable to Milepost 90.7, which was where the equipment used to measure coal dust emissions was located for the Joint Line and where the data on coal dust emissions had been gathered since September 2005.

Mr. Sultana started with the train-specific data for trains passing Milepost 90.7 from September 2005 through August 2007. As described by Mr. Sultana and Dr. Emmitt, SWA had used the data collected by the electronic dust monitors on the TSMs to identify an "Integrated Dust Value" or "IDV" for each passing train. The IDV was a measurement of the number of coal dust units emitted by the train when passing Milepost 90.7. By August 2007, SWA had improved on the calculation of the IDV and was now using an improved form called IDV.2. *See* Exhibit 21. Mr. Sultana added together all of the IDV.2 units associated with the trains passing Milepost 90.7 from September 2005 through August 2007 and identified the IDV.2 value which, if it had not been exceeded by any of the passing trains during that time period, would have eliminated 95% of the total dust units emitted by the passing trains. The value he identified was an IDV.2 of 134.

As Mr. Sultana explains, he also found that the e-sampler dust monitors used on the TSMs produced somewhat varying IDV.2 readings on the same air sample of coal dust. This variation is unavoidable given the equipment being used, but Mr. Sultana concluded that it could be addressed by setting a maximum IDV.2 level that takes account of the variation through accepted statistical techniques. Mr. Sultana identified the range of variability and concluded that a train producing coal dust at an IDV.2 level of 134 could produce an IDV.2 reading on another dust monitor of as much as 300. Therefore, to be sure that trains producing 134 or less would not be found to violate the IDV.2 standard, he set the maximum IDV.2 standard to 300. *See* Exhibit 22. As Mr. Sultana explains, the standard is very conservative. Mr. Sultana performed the same analysis using data that had been collected at Milepost 558.2 on BNSF's Black Hills Subdivision and set a maximum IDV.2 level of 245.

When SWA provides BNSF with IDV.2 data on trains passing the TSM, SWA excludes trains where the dust reading might not be properly attributable to the train, for example when the train passed the TSM just as another train was passing on a parallel track. We found that in 2009 almost 14% of trains passing Milepost 90.7 for which there were usable IDV.2 data exceeded the IDV.2 standard. However, this does not mean that only 14% of the PRB coal trains are emitting large amounts of coal dust on the PRB lines. It means only that 14% of the PRB trains are emitting coal at levels above our performance standard at the specific point where the TSM is installed. Coal dust emissions from moving coal trains are highly episodic. A loaded coal train could pass Milepost 90.7 with no coal emissions only to emit a large plume of coal dust a mile or less away. Tests we carried out using instrumented trains show that episodes of dusting occur all along the PRB rail lines. *See* Exhibit 23. Our monitoring efforts are limited by the practical need to set up monitoring devices at a fixed location. However, we are confident that if the shippers and mines take action that is sufficient to substantially eliminate coal dust emissions at Milepost 90.7, those same efforts will result in the substantial elimination of coal dust along the entire Joint Line and Black Hills Subdivision lines. For example, if the shippers and mines adopt surfactant programs that limit coal dust emissions at Milepost 90.7 on the Joint Line and Milepost 558.2 on the Black Hills Subdivision to the levels specified in the standards at issue here, BNSF is confident that coal dust throughout the PRB will be eliminated.

BNSF Has Conducted Substantial Testing of Surfactants That Yields Promising Results.

Surfactant application is a well established way to reduce coal dust emissions from coal cars in transit. *See* Exhibit 24. I understand that NS has successfully used surfactants to curtail emissions and that surfactants are also used in Canada. Surfactants can be used to create a crust or artificial lid that keeps coal dust in the car. Other surfactants create an adhesive coating that causes coal particles to stick together. There are several different coal surfactants available on the market today with a range of characteristics.

BNSF began testing surfactants even before the derailments in 2005 as a means of reducing coal dust emissions. After retaining SWA, we expanded substantially our testing of surfactants. SWA conducted laboratory tests on dozens of products for characteristics likely to reduce or eliminate coal dust emissions. SWA did tests on the erosion properties of treated coal, the effect of rain simulation, solar heat, wind, curing time, penetration depth, static strength, and freeze recovery. BNSF tested numerous products to ensure that products used in field tests would not corrode railcars, were not harmful to handle, and were non-hazardous to field personnel. One of BNSF's coal shippers tested surfactants in its laboratory to make sure the surfactants were not harmful to a utility's boilers. Through these tests, we identified numerous promising surfactant products and set up field tests on the effectiveness of those products.

I have described above the instrumented trains that use RTEPS/PCs that monitor ambient conditions and coal losses throughout an entire route of movement. Beginning in 2005, we used those trains to test the effectiveness of various surfactants. We generally set up the trains so that the RTEPS instruments were mounted onto one of the last cars on the train. The RTEPS would allow us to monitor conditions like wind speed, humidity, or rainfall that might have an impact on the effectiveness of a particular surfactant. Then, with the shipper's permission, we would divide the train into groups of treated and untreated cars and mount PCs on the rear sill of the last car in each group. We would then collect and weigh the dust collected in the PCs to determine the effect of surfactant treatment on the loss of coal from the car. Based upon the testing and evaluations we have completed, we are confident that proper application of a quality surfactant onto a properly profiled loaded coal car can reduce coal dust emissions from the rail car top by more than 85%.

When BNSF extended the effective date of its Rules Publication 6041-B, items 100 and 101, in October 2009, BNSF announced, in response to requests from our shippers, that it would conduct a large-scale trial of dust mitigation methods, focused on surfactants, to give shippers and the mines further opportunities to assess potential remediation measures. The trial, which is currently underway, will give shippers and the mines an opportunity to test various products and to assess their effectiveness in reducing coal dust emissions. *See* Exhibit 25. Products are selected for the trial only if they first pass the SWA laboratory analysis showing that the products have promising dust suppression characteristics and the BNSF tests showing that they are not harmful. There is a selection committee consisting of shippers and mines that will determine which products to test after the initial testing of two products is completed. We are conducting field tests using the RTEPS/PCs described above. Testing is conducted on trains that are half-treated, leaving the other half untreated as a control, and performance reports on each train tested are sent to all the trial participants. We are also monitoring the dust emissions from passing trains using the TSMs and providing the IDV.2 data generated by the dust monitor on the TSMs to the participants in the trial. The trials are expected to run until the end of August 2010, and the total tonnage to be tested is 36.2 million tons. BNSF is confident that the data generated in the current trial will give shippers and the mines information that will allow them to make informed decisions regarding what measures they should adopt to achieve compliance with BNSF's coal dust emissions standards.

I declare under penalty of perjury that the foregoing is true and correct. Further, I certify that I am qualified and authorized to file this Verified Statement.

Executed on March 15, 2010

William VanHook

VERIFIED STATEMENT OF CRAIG SLOGGETT

BEFORE THE
SURFACE TRANSPORTATION BOARD

STB Finance Docket No. 35305

PETITION OF ARKANSAS ELECTRIC COOPERATIVE
FOR A DECLARATORY ORDER

VERIFIED STATEMENT OF CRAIG SLOGGETT IN SUPPORT OF BNSF RAILWAY COMPANY'S OPENING EVIDENCE

I am Craig Sloggett, General Director, Maintenance for BNSF Railway Company ("BNSF"). My office is located in Gillette, Wyoming, and I have responsibility for the overall maintenance and maintenance planning on BNSF's Powder River Division, which territory includes all of the BNSF coal routes into and out of the Powder River Basin ("PRB"), including both the Joint Line and the Black Hills Subdivision. In this capacity, I oversee two Division Engineers who are responsible for the entire Powder River Division and all engineering personnel under their supervision. Further, I am responsible for the maintenance of the signal, bridge and other property of the BNSF on the Powder River Division, exclusive of mechanical and communication facilities.

The purpose of my verified statement is to convey from my firsthand experience the magnitude of the coal dust problem on the Joint Line and Black Hills Subdivision and the impact that coal dust is having on the railroad. I will also explain why, from the perspective of BNSF's maintenance-of-way efforts, it is essential to limit emissions of coal dust from railcars.

I have worked for BNSF or its predecessor, the former Burlington Northern Railroad, for 32 years, during which time I have held a variety of positions with responsibility for railroad engineering and maintenance. I began my career in 1978 as a track laborer. After holding various front-line maintenance jobs, I became a supervisor, first as Assistant Roadmaster and then as Roadmaster. In the early-to-mid 1990s, I was the Roadmaster responsible for the line from Gillette, Wyoming to Edgemont, South Dakota on the Black Hills Subdivision, which is one of BNSF's primary coal routes leading to and from the PRB coal mines. I was later promoted to various capital planning positions and eventually became a Manager of Gangs with responsibility for all maintenance gangs across four of BNSF's Divisions. In 1998, I became a Division Engineer overseeing all maintenance-related personnel for BNSF's Southwest Division. This Division includes the New Mexico portion of the high density BNSF intermodal route between Los Angeles and Chicago (referred to as the "transcon"), as well as several New Mexico coal mines served by BNSF. In 2007, I became Division Engineer for the Powder River Division with responsibility for overseeing all maintenance-related personnel for that Division. Later in 2007, I was promoted to General Director, Maintenance for the Powder River Division, which is the position I currently hold.

Coal Dust is Accumulating at Alarming Rates and Threatening Track Stability.

My first position in the PRB was as Roadmaster on the Black Hills Subdivision in the early-to-mid 1990s. At that time, small amounts of coal dust were visible in certain parts of my territory but the coal dust did not accumulate in quantities that had a significant or adverse impact on track integrity. When I returned to the area in 2007 as Division Engineer, I was shocked by the amount of coal dust accumulating in the ballast, on the track, and on the railroad right of way on both the Black Hills Subdivision and the Joint Line. I recall my first trip to the Powder River Basin in my new position in 2007. I was driving alongside the Joint Line track near Nacco Junction. I saw ahead of me on the track the headlight of the lead locomotive on a loaded coal train encircled in a cloud of black dust. This is a regular occurrence on the Joint

Line and Black Hills Subdivision. I have experienced on many occasions the feeling of being pelted with coal particulates when standing on the railroad right of way while a loaded coal train passes by. When I park my white truck along the coal routes, it becomes covered in black coal dust from passing trains.

Since my return to the Powder River Division, I have seen firsthand the extent to which the accumulation of coal dust causes damage to the railroad infrastructure, in particular, to the ballast that is so critical to permitting moisture to drain away from the railroad ties and track. When ballast becomes fouled with coal dust and cannot drain properly, it begins to break down, lose its stability, and allow railroad ties to break and/or the track to move out of alignment, which can lead to train derailments if not repaired. These are unsafe conditions that require the imposition of a slow order or speed restriction until appropriate maintenance can be performed or, in some cases, require the track to be taken out of service altogether so that necessary repairs can be made immediately so that the affected area may provide for the safe passage of trains again. For example, in May 2008, our inspectors imposed 25 mph slow orders on multiple sections of track between MP 90.5 and 103.6 that were severely fouled with coal dust until track windows could be scheduled to perform undercutting to clean and replace fouled ballast. In October 2007, when we discovered a section of track near MP 75.3 with extensive ballast contamination, we lowered the track speed limit from 50 mph to 25 mph until the track could be taken out of service for undercutting. These are only two examples of numerous slow orders and track windows required to address the accumulation of coal dust and its effects on the track structure.

During seasons of high precipitation, particularly though not exclusively in the spring and summer, railroad track structure is particularly vulnerable to moisture. In the spring in

Wyoming, the frozen ground begins to thaw, releasing moisture. During the spring thaw, we typically experience snow and rain, which adds to the moisture level in the ground. When railroad ballast is fouled with coal dust, it is unable to serve its primary purposes of allowing moisture to drain away from the track and supporting the track structure. Heavy rain or snow can quickly overwhelm the ability of fouled ballast to drain water away from the track. Summer rains can cause the same problem. Pictures illustrate the effect of coal dust and moisture on ballast most effectively. *See* Exhibits 1-3. Track structure with fouled ballast deteriorates very quickly in wet conditions. I have seen sections of track that appear to be in sound structural condition and then, within 24 hours of a precipitation event, a portion of the track begins to dip or sink, as the ballast below it retains water and begins to give way.

Fouled ballast can be difficult to detect. In some instances, the presence of mud or other moisture and the accumulation of coal dust may indicate to track inspectors that ballast may be fouled. In other instances, there are no obvious visible signs, as most railroad ballast is hidden within the track structure and only the rock on top is visible. On the Joint Line, ballast must extend a minimum of 12 inches below the bottom of concrete ties and it is difficult to see into the ballast beyond the first inch or two without digging into the ballast itself. Exhibit 4 contains a picture of track that appeared to be in good working condition on the surface. However, when BNSF engineering personnel dug into the ballast, they discovered extensive coal dust contamination several inches below the surface.

Coal dust accumulation on the track (e.g., on the tie plates, on top of the bottom flange of the rail, and on the ties) and on the right of way is more visible than coal dust accumulation in ballast and therefore easier to detect. Even though visible, such accumulation may also cause significant problems for the railroad. For example, coal dust accumulation on the track interferes with the proper inspection of ties and rail by BNSF engineering personnel and is likely to work its way into the ballast. When coal dust accumulates at switch locations, over which a train switches from one track to another, it can impede the proper working of switches, ignite from the heat generated by railroad heaters used to keep the switches from freezing in the winter, and, due to increased vibration from a train passing through a switch, coal dust can vibrate down into the lower levels of the ballast section supporting the switch, taking moisture with it when wet. *See, e.g.*, Exhibit 1. Coal dust fires burn and smolder for long periods of time and can be very difficult to extinguish, particularly when they are fueled by large amounts of coal dust, both on and off the track. When coal dust accumulates on the right of way, it can also catch fire and burn for miles along the track.

The coal dust problem today is quite evident from the visible accumulation on both the Joint Line and Black Hills Subdivision. The accumulation I have experienced in the last three years far exceeds the minor accumulation that I saw while working on the Black Hills Subdivision 15 to 20 years ago. It is a constant battle to remove coal dust from the track and surrounding areas and to repeatedly clean ballast across the territory that has become severely fouled with coal fines. Below are a few examples of the very rapid accumulation of coal dust emitted from passing trains:

- In the early spring of 2009, we undercut a fouled section of track ballast near MP 90.5. In October of 2009, we undercut a section next to the one undercut in the spring and purposely overlapped the prior track ballast. The new "clean" ballast from that section was already severely fouled with coal dust in just a few months. *See* Exhibit 1.

- BNSF recently constructed additional main line track on the Joint Line. In some locations the Joint Line now consists of three main lines (triple track) and in other locations the Joint Line consists of four main lines (quadruple track). For new track construction, BNSF first prepares the subgrade and then places the subballast, ballast, ties and track along the new segment, without switches. Once the track is complete, BNSF then installs switches in the new track, which involves removing small sections of newly laid track and ballast to insert switches that allow trains to travel from one track to another. When we installed a switch in new quadruple track at MP 74, we discovered that the new ballast installed just a few months earlier was already contaminated with approximately 3 to 4 inches of coal dust that had filtered down through the ballast. We uncovered similar contamination when we installed a switch at MP 33, where we had recently installed new triple track.

- In 2006, before my return to the Powder River Division, BNSF undertook extensive ballast replacement in switch locations on the Joint Line. In 2007, many of these switches were reballasted because they had already become severely fouled with coal dust.

BNSF is Undertaking Unprecedented Maintenance Efforts to Address Coal Dust Emissions.

BNSF has undertaken extraordinary maintenance efforts on the Joint Line and Black Hills Subdivision to combat the accumulation of coal dust and its adverse impact on the railroad. In 32 years of railroad maintenance across the BNSF system, I have never seen another territory that requires such extensive maintenance. BNSF performs a variety of extra work not performed elsewhere on its system to prevent coal dust accumulation and associated fouled ballast. This work includes efforts to identify potential track problems, to remove coal dust from the ballast, and to remove coal dust from the track and right of way.

During periods of high precipitation and moisture in the Powder River Basin, in particular snow, rain and ground thawing in the spring and rains in the summer, we augment normal track inspection efforts by bringing railroad officers and other engineering department employees from all over the system to the Joint Line and Black Hills Subdivision to ride trains 24 hours a day. These efforts are in addition to and serve to supplement the inspections performed by BNSF track inspectors assigned to this territory. BNSF further supplements its manual inspections with mechanical inspections by a track geometry car and a Track Strength Testing, Analysis and Recording ("TrackSTAR") car, both of which make detailed measurements of the track and rail condition and report irregularities outside of acceptable criteria. The TrackSTAR car also applies thousands of pounds of horizontal force on the rails and measures the movement of the rails outward. During the spring and summer, BNSF has brought a track geometry car to the Powder River Division to run continuously across these critical line segments to assist in the early detection of deteriorating track conditions. No other territory on BNSF has made these extraordinary inspection efforts a standard part of its inspection program.

Undercutting is a ballast maintenance technique used by railroads that involves lifting the track and ties off the ballast, removing the underlying ballast, cleaning it, and replacing it with clean ballast. As Division Engineer in the Southwest Division, it was my experience that the ballast on the majority of the BNSF transcon route, which is a high density line used primarily for intermodal traffic, needed to be undercut once every 15 to 20 years, while certain limited sections might need to be undercut every 10 or more years. In my experience working in the Powder River Division over the last three years, we have determined that certain segments of the Joint Line must be undercut every 2 to 3 years as a direct result of coal dust accumulation in the ballast. Other segments of the Joint Line where the coal dust may not accumulate as quickly must be undercut at least every 5 to 6 years, at least three times as often as the majority of BNSF's high density transcon line through New Mexico that services only a small number of coal trains. Below are several examples of track segments for which BNSF has had to accelerate its undercutting program in order to address coal dust fouled ballast:

- In October 2007, we discovered that a section of track near MP 75.3 was severely fouled with coal dust and required immediate undercutting. That section had just been undercut in the fall of 2005 following the May 14, 2005 Joint Line derailment of a BNSF train that occurred less than a mile from that location. *See* Exhibit 5.

- Also in October 2007, inspection revealed coal dust fouled ballast on the bridge at MP 62, near the site of the May 15, 2005 Joint Line derailment of a UP train. This location had been undercut in August 2005 but needed to be undercut again in 2008. *See* Exhibit 4.

- In May 2008, our inspectors identified sections of track between MP 90.5 and 103.6 that required immediate undercutting. This track had been undercut and reballasted in September 2005, just 31 months prior. BNSF had planned to undercut this section of track in 2009, but the planned work had to be moved up to 2008, just over 2.5 years since the last undercutting. The root cause of this additional maintenance was determined to be coal dust accumulation that had fouled the ballast. *See* Exhibit 2.

- In August 2008, inspection revealed that main track one on the bridge near Nacco Jct., which had been undercut three years ago that very week, was fouled with coal dust and needed to be undercut again. *See* Exhibit 6.

In addition to more frequent undercutting, BNSF currently performs another ballast maintenance technique called shoulder ballast cleaning on the entire Joint Line annually. This technique involves removing all ballast at the shoulder of the track, removing accumulated particulates and replacing it with clean ballast. In my position as Division Engineer on the BNSF transcon route in New Mexico, we found that undercutting the track approximately every 15 to 20 years was sufficient to maintain ballast integrity and that the additional maintenance of shoulder ballast cleaning was not required.

BNSF has also undertaken extraordinary efforts to remove coal dust from the track and from the right of way. BNSF employs a variety of extra measures not performed elsewhere on its system to remove coal dust. Vacuum trucks are regularly employed to vacuum coal from the track and, in particular, the switch areas. BNSF uses a badger ditcher, which is a machine that runs on the track and has an attachment with a digging wheel that picks up coal dust that has accumulated between the tracks. BNSF uses front end loaders and motor graters to consolidate accumulated coal dust along the right of way into piles for disposal or to recycle the coal dust for use as road base on the access roads along the BNSF right of way.

In 2008, BNSF undertook a large scale effort to remove accumulated coal dust from portions of the Joint Line with the greatest accumulation. The coal dust was consolidated into piles totaling more than 28,000 tons and loaded into more than 300 rail cars for disposal at a landfill. This volume does not include coal dust that had been previously vacuumed or used as roadbase. BNSF is currently engaged in another effort similar in scope to that performed in 2008 to remove additional volumes of accumulated coal dust. Without significant reduction in coal dust emissions, I expect that we will need to perform such large scale removals on a regular basis going forward.

Both the Joint Line and Black Hills Subdivision are in operation 24 hours a day, 365 days a year. In order to perform the majority of its maintenance work, including undercutting, shoulder ballast cleaning, and most coal dust cleanup and removal, BNSF must slow or stop train traffic on the railroad line on or near where this work is being performed to ensure the safety of our workers and to ensure the safe passage of trains as we work on the track structure itself. To do so, BNSF may issue a slow order, restricting trains to a certain speed, or place a track window, during which time the track is out of service for maintenance, requiring trains to use other tracks as available. Wherever possible BNSF attempts to minimize the disruption that slow orders and track windows have on the flow of trains, but given that trains operate continuously around the clock, train delays are inevitable when the trains are slowed down or necessary track is taken out of service, thereby reducing the effective capacity of the railroad.

Conclusion

As described herein, BNSF performs extensive maintenance on the Joint Line and Black Hills Subdivision that is not required on its other line segments. These extraordinary efforts are necessary on these line segments to prevent failure of the track and underlying ballast, which is increasingly fouled with coal dust emitted from the continuous passing of loaded trains. As long as significant volumes of coal dust continue to be permitted to escape from trains, BNSF will face the risk of ballast fouling and resulting track instability. Due to the hidden nature of fouled ballast, there will always be the possibility that fouled ballast could go undetected. This risk of undetected fouled ballast underscores the need to address coal dust at the source by limiting emissions from loaded coal trains rather than attempting to clean up the coal after it has spilled out of coal cars.

I declare under penalty of perjury that the foregoing is true and correct. Further, I certify that I am qualified and authorized to file this Verified Statement.

Executed on March 15, 2010

Craig Sloggett

VERIFIED STATEMENT OF CHARLES SULTANA

BEFORE THE
SURFACE TRANSPORTATION BOARD

STB Finance Docket No. 35305

PETITION OF ARKANSAS ELECTRIC COOPERATIVE CORPORATION FOR A DECLARATORY ORDER

VERIFIED STATEMENT OF CHARLES SULTANA IN SUPPORT OF BNSF RAILWAY COMPANY'S OPENING EVIDENCE

My name is Charles Sultana. I am a Six Sigma Specialist in the Mechanical Department of BNSF Railway Company ("BNSF"). As I explain below, the Six Sigma methodology is a process for solving business problems that relies heavily on facts and data. As BNSF's Six Sigma Specialist, I had primary responsibility for developing the specific coal dust emissions standards that are at issue in this declaratory order proceeding. As I explain below, BNSF's coal dust emissions standards are based on a large quantity of data collected and carefully analyzed over several years from the coal dust emitted by trains operating in the Powder River Basin ("PRB"). My responsibility was to analyze the data for purposes of identifying an achievable and conservative limit on coal dust emissions that would, if met by all shippers, substantially eliminate coal dust on the PRB rail lines. The purpose of my verified statement is to describe for the Board the development and logic of the emissions standards that I developed.

The Six Sigma Methodology

I was hired by BNSF in 2006 as a Six Sigma Specialist in BNSF's Mechanical Department. Since I arrived at BNSF, I have worked on projects in the Engineering and Mechanical departments as well as the Finance and Marketing departments. My primary responsibility is to bring an advanced level of analytical and problem solving skills as developed and incorporated in the Six Sigma methodology to important problems identified by BNSF management. I was certified as a Six Sigma "Black Belt" in 2000, representing mastery of the Six Sigma methodology, and certified as a "Master Back Belt," the highest Six Sigma qualification level, in 2009. I have a Bachelor of Science degree in Mathematics from University of Texas at Arlington.

The Six Sigma methodology is a disciplined, data-driven methodology for eliminating defects and variation in any business system. The word "Sigma" represents the standard deviation within a population, i.e., the amount of variability within a defined population. The theory underlying the Six Sigma methodology is that if there are six standard deviations between the process mean (the average value of a given population) and the nearest specification limit (the upper or lower acceptable value), practically no member of the population will fail to meet specifications. The purpose of the Six Sigma methodology is to find ways to reduce variation in a given population.[1] The Six Sigma process is data intensive and relies heavily on statistical analyses.

When I arrived at BNSF, I was asked by Lisa Stabler, Assistant Vice President of Mechanical Quality and Reliability, to work with a group of BNSF employees and outside consultants that were investigating the problem of coal dust in the PRB. I was informed that large quantities of coal dust were being emitted from loaded coal cars moving on the Joint Line and on BNSF's Black Hills Subdivision and that coal was being deposited on BNSF's right-of-way, where it contaminated the rail ballast and created the risk of unstable track conditions.

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[1] For more information on the Six Sigma process, *see* Peter S. Pande et al., *The Six Sigma Way: An Implementation Guide for Process Improvement Teams* (2002) (general overview); American Society for Quality, http://www.asq.org/certification/six-sigma/index.html (last visited Feb. 25, 2010) (explaining certification courses).

Extensive data collection was underway to understand the scope of the coal dust problem. Ms. Stabler asked me to help understand and evaluate the data that were being collected.

Initial Efforts to Assess the Scope of the Coal Dust Problem

Shortly after being assigned the coal dust project, I went to Gillette, Wyoming, to investigate the physical properties of the coal in the Powder River Basin that made it susceptible to dusting. I examined the way the coal is mined, how it is stored, crushed, loaded, and transported and I took samples at different stages of the process. I measured the dustiness of coal at each stage to determine where coal dust appeared to be created. I concluded that the coal coming out of a mine's storage silo, where the crushed coal is kept prior to being loaded into empty coal cars, had substantially more dust than the coal entering the silo. It appeared that coal dust might be created in the silo by the shifting of coal as coal moved within and through the coal silo or that coal dust was accumulating in pockets within the silo and therefore deposited in large quantities in the cars during the loading process. We informed the mines of the results of these preliminary observations.

I also carried out various analyses of data being collected in the field by BNSF on coal trains in transit to determine whether it was feasible to isolate specific factors that caused dusting to occur on coal trains in transit. When I began working on the coal dust problem, BNSF was working extensively with Simpson Weather Associates ("SWA") to set up a data collection system relating to coal dust emissions. The data collection system that was being implemented had three parts. First, a network of dustfall collectors had been established at various locations along the PRB lines. These collectors measured the aggregate volume of coal dust that accumulated over a 30-day period of time at a specific location. The data from dustfall collectors therefore provided a broad overview of dustfall patterns over time. However, they did not provide information that could be linked to particular train movements. So while the data confirmed that dusting had indeed occurred, I did not believe these data would be particularly useful in setting a coal dust emission standard applicable to individual trains.

Second, and more important for my purposes, BNSF and SWA had set up a Track Side Monitor ("TSM") at milepost 90.7. The TSM is a combination weather tower and coal dust monitor that collects data on each train as it passes by the TSM. *See* Exhibit 1. Towers were set up on both sides of the tracks so that dust readings could be made from the downwind tower. The dust monitor on the TSM is a sophisticated electronic device, called an e-sampler, that measures coal dust in the air at five-second intervals. SWA had developed a methodology for summing up all of the dust units recorded by the e-sampler in five-second intervals over the period of time that a particular train was passing the TSM. SWA was also able to identify and exclude from the dust units measured by the e-samplers the dust units that were attributable to the diesel locomotives on the train and the dust units attributable to background dust in the air before and after the passage of the train. The graph attached at Exhibit 2 illustrates the process by which these adjustments to the e-sampler readings were made. Using this approach, SWA was able to calculate a total number of coal dust units measured by the e-samplers for specific trains as they passed Milepost 90.7. The total dust unit calculation for a particular train was called the "Integrated Dust Value" or IDV of that train.

By the time I started working on the coal dust project, SWA had collected IDV data on thousands of trains passing Milepost 90.7. However, not all IDV calculations were considered reliable indicators of the amount of dust attributable to a particular train. For example, if a loaded train passing Milepost 90.7 was closely following another loaded train, it was possible that the coal dust units attributable to the second train were in fact produced by the first train.

Therefore, SWA excluded IDV readings where two trains passed within minutes of one another. Even with these exclusions, SWA had IDV data for several thousand trains.

SWA and BNSF's Technical Research and Development group had also set up several test trains with instruments mounted on the trains. The instruments included an Rail Transport Emission Profiling System ("RTEPS") and Passive Collectors ("PCs"). The RTEPS are essentially mobile weather stations that record real time data regarding ambient conditions (e.g., temperature, rainfall, humidity, wind speed) over the course of a train trip. *See* Exhibit 3. The Passive Collectors are boxes attached to the sill of coal cars that collect coal dust particles as they are blown off of the loaded coal. *See* Exhibit 4. Passive Collectors were generally set up on several different cars in a test train. RTEPS data was recorded over the full length of the train trip and the coal collected in the PCs would be gathered at various intervals along the trip.

Through these three data-gathering approaches, BNSF had collected a vast amount of data on coal dust and coal dust emissions in the PRB. Before attempting to develop a specific coal dust emission standard, I did several analyses of the data collected by SWA to see whether it was possible to isolate specific causes of coal dust emissions from loaded trains. For example, I looked at the data collected by SWA from the Track Side Monitors to analyze the effect of wind and train speed on the emission of coal dust from trains passing Milepost 90.7. I determined the vector speed for each train from the TSM data on the wind speed, wind direction and train speed at the time the train passed Milepost 90.7 and did a regression analysis of vector speed and dusting episodes as measured by the TSMs.

This analysis suggested that the relationship between dusting events and vector speed was not a linear one. Wind was clearly an important factor in dust emissions, but I found that as vector speed increased, the amount of dust emitted from a passing train did not increase in a linear fashion. *See* Exhibit 5. I did additional analyses to determine whether other factors such as time of day would explain the dust events occurring at Milepost 90.7 and found no other significant relationships. I concluded from these analyses that the causes of coal dust emissions at Milepost 90.7 were largely attributable to factors affecting the coal before the trains arrived at the TSM monitoring station. For example, the dryness of the coal by the time a train reached Milepost 90.7 clearly affected the likelihood that dust would be emitted. Wet coal loaded into the coal cars at the mines could dry out at varying rates based on weather conditions. The amount of dust in the coal itself when loaded into the cars would also affect the likelihood of dust emissions at Milepost 90.7.

Creation of an IDV-Based Coal Dust Standard

After working for a few months on the coal dust project, I was asked by William VanHook, Assistant Vice President and Chief Engineer - Systems Maintenance and Planning, the person heading up BNSF's efforts on the coal dust issue, to determine whether a coal dust emission standard could be developed that would identify, on a train-specific basis, trains emitting exceptional levels of coal dust. In response, starting in late 2006, I focused my efforts on the development of a coal dust emission standard.

As noted above, the TSMs mounted at Milepost 90.7 calculated an IDV for each loaded train passing that point on the Joint Line. By late 2006, when I started working on the development of a coal dust emission standard, SWA had made IDV calculations for over 10,000 trains. I concluded that the IDV calculations could be used to set a performance standard that would allow BNSF to identify trains that are producing excessive amounts of coal dust. However, before establishing a specific performance standard, I wanted to be sure that the measurements being made by the e-samplers used to calculate IDV values were reliable. I was somewhat concerned about the month-to-month variation I was seeing in the IDV data that had been collected. Therefore, over several months I worked with SWA to conduct laboratory and field tests of the e-samplers to determine the extent to which the e-samplers could produce varying measurements of the same coal dust source.

In these tests, two e-samplers were placed side-by-side with a common air intake to make coal dust measurements of the same source of coal dust. At Milepost 90.7, we mounted two e-samplers side-by-side and collected dust data from the devices for several months. We also did laboratory tests where we did the side-by-side tests on three additional e-samplers in pairs of two (1/2, 1/3, 2/3). In total, we had nearly 400 data points showing simultaneous measurements from two e-samplers in the side-by-side tests. We found that each of the side-by-side e-samplers generated a somewhat different reading of dust units even though the same source was being analyzed. For example, one e-sampler unit might read 100 dust units while another e-sampler at its side might read 125 dust units from the same dust source. We concluded that the likely cause of this variation was the fact that coal dust particles are not evenly distributed in the air. However, the data we collected from these e-sampler tests allowed us to determine the range of variation in e-sampler readings from a common source. My study results are set out at Exhibit 6.

The variation in e-sampler readings meant that it was not possible to have a high degree of confidence that a particular e-sampler reading of coal dust units could be replicated exactly by other e-samplers measuring the same dust source. However, the test results also made it possible to have a high degree of confidence that a particular e-sampler reading would be within a defined range of possible values as measured by other e-samplers. Therefore, I concluded that a valid standard for coal dust emissions could be based on the e-sampler readings taken at Milepost 90.7 so long as it took account of the variation inherent in the e-samplers measuring coal dust.

To develop an appropriate coal dust emission standard, I started with the IDV data collected from the TSM at Milepost 90.7 on all trains passing that location from September 2005 through August 2007 (excluding the data for trains that passed too close to one another to produce reliable values, as discussed above). As I explained above, the IDV for a particular train represents the number of dust units measured by the e-sampler during the passage of that train by Milepost 90.7. By August 2007, when I began my data analysis, SWA had improved on the development of the IDV calculation by removing additional data associated with locomotives and with background dust values. A description of SWA's improvement upon the IDV calculation is set out in Exhibit 7. The improved IDV calculations are referred to as IDV.2. SWA revised all prior IDV calculations for the trains moving between September 2005 and August 2007 to recalculate IDV.2 values for each train using the improved IDV.2 logic.

I took the IDV.2 calculations for all usable trains from this period and added together the dust units that had been measured for that group of trains over the two-year period. This produced a total of about 2 million dust units. I could then determine an IDV.2 value which, if not exceeded by the trains in the group, would have reduced those 2 million dust units by varying percentages. For example, if my goal was to achieve a 50% reduction in the 2 million dust units, I would seek to identify the IDV.2 value which, if not exceeded by any of the trains in the data set, would have resulted in only 1 million dust units being emitted from the study trains during the study period. For a 75% reduction, I would seek to identify the IDV.2 value which, if not exceeded by any of the trains in the data set, would have resulted in only 500,000 dust units being emitted from the study trains during the study period.

To carry out this analysis, I plotted on a graph the threshold IDV.2 levels on one axis and on the other axis the percentage reduction in dust units for the corresponding threshold IDV.2

levels. *See* Exhibit 8 at BNSF_COALDUST_0039335. Exhibit 8 is an October 9, 2007 internal presentation I made at BNSF describing my methodology. The graph showed the percentage of dust units that would have been reduced if all trains in the data set had been at or below specific "threshold" IDV.2 levels. For example, the graph shows that if no trains operated with an IDV.2 level above 2,000, about 25% of the dust units would have been eliminated. Similarly, if an IDV.2 level of 1,000 had never been exceeded by the trains in the data set, about 50% of the dust units would have been eliminated. I was told by Steve Bobb, the Group Vice President, Coal Marketing, who was an active participant in the coal dust review group at BNSF, that I should strive for a 95% reduction in coal dust. I determined that an IDV.2 level of 134, if never exceeded by the trains in the data set, would have achieved a 95% reduction in coal dust units at Milepost 90.7.

This was not the end of the analysis, however, because it was necessary to take into account the variability in e-samplers. As discussed above, two e-samplers measuring the same coal dust source could produce IDV.2 values within a defined range. To determine the range of variability of the e-samplers, I charted all the data from the side-by-side e-sampler measurement tests from the laboratory and in the field. See the two fitted line plots on Exhibit 8 at BNSF_COALDUST_0039336. Each point on the plot represents the IDV.2 values recorded on two e-samplers that had been placed side-by-side. The chart shows for any given IDV.2 value on Monitor B (x axis) the corresponding IDV.2 value that was produced by Monitor A (y axis) in the side-by-side test. In the right-hand chart, the solid line is the ideal regression line of all plotted values and values between the dashed lines contain 90% of all the values. By using 90% of the values, 5% of the values were above the dotted line and 5% were below the line. This allowed me to account for 95% of the expected variation in the dust monitors. The chart goes past 2,000 but I was interested in what is happening around 134 IDV.2, which I had previously determined to be the threshold IDV.2 value for eliminating 95% of the coal dust units. The chart to the left is a blow up of the chart on the right, focusing on the values only up to 500 IDV.2

To account for the e-sampler variability, I placed a vertical line at 134 on the x-axis. The points along that vertical line indicate that a reading of 134 on Monitor B corresponded to readings on Monitor A of between about 100 and about 300. Therefore, to be within the upper limit of the 90% dotted lines, the value on Monitor A could be as high as 300. I did the same analysis for Monitor A by drawing a horizontal line at 134 from the y axis. Again, to be within the upper limit of the 90% dotted lines, a reading of 134 on Monitor A could have been as high as about 280 on Monitor B. The values of 280 and 300 are close enough that an IDV.2 standard of 300 would give 95% confidence that the actual IDV.2 value of the reading is at least 134. In other words, taking the variability of the e-samplers into account, it is 95% certain that a train producing over 300 IDV.2 dust units is actually producing over 134 IDV.2 dust units.

This is a highly conservative standard. It is certainly possible that a train producing, for example, 250 IDV.2 dust units is actually producing 250 IDV.2 dust units, far in excess of what is needed to eliminate 95% of the coal dust. But given the variability of the e-samplers, it is also possible that the train producing 250 IDV.2 dust units is actually producing less than 134 dust units. Therefore, BNSF set the IDV.2 limit at 300 to make sure that trains in fact producing less than 134 IDV.2 units would not be found to violate the standard.

I then returned to the graph discussed above that compared the percentage reduction of coal dust units to IDV.2 levels. See Exhibit 8 at BNSF_COALDUST_0039337. The data show that at a 300 IDV.2 level, there is a high degree of confidence that coal dust emissions would be reduced by at least 85%. If none of the trains in the data set had an IDV.2 exceeding 300, 85%

of the total coal dust from these trains would have been eliminated. Thus, while BNSF wanted to set a standard that achieved a 95% reduction in coal dust emissions, the variability of the e-samplers required that we accept a somewhat lower reduction. Given the conservative approach I took, I have a high degree of confidence that compliance with the coal dust emissions standard by all trains passing Milepost 90.7 will eliminate at least 85% of the dust emissions at Milepost 90.7.

I conducted a similar analysis to determine a coal dust limit using TSM data for trains passing Milepost 558. *See* Exhibit 9. My analysis of the Milepost 558 data produced an IDV.2 limit of 245.

Verification of the IDV.2 Methodology

Before BNSF established the IDV.2 standard as an operating rule, I wanted to obtain an independent review of the approach I had taken in developing the coal dust emissions standards. I first contacted a firm called Six Sigma Qualtec and provided them with the data set I had used to develop the IDV.2 standard and explained to them BNSF's basic objectives. Qualtec raised two issues with my analysis. First, they noticed that the data had numerous zero values (IDV.2 readings of zero) and they suggested that the zero values should not be used. I disagreed. It is not a valid scientific approach to exclude data unless there is reason to believe the data are flawed or unreliable. Given the highly episodic nature of coal dust emissions, where loaded coal will remain highly stable for periods of time before being released, there was no reason to believe that the zero IDV.2 readings reflected a flaw in the instruments or data; instead, those zero values reflected that certain trains did not emit dust at measurable levels at Milepost 90.7. Qualtec also noted that the variability of the e-samplers was not constant across the entire range of IDV.2 values. While this was true, it was not particularly relevant to the standard BNSF had developed because the variability of IDV.2 values in the range of the standard that I had determined (around 134) was relatively constant.

We contacted another independent Six Sigma firm, Smarter Solutions, to review our standard setting process. Smarter Solutions had a Six Sigma Master Black belt who had worked previously with the type of specialized equipment BNSF was using at the TSMs to calculate IDV.2 values. After reviewing my analysis and the underlying data, Smarter Solutions concluded that it was appropriate to leave the zeros in the analysis. They further concluded that there was no reason to address the fact that variability was not constant over the entire range of IDV.2 values, since variability was relatively constant within the range of values where the standards were being set. Overall, Smarter Solutions agreed that the approach I had taken was a reasonable one. *See* Exhibit 10. In fact, they concluded that BNSF was probably being too conservative, and they suggested that an IDV.2 value of 231.4 could be used as the dust emissions limit at Milepost 90.7. Nevertheless, BNSF chose to remain with its conservative limit of IDV.2 300. BNSF implemented that standard as a Joint Line operating rule and included that standard in BNSF's rules in 2009.

I declare under penalty of perjury that the foregoing is true and correct. Further, I certify that I am qualified and authorized to file this Verified Statement.

Executed on March 15, 2010

Charles Sultana

VERIFIED STATEMENT OF G. DAVID EMMITT

BEFORE THE
SURFACE TRANSPORTATION BOARD

STB Finance Docket No. 35305

PETITION OF ARKANSAS ELECTRIC COOPERATIVE CORPORATION FOR A DECLARATORY ORDER

VERIFIED STATEMENT OF G. DAVID EMMITT IN SUPPORT OF BNSF RAILWAY COMPANY'S OPENING EVIDENCE

My name is G. David Emmitt. I am the President and Senior Scientist of Simpson Weather Associates ("SWA"). SWA is a scientific research and development firm that focuses on environmental and energy issues. For over twenty five years, I have worked at SWA on matters related to fugitive coal dust and its mitigation. SWA was retained by BNSF in 2005 to assist BNSF in understanding the scope of the problem of coal dust escaping from loaded coal trains in the Powder River Basin ("PRB") and to investigate remediation measures. The purpose of my statement is to describe for the Board the extensive data collection and analysis that I and my firm have carried out for BNSF in the past five years to provide BNSF with a quantitative foundation for establishing standards on coal dust emissions.

Background and Experience

In 1975 I received a Ph.D. in Environmental Sciences (Atmospheric Physics) from the University of Virginia, Charlottesville, Virginia. After a post doctorate tenure as a Visiting Scientist at the Max Planck Institute for Meteorology in Hamburg, Germany, I spent the first five years of my career studying hail storms in South Africa while maintaining my association with the University of Virginia as a Research Assistant Professor. In 1981, I accepted a position of Visiting Space Scientist at NASA's Marshall Space Flight Center in Huntsville, Alabama. Since my tenure at NASA, I have continued to be actively engaged in the use of airborne Doppler Wind LIDARs to investigate the atmosphere (tropical cyclones, tornadoes, etc.) and to prepare for a future space-based wind LIDAR. In 1983, I joined SWA and brought my LIDAR research with me. In 1984, I became involved in basic and applied research associated with fugitive dust emissions from coal piles. This interface between the atmosphere and a significant environmental issue became the focus of laboratory, field and theoretical investigations continuing to the present. SWA has become known for its unique expertise in the understanding, monitoring and control of fugitive coal dust emissions from coal storage piles and rail cars. My CV is attached to this statement as an Appendix.

During the past 26 years, I have led a small team of researchers in projects funded primarily by the private sector (coal companies, railroads, chemical companies, and utilities) focused upon reducing product losses from coal storage piles and open rail cars. In addition, I have received funding from the Center for Innovative Technology to develop techniques for imaging the load profiles of coal in rail cars. The scope of our work ranges from the theoretical (mathematical expressions for the propensity of coal to be blown into the air by the action of air in motion) to the operational deployment of scanning lasers to produce 3D images of the coal loaded in rail cars. SWA continues to perform laboratory evaluations of chemical binders, often referred to as "surfactants" or "topper agents," used to control fugitive dust emissions. I use the term "binder" in this statement to refer to these chemical solutions.

SWA is best known for its unique capabilities in the area of fugitive coal dust emissions from rail cars. My first project involving material losses from coal cars was funded by Norfolk Southern Railway ("NS") in 1987, and led to an extensive, five-year study. Through the use of instrumented caboose, laboratory and field experiments, SWA expanded its understanding of how coal is lost during transit and how to reduce those losses through load profiling and chemical binders. SWA also developed unique technologies for assessing coal losses. These technologies include the TrackSide Monitor ("TSM") which is installed next to the tracks to detect and quantify dust emissions from passing trains, the Rail Transport Emission Profiling System ("RTEPS") which is attached to the rear sill of coal cars and the laser based Coal Car Load Profiling System ("CCLPS") which provides a 3D image of the coal load in a rail car. NS continues to operate a program of fugitive dust control and performance monitoring based on SWA techniques in Virginia, Ohio and Pennsylvania, and provides annual reports on its performance.

The Problem of Coal Dust

The scope of coal mining operations and coal transportation in the PRB is impressive. A large amount of coal is moved out of the PRB. Thousands of loaded coal cars are transported over the same rail lines each day. If coal escapes from these loaded cars and is deposited on the right of way, coal will accumulate rapidly. Others have studied the impact of coal deposits on rail ballast integrity and have found that coal dust accumulation has serious adverse effects on rail ballast integrity.

The presence of coal along the right of way on the Joint Line in eastern Wyoming is obvious to anyone that has spent time in the area. In many places, there are visible deposits along the right of way. In other places, removing the small top layer of soil or ballast reveals coal beneath the surface. I have spent much of my professional career working with railroads and I have never seen such extensive right-of-way contamination as that which occurs in the PRB from coal that has escaped from coal cars.

There are a multitude of factors that influence the amount of coal that escapes from coal cars in transit and contaminates the rail ballast. The type of coal at particular mines, the size of the coal loaded into coal cars, the way the coal is processed at the mines, and the way coal is loaded by the mines into coal cars all have an impact on the amount of coal that is lost in transit. Numerous other factors also impact dusting. Weather is an important factor. Dry coal tends to escape from coal cars much more readily than moist coal, so weather conditions that produce dry coal can dramatically affect the amount of coal escaping from coal cars. Wind conditions – particularly the strength and direction of wind relative to the train movement – also affect the amount of coal dust produced by moving coal cars. Train speed is a primary and obvious covariate with coal dust emissions.

Simple observation of coal trains in transit makes it clear that dusting, *i.e.*, instances when dust escapes from the moving car, is highly episodic. Coal dusting does not regularly occur at the same time or place for each coal train. Coal that is moist and relatively stable when loaded can dry out as the train moves through dry air until the coal surface becomes highly unstable. In my experience, a coal train can be moving rapidly with no emission of coal dust and suddenly large plumes of dust can escape with no apparent immediate cause. My opinion is that while the coal from some mines tends to have a higher incidence of coal dusting than others, all mines experience some significant dusting events of their coal during transit.

Coal Dust Data Collection and Analysis

In May 2005, there were two coal train derailments within days of one another on the Joint Line that caused massive dislocations in rail operations in the PRB. I understand that BNSF subsequently concluded that the presence of coal dust in the ballast contributed to those derailments. Shortly after the derailments, BNSF retained SWA to obtain a better understanding of the scope of the coal dust problem in the PRB and to begin to identify ways to remediate coal dust accumulation. A major objective of the work my firm was asked to perform was to rigorously collect and analyze data relating to the loss of coal from the tops of moving coal cars.

Even before I started working with BNSF in 2005, BNSF had been studying the problem of coal dust. An environmental engineering firm, Conestoga-Rovers Associates ("CRA"), had worked with BNSF to get a basic understanding of the scope of the coal dust problem. With CRA's assistance, BNSF had set up dust fall collectors near the rail ballast along the Joint Line to assess the amount and type of coal that was escaping from moving coal cars. BNSF had also looked at ballast samples to determine the extent of fouling produced by the presence of coal in the ballast.

After the derailments, BNSF wanted to expand its data collection efforts and to identify measures that could be taken to remediate coal dust emissions. BNSF retained SWA to assist in those efforts. I have worked extensively with BNSF since 2005 to define the coal dust problem in and near the PRB and to help BNSF keep its shippers informed of BNSF's investigations. I have also kept the Union Pacific Railroad Company ("UP") informed of SWA's work relating to the Joint Line, as UP is a co-owner of the Joint Line. I attended several meetings of the National Coal Transportation Association ("NCTA") and made numerous presentations at those meetings reporting on the research SWA was carrying out for BNSF.

Our efforts for BNSF focused on the following areas.

Load Profiling

One of the first things I did after being retained by BNSF was to advise BNSF on the benefits of changing the profile of the coal loaded into the coal cars. I have studied the dynamics of coal dust emissions extensively. I applied that knowledge in my work with NS to change the loading profile of coal in NS coal cars to reduce the emission of dust from their cars. It was immediately clear to me from my review of coal car loading in the PRB that a change in the loading profile could also bring about a measureable reduction in PRB coal losses during transit.

Coal cars were being loaded with trapezoidal shapes and sharp edges. But as the cars move, the wind and vibration of the cars tend to groom the coal in the cars into a more aerodynamic shape. In this process of self-grooming during transit, substantial amounts of coal are blown around and off of the cars. I advised BNSF that the mines should load coal cars into the shape that would naturally be created by the wind to minimize the disruption of the coal during transit. *See* Exhibit 1.

While I had done studies of the optimal load profile for NS on eastern coal, PRB coal had different characteristics. Therefore, I did additional testing to determine an appropriate profile for the PRB coal. The important issue here was the angle of repose for dry PRB coal. I determined that a 30-degree angle was appropriate – if coal was loaded at an angle exceeding 30 degrees, coal would seek a 30-degree angle as it dried and the loose coal would blow off of the cars as it settled into the 30-degree angle. I provided BNSF with an optimum load profile and helped BNSF convince the mines to modify their loading behavior. *See* Exhibit 2.

We initially encountered resistance from mines in seeking a change in the loading profile. One concern was that a modified loading profile would reduce the amount of coal that could be loaded into the cars. I did some tests with laser imaging and showed the mines that the modified profiles would simply redistribute the coal in the car but would not reduce the amount of coal that could be loaded into the cars. Since then, the mines have modified their loading chutes and the loading profile has improved. *See* Exhibit 3.

I also assisted in conducting field tests to determine the amount of coal dust emissions that could be reduced by loading coal to the proper loading profile. Our initial tests were performed by grooming loaded coal cars with a type of rake attached to a back hoe, although later tests were conducted on coal cars that had been loaded with modified loading chutes. I describe below the process that I developed for testing coal trains in transit using specialized instruments, including a Passive Collector ("PC") mounted on the rear sill of loaded coal cars. A PC is a metal box that captures coal dust blown into the box as the train moves. To test the relative impact of a properly profiled coal car, we attached PCs to the rear sill of cars that had been groomed by the profile bars and to cars that had not been groomed. We collected the coal that accumulated in the different PCs over a train trip and weighed the coal deposits. These simple tests performed on a very limited number of trains suggested that proper grooming of coal cars could achieve in some cases over 30% reduction in coal loss during transit. *See* Exhibit 4. I have subsequently come to believe, based upon dustfall collector data, that in practice the actual reduction in coal emissions from grooming is considerably less than 30%. *See* Exhibit 5 at BNSF_COALDUST_0064122. I believe the substantially smaller benefit we are seeing is likely attributable to widely varying loading practices at the mines, which do not always give proper attention to the load profile during the loading process. Use of a modified loading chute is not enough to ensure proper grooming of coal cars. In order to monitor loading practices and load profiles, SWA will install permanent CCLPS systems. The CCLPS system is a laser imaging system that produces a 3-D image of the loading profile of a passing loaded coal car. *See* Exhibit 6. Our objective is to provide immediate feedback to mine loading operators on the profile of loaded cars so that the mines can refine their loading practices to achieve the proper loading profile.

Track Side Monitors

My work for NS also involved establishing field monitoring stations that can sample the amount of coal dust emitted by particular trains. Building on my NS experience, I provided BNSF with design specifications and instruments for Track Side Monitors. A TSM is a combination of a weather system and a dust monitor mounted on a tower about 60 feet to the side of the track. *See* Exhibit 7. The dust monitor data collected from these instruments is telemetered directly to SWA from Wyoming to Charlottesville, Virginia.

The weather system on the TSM provides real time continuous measurement of wind speed and direction, precipitation, temperature and relative humidity. The dust monitor on the TSM is mounted on the tower at about the height of the top edge of the cars. The dust monitor is an electronic device, the Met One Instruments E-Sampler, which continuously draws in ambient air, passes light through the air and measures the scattering of light that results from particles in the air. *See* Exhibit 8. The dust monitors produce a relative measure of the amount of dust in the air in dust units. The dust monitors are highly sophisticated instruments that are programmed to self-calibrate every 12 hours. They are the only such units that we have found suitable for long-term outdoor operations. It is my view that the E-Sampler dust monitors are the best possible equipment available for field monitoring and sampling of dust emissions from individual moving coal trains. In particular, the continuous sampling of air every five seconds allows measurement of dust emissions over the entire length of the passing train.

Two E-Sampler dust monitors are located at the Milepost 90.7 TSM on the Joint Line, one on a tower west of the tracks and one on a tower east of the tracks. Two E-Sampler dust monitors are also located at Milepost 558.2 TSM on BNSF's Black Hills Subdivision, one on the north and one on the south side of the tracks. Two E-Sampler dust monitors have also been set up at Milepost 693.4 TSM on BNSF's Big Horn Subdivision on the north and south sides of the tracks. At or near each location of the TSM, there is an Automatic Equipment Identifier ("AEI"), or other railroad train presence devices that allow us to identify each passing train. In addition, wheel detectors have been installed on the tracks at each TSM location that indicate train presence. The wheel detectors are also used to determine the train's speed. *See* Exhibit 9 at BNSF_COALDUST_0000693.

As indicated, the E-Sampler monitors dust by continuously sampling the air. Dust monitor readings are collected and stored every five seconds, whether a train is present or not. Wheel detectors and AEI data provided by the railroad indicate when the dust monitor readings can be assigned to a specific train. The dust readings registered by the dust monitors of each five-second sample, which effectively produce a snapshot of that point in time, are then integrated over the entire time period that the train is passing the TSM to determine a relative comparable measure of the amount of dust that was emitted by a passing train. The results can be plotted on a graph. *See* Exhibit 10 at BNSF_COALDUST_0039367.

As seen in the graph, there are spikes in the dust readings associated with the passage of the diesel locomotives. The dust readings associated with the diesel locomotives can be identified and removed from the calculation of the total number of dust units. In addition, it is clear from the graph that the dust monitors register background dust before and after the passage of a train. In order to focus only on the coal dust emitted from a passing train, this background dust reading is also removed from the total. In addition, only the dust values above the background level are included in the calculation. What is left after these adjustments is a reading of the total amount of coal dust, in relative "dust units," that are emitted by a passing train. The total is called the "Integrated Dust Value" or "IDV" of a particular train. The IDV.2 referred to in the BNSF Rules Publication at issue in this case reflects certain improvements in the logic used to calculate the dust units associated with the passing trains, as described in Exhibit 10. Some trains are not assessed an IDV.2 because of high or variable background dust measurements, coincident train passage or equipment malfunction.

The E-Sampler dust monitors used at the TSMs exhibit some variability when measuring coal dust, as do all monitors to some degree. In other words, two dust monitors may give slightly different dust unit readings for the same plume of dust. SWA and BNSF conducted laboratory and field tests of these monitors to determine the extent of the variability. Tests were conducted with side-by-side dust monitors. The variation in dust unit readings from these side-by-side tests appears to be attributable to the fact that individual dust particles have varying size and shape and are not evenly distributed in the air. Thus, even when a common source of coal dust is tested, light will be reflected differently on the different particles in each sample, leading to somewhat divergent readings. Mr. Charles Sultana of BNSF took account of this variability in the E-Sampler dust monitors when he determined the IDV.2 limit that is at issue in this case. BNSF's use of the E-Samplers and the corresponding IDV.2 calculations for individual trains provides BNSF with a reliable way to monitor coal dust levels on a train-specific basis and to identify trains emitting excessive levels of coal dust.

Dustfall Collectors

As I noted above, before I began working for BNSF, BNSF and its consultants at CRA had set up a number of dustfall collectors to get an idea of the amount of coal that was escaping from loaded coal trains. I used SWA's modified dustfall collector design, based upon the American Society for Testing and Materials ("ASTM") standard, and expanded the network of collectors. *See* Exhibit 11 at BNSF_COALDUST_0080213-17. Dustfall collectors are an approved ASTM method of measuring dust fall at specific locations. I also recommended that the dustfall collectors be set up at varying distance from the tracks so that the amount of coal dust could be evaluated as a function of distance from the tracks.

The dustfall collectors cannot be used to determine the amount of coal that is emitted from individual trains. As discussed above, we use the TSMs to measure coal dust emitted from individual trains. Rather, the dustfall collectors measure the coal deposited at a particular location over time. Coal is collected from the dustfall collectors for approximately 30 days and the amount of coal accumulation is measured. Over time, it is possible to detect patterns of coal dust emissions and deposits on the ground. For example, it is clear that coal dust emissions appear to be greatest in winter months, due to higher wind speeds and lower atmospheric moisture. *See* Exhibit 11 at BNSF_COALDUST_0080217. The dustfall collectors will also be a valuable tool to measure the overall impact of dust suppression measures taken by coal shippers when BNSF's coal dust standards go into effect.

Instrumented Trains

Based on my work with NS, I also adopted for BNSF testing devices that can be mounted on individual coal cars on particular trains. The devices consist of a Rail Transport Emission Profiling System and Passive Collectors. *See* Exhibit 11 at BNSF_COALDUST_0080229-30. The RTEPS contains several instruments that are used to monitor various external factors that can affect coal dust emissions. The RTEPS includes an airborne dust monitor similar to the E-Samplers used at the TSMs, a precipitation gauge, a monitor for ambient temperature and relative humidity, a propeller anemometer, an infrared sensor to measure the surface temperature of coal in the car, and a Global Positioning System. The RTEPS is mounted directly onto a car in a test train, usually a car toward the end of the train. The RTEPS collects data for the test train on the ambient stresses (e.g., temperature, wind conditions) applicable over the entire route of the train.

In addition, the instrumented trains contain PCs, which, as described previously, are wind tunnel designed boxes mounted on the rear sill of a coal car. The boxes collect coal that is blown into the boxes over the course of a train trip. These passive collectors are usually mounted on several cars in the test train. Passive collectors are typically mounted at least 20 cars behind the lead locomotive to avoid contamination of the materials collected in the passive collectors by influences of the locomotives. At various intervals along the route, the passive collectors are emptied and the coal accumulated in the collector is weighed.

Since 2005, we have conducted more than 100 tests with the RTEPS/PC instruments. One objective of these tests was to confirm that substantial amounts of coal dust are being emitted from the top of coal cars. In BNSF's discussions with coal shippers and mines, there was some skepticism at first that coal was actually coming off the top of coal cars in significant quantities. The RTEPS/PC analyses showed that there were in fact significant episodes of coal dust emissions along the route of movement. *See* Exhibit 12.

The instrumented trains were also used to test the effectiveness of modifying the loading profile, as discussed above. Instrumented trains were also used to test other possible dust suppression measures, most importantly, the use of binders or surfactants. SWA's efforts to assist BNSF and its shippers to understand the value of binder use is discussed below.

Binder Testing

There is substantial experience outside of the PRB in the use of chemical binders to limit coal dust emissions from moving coal cars. Binders can be used as "body treatments" or "topical treatments." When used as body treatments, the binder is applied before the coal is loaded into the car. As topical treatments, binders are sprayed on top of a loaded coal car. Topical binders limit coal dust emissions by creating a crust of individual particles stuck together that prevents dust from escaping or by creating a flexible, adhesive coating on top of the coal. Binders have been used by NS to control coal dust emissions for their export coal in the East. Binders are also widely used in Canada and in Australia to limit coal dust emissions.

BNSF asked SWA to assist in evaluating the impact of binders on coal dust emissions. Many binders are available for use on loaded coal cars. The various chemicals have different characteristics and varying degrees of effectiveness in coal dust suppression. Indeed, the same chemical binder may act differently when used on coal of different type or mixed with water having differing chemical properties. We performed extensive laboratory tests on different chemical binders to determine whether the products met basic standards. SWA's tests included tests for the depth of penetration by the sprayed surfactant, the curing and drying time and simulated wind/thermal stresses, among other things. *See* Exhibit 13. SWA has tested close to 100 products.

In addition, SWA used the trains set up with RTEPS/PCs to carry out field tests on certain selected binders. Since 2005, SWA has carried out these instrumented train tests on over 100 trains with coal cars that had been treated with binders. The field tests generally involved applying the binder solution on half of the loaded cars on a train and leaving the other half of the train untreated. Passive collectors were mounted on cars in both sections of the test trains. The coal dust from each PC was collected and measured. We found that the effectiveness of binders varied based on the chemical used, the ambient conditions at the time of application, and the care with which the binders were applied. We also found that the binders worked best when applied to loaded coal cars that had been loaded according to our suggested load profile. Our tests showed that coal dust emissions from loaded coal cars could be reduced as much as 95% to 98% when properly loaded and treated with dust suppressing binders. *See* Exhibit 14. It is clear that there are products available to coal shippers and the mines that would effectively eliminate coal dust from moving trains.

BNSF has recently initiated a more extensive field test of binders with the participation of several coal shippers, mines and chemical vendors. The objective of the current field test is to give the interested parties the data that will allow them to evaluate and compare the effectiveness of different chemical binders and to choose optimal mitigation measures. SWA is assisting BNSF in this field test. SWA is conducting laboratory tests on binders that will be used in the field tests to determine whether they meet basic standards necessary to achieve a substantial reduction in coal dust emissions. SWA is also assisting in the preparation of instrumented trains that will be used in the field tests and will be collecting and compiling the data from the test trains to share with participants in the trial.

Based on my research, data analysis and testing of coal dust, I am confident that the use of careful profiling of coal loads and application of appropriate binding agents to the top of loaded coal cars would bring about a reduction of coal dust emissions sufficient to meet BNSF's IDV.2 standard.

I declare under penalty of perjury that the foregoing is true and correct. Further, I certify that I am qualified and authorized to file this Verified Statement.

Executed on March 15, 2010

G. David Emmitt

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EDUCATION:

Ph.D., 1975, University of Virginia, Charlottesville, VA, Major: Meteorology
"Momentum redistribution by enhanced mixing over a heated island"

M.S., 1972, University of Virginia, Charlottesville, VA, Major: Environmental Sciences, "Wind wave prediction on impounded water bodies: a case study, Smith Mountain Lake"

B.S., 1969, Eastern Nazarene College, Wollaston, Massachusetts, Major: Physics

PRESENT EMPLOYMENT:

April 1998-present	President and Senior Scientist, Simpson Weather Associates, Inc.
July 1992-present (int)	Research Associate Professor (Scholar in Residence), University of Virginia, Department of Environmental Sciences

PREVIOUS EMPLOYMENT:

August 1986-April 1998	Executive Vice President & Senior Scientist, Simpson Weather Associates, Inc.
August 1983-August 1986	Vice President, Simpson Weather Associates, Inc.
July 1981 - August 1983	Visiting Space Scientist, Universities Space Research Association, NASA/MSFC, Huntsville, AL

January 1978 - December 1980 Research Assistant Professor, University of Virginia, Department of Environmental Sciences, Charlottesville, VA

August 1978 - July 1981 Cloud Physics Consultant, Butler National Corporation
Lenexa, KS

August 1976 - January 1978 Visiting Scientist, Max-Planck Institut fur Meteorologie
Hamburg, West Germany

August 1975 - August 1976 Research Associate/Assistant Professor, University of Virginia

PROFESSIONAL ACHIEVEMENTS:

2008: Appointed to the Interactive Information and Processing Systems Committee of the American Meteorological Society
2007: Appointed Member of ISETCSC External Advisory Committee
2006: Nominated for the National Academy of Sciences (Atmospheric Panel)
2005: Member of Mission Definition Team for global laser wind sounder
2004: Selected member of NOAA's Thorpex Science Implementation Team
2002: Elected Fellow, American Meteorological Society
2001: Selected member of NASA's Global Tropospheric Wind Sounder Science Team
2000: Selected member of NASA's Code Y Information Technology Subcommittee of Earth Science Advisory Committee
2000: Elected Chair of NASA's Working Group on Space-based Hydrology Mission
1999: Elected Chair of NASA's Consolidated Space Operations Contract (CSOC) Science Working Group
1999: Selected member of NASA's New Data Information System Study team
1998: Elected Chairman, NASA's EOSDIS Science Panel
1997: Mission Scientist on NASA's Space Readiness of Coherent Lidar Experiment
1996: Chairman, NASA/GSFC's DAAC User Working Group
1994: Received "Heros of Reinvention" Award from Vice President Gore in recognition of work done on NASA's Earth Observing System Data Information System
1993: Appointed to NASA's Focus Team on Science and Data Organization/Access
1992: Selected to serve on NASA/CNES (USA/French) Joint Science Team for a space-based Doppler lidar.

1991: Selected to serve on NASA's EOSDIS Version 0 Science Advisory Panel.

1991: Elected to serve as Chairman of NASA's Hydrologic Cycle Data Access and Archive Working Group.

1990: Selected as member of NASA's Earth Observing System Data Information System Science Advisory Panel.

1989: Selected to serve on NASA's Lidar Atmospheric Wind Sounder Science Team to guide the development, deployment and use of a space-based lidar for global wind measurement.

1988: Served on NASA's GLOBE science committee for research on the global distribution of aerosol backscatter.

1987: Served on EPA's Meteorology Division In-House Peer Review Panel.

1987: Served on the 5-man Cloud/Chemistry Cloud Physics Organization's Experiment Design Committee (DOE/NSF).

1986: Selected to serve on NASA panel for a Lidar Atmospheric Wind Sounder (LAWS) as an EOS facility.

1985: Served as member of the NASA organizing committee for Symposiums and Workshops on Global Wind Measurements.

1985: Served on advisory panel for the SPACE/MIST storm research field experiment (1986).

1984-87: Member of American Meteorological Society's Cloud Physics Committee.

1982: Received NASA Award for work on the design, execution and analysis of a flight program to sample the exhaust cloud associated with the launch of the NASA Shuttle.

1981: Received NASA Group Award for research done with the NASA airborne Doppler lidar wind measurement experiments conducted during the CCOPE in Montana.

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Garstang, M., P. D. Tyson and **G. D. Emmitt**, 1975: The structure of heat islands. Rev. Geophys. Space Sci., 13, 139-165.

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2005: Investigation of flows within complex terrain and along coastlines using an airborne Doppler wind lidar: Observations and model comparisons (S. Greco and G. D. Emmitt) Annual Amer. Met. Soc.Conference ,Sixth Conference on Coastal Atmospheric and Oceanic Prediction and Processes, San Diego, CA, January.

2005: Airborne Doppler Wind Lidar Investigations of OLEs over the Eastern Pacific and the Implications for Flux Parameterizations (Emmitt G.D., C. O'Handley, S. Greco, R. Foster and R.A. Brown), Annual Amer. Met. Soc. Conference ,Sixth Conference on Coastal Atmospheric and Oceanic Prediction and Processes, San Diego, CA, January.

2005: Investigation of flows within complex terrain and along coastlines using an airborne Doppler wind lidar: Observations and model comparisons (Greco, S. and G.D. Emmitt),Annual Amer. Met. Soc. Conference, Sixth Conference on Coastal Atmospheric and Oceanic Prediction and Processes, San Diego, CA, January

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2003: Observing system simulation experiments for NPOESS – assessment of Doppler wind lidar and AIRS (M. Masutani, J.C. Woollen, S.J. Lord, G.D. Emmitt, S. Wood, S. Greco, T.J. Kleespies, H. Sun, J. Terry, J.C. Derber, R.E. Kistler, R.M. Atlas, M.D. Goldberg, and W. Wolf), AMS The Simpson Symposium, Long Beach, CA, February.

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2003: Observing systems simulation experiments using the NCEP data assimilation system (S.J. Lord, M. Masutani, J.S. Woollen, J.C. Derber, R.E. Kistler, T.J. Kleespies, H. Sun, G.D. Emmitt, S. Wood, S. Greco, J. Terry, and R.Atlas), AMS 7th Symposium on Integrated Observing Systems, Long Beach, CA, February.

2003: Recent observing system simulation experiments at the NASA DAO (R. Atlas, G.D. Emmitt, J. Terry, E. Brin, J. Ardizzone, J.C. Jusem, and D. Bungato), AMS 7th Symposium on Integrated Observing Systems, Long Beach, CA, February.

2003: OSSEs to determine the requirements for space-based lidar winds for weather prediction (R. Atlas, G.D. Emmitt, J. Terry, E. Brin, J. Ardizzone, J.C. Jusem, and D. Bungato), SPIE's Laser Radar Technology and Applications VIII, Orlando, FL, April.

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2003: Airborne coherent Doppler lidar: investigation of the marine boundary layer and ocean surface motions (G.D. Emmitt, S. Greco, and C. O'Handley), AeroSense Photonics for Defense and Security, Orlando, FL, April.

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2001: Feasibility and science merits of a hybrid technology DWL (G.D. Emmitt), 11th Coherent Laser Radar Conf., Malvern, England, July.

2001: The impact of Doppler lidar wind observations on a single-level meteorological analysis (L.P. Riishojgaard, R. Atlas and G.D. Emmitt), SPIE Lidar Remote Sensing for Industry and Environmental Monitoring, II, San Diego, CA, July 29-August 3.

2001: Calibration and initial results from the OSSEs for NPOESS (M. Masutani, J.S. Woollen, J. Terry, S.J. Lord, T.J. Kleespies, G.D. Emmitt, S.A. Wood, S. Greco, J.C. Derber, R. Atlas and M. Goldberg), AMS 11th Conf. Satellite Meteor. and Oceanogr., Madison, WI, October.

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AFB, MA, October 24-26.

1994: Query scenarios for interdisciplinary scientists interfacing with EOSDIS, Version 0, Series II(S.A. Wood, G.D. Emmitt, K. McDonald). Paper presented at AMS Tenth Internat. Conf. on Interac. Info. and Process. Systems (IIPS) for

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Doll). Paper presented at the 96th National Western Mining Conference and Exhibition, March, Denver, CO.

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1991: Clear line of sight (CLOS) statistics within cloudy regions and optimal sampling strategies for space-based lidars (G.D. Emmitt and G. Séze). Proc. AMS Seventh Symp. on Meteor. Observa. and Instru., New Orleans, LA, January 14-18, 440-442.

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1989: Simulated space-based Doppler lidar performance in regions of backscatter inhomogeneities (with S. Wood). Optical Society of America's Conference on Lasers and Electro-Optics, Anaheim, CA, January.

1988: Subvisible cirrus in space-based Doppler lidar simulations (with S. Wood). Atmospheric Transmission Conference, AFGL, Hanscom, MA, June.

1988: Ground-based simulation of a space-based Doppler lidar atmospheric wind sounder (with S. Wood). Optical Society of America's Conference on Lasers and Electro-Optics, Anaheim, CA, April.

1988: Direct measurement of boundary layer winds over the oceans using a space-based Doppler Lidar Wind Sounder. American Meteorological Society's Third Conference on Satellite Meteorology and Oceanography, Anaheim, CA, February.

1987: Assessment of error sources for one component wind measurements with a space-
based Doppler lidar (with J. W. Bilbro). Optical Society of America's Fourth Conference on Coherent Laser Radar: Technology and Applications, Aspen, Colorado, July.

1987: Error analysis for total wind vector computations using one component measurements from a space-based Doppler lidar. Optical Society of America's Fourth Conference on Coherent Laser Radar: Technology and Applications, Aspen, Colorado, July 1987.

1987: Impact of a space-based Doppler lidar wind profiler on our knowledge of hurricanes and tropical meteorology (with S. H. Houston). AMS 17th Conference on Hurricanes and Tropical Meteorology, Miami, Fl, April 1987.

1987: A numerical investigation of the role of whisker production in dry ice seeding experiments (with R.D. Farley). AMS 11th Conference on Weather Modification, Edmonton, Alberta, Canada, October 1987.

1986: Assessment of measurement error due to sampling perspective in the space-based Doppler lidar wind profiler (with S. Houston). Second Conference on

Satellite Meteorology/Remote Sensing and Applications, May 13-16, Williamsburg, VA.

1986: Constraints on resolving meso-α and meso-ß phenomena using a space-based Doppler lidar wind profiler (with S. Houston). Second Conference on Satellite Meteorology/Remote Sensing and Applications. May 13-16, 1986, Williamsburg, VA.

1986: Topographical influences on radar echo properties --implications to weather modification projects in mountainous terrain (with W. London). Tenth Conference on
Weather Modification, May 27-30, Arlington, VA.

1986: Dry ice pellet whiskers--laboratory evaluation of their production and potential importance to cloud seeding. Tenth Conference on Weather Modification, May 27-30, Arlington, VA.

1985: Convergence and vorticity structures in convective storm outflows as detected by an airborne Doppler lidar velocimeter. 14th Conference on Severe Local Storms, October 29-November 1, Indianapolis, IN.

1985: Discrimination of local and synoptic scale forcing of cumulus convection along the eastern Transvaal escarpment using Meteosat imagery. Second Annual Conference of the South African Society for Atmospheric Sciences, November 11-12, Pretoria, SA.

1985: Doppler lidar sampling strategies and accuracies-regional scale. Paper presented at the Symposium and Workshop on Global Wind Measurements, July 29-August 1, Columbia, Maryland.

1984: Behavior of cylindrical dry ice pellets in the presence of supercooled water droplets--field and laboratory experiments. Paper presented at the Ninth Conference on Weather Modification, May 21-23, Park City, Utah.

1984: Airborne simulation of a satellite based Doppler lidar (J.W. Bilbro and G.D. Emmitt), Proc. of the SPIE, Vol. 493, National Symposium and Workshop on Optical Platforms, pp. 321-325.

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1983: Evolution of the Nocturnal Boundary Layer as Sensed by a Doppler Lidar Velocimeter. Paper presented at 2nd Topical Meeting on Coherent Laser Radar; Technology and Applications, August 1-4, Aspen, Co.

1983: Ground based CO_2 Doppler lidar wind measurements of winds in the vicinity of cumulus convection. Paper presented at 9th Conference on Aerospace and Aeronautical Meteorology of the AMS, June 6-9, Omaha, NE.

1982: Conical lidar scanning from low earth orbit--the effects of meso-α and convective scale atmospheric phenomena. Paper presented at 11th International Laser Radar Conference, July, Madison, WI.

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1980: Mesoscale nocturnal boundary layer jets. Minisymposium on Mesoscale Phenomena and their Interactions, September, Geophysical Fluid Dynamics Laboratory, NOAA, Princeton, N.J.

1978: Determination of σ by direct and indirect cloud transport measurements. Paper presented at the GATE Symposium on Oceanography and Surface Layer Meteorology, Kiel, West Germany, May 16-20.

1976: Mass and energy transports of convective clouds, G.D. Emmitt, M. Garstang and J. Simpson. Paper presented at the 10th Tech. Conf. on Hurricanes and Tropical Meteorology, AMS, July, Charlottesville, Va.

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1974: The structure of heat islands (P.D. Tyson, M. Garstang and G. D. Emmitt, 1974:. Occasional paper #12, Department of Geography and Environmental Studies, University of the Witwatersrand, Johannesburg, South Africa, 71 pp.

1975: The first 1000 m above a GATE ship (M. Garstang, J. Simpson, G. D. Emmitt, G. Barnes, E. Tollerud). Paper presented at the 9th Tech. Conf. on Hurricanes and Tropical Meteorology, Key Biscayne, FL.

1975: Momentum redistribution by enhanced mixing (G.D. Emmitt). Paper presented at the 9th Tech. Conf. on Hurricanes and Tropical Meteorology, AMS,

May, Key Biscayne, FL.

1977: The U. S. GATE tethered balloon system: A discussion of the measurements (M. Garstang, G. D. Emmitt, G. Barnes, D. Fitzjarrald, E. Tollerud and J. D. Brown). Part 3 of Report #2 NSF grant #ATM74-21702 and Final Report on NOAA contract #04-6-
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1984: Evaluation of two 1-D cloud models for the analysis of VAS Soundings (G.D. Emmitt). Prepared for Marshall Space Flight Center, Huntsville, AL, under Contract NAS8-34767. NASA Contractor Report 3771.

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1986: Simpson Weather Associates, Inc. and Kansas International Corporation Limited, Program for Atmospheric Water Supply, 1983-86 Final Report to the Water Research Commission, Pretoria, South Africa.

1987: Contributor to Laser Atmospheric Wind Sounder (LAWS); Instrument Panel Report (Chairman R. J. Curran) (G.D. Emmitt), NASA Earth Observing System, Volume IIg, NASA Headquarters, Washington, D.C.

1994: Norfolk Southern Rail Emission Study (NSRES). Final Rept., February.

1999: NASA Post-2002 Land Surface Hydrology Mission Component for Surface Water Monitoring: HYDRO-SAT HYDROlogical SATellite (C. Vörösmarty, C. Birkett, L. Dingman, D. Lettenmaier, Y. Kim, E. Rodriguez and G.D. Emmitt). Report from the NASA Post-2002 Land Surface Hydrology Planning Workshop, Irvine, CA, April 12-14.

PRESENTATIONS: Seminars/Workshops

2007: Integrating airborne DWL and PBL Models in realtime (G. D. Emmitt, C. O'Handley, S.A. Wood and S. Greco), Working Group on Space-Based Lidar Winds, Miami, FL, February 6 -9.

2007: Prospecting for thermals using an airborne DWL (G.D. Emmitt and C. O'Handley), Working Group on Space-Based Lidar Winds, Miami, FL, February 6 -9.

2007: Correlations of wind shear and clouds: numerical model results (S.A. Wood and G.D. Emmitt), Working Group on Space-Based Lidar Winds, Miami, FL, February 6 -9.

2007: Simulations of hybrid DWL performance with GLAS cloud penetrating statistics (G. D. Emmitt and S. A. Wood), Working Group on Space-Based Lidar Winds, Miami, FL, February 6 -9.

2007: Doppler wind lidar flights: prospecting for vertical motions to enhance SkyWalker performance (G. D. Emmitt, C. O'Handley and S. Greco), DARPA , Arlington, VA, January 31.

2006: Adaptive targeting of a space-based Doppler wind lidar: data and technology implications (G. D. Emmitt), SPIE Europe Remote Sensing, Stockholm, Sweden, September 11 – 14.

2006: Using ICESAT observations to obtain CFLOS statisitics for use in the design of space-based lidars (invited paper) (G. D. Emmitt and S. Greco), SPIE Europe Remote Sensing, Stockholm, Sweden, September 11 – 14.

2006: Tropospheric wind profiler: multi-spectral DWL (G. D. Emmitt), NASA/ESTO lidar workshop, Washington, DC, June.

2006: GLAS cloud statistics and their implications for a hybrid mission (G. D. Emmitt and S. Greco), Working Group on Space-Based Lidar Winds, Welches, OR, June 28 – 30.

2006: New sampling perspectives for TODWL (G. D. Emmitt and C. O'Handley), Working Group on Space-Based Lidar Winds, Welches, OR, June 28 – 30.

2006: Development of a remote sensing testbed for tropospheric air quality and winds (M. Newchurch, et.al and G. D. Emmitt), Working Group on Space-Based Lidar Winds, Welches, OR, June 28 – 30.

2006: OSSE plans related to a hybrid mission and ADM follow-on missions (G.

D. Emmitt), Working Group on Space-Based Lidar Winds, Welches, OR, June 28 – 30.

2006: Planning for airborne DWL participation in PARC (G.D. Emmitt and M. Hardesty), Working Group on Space-Based Lidar Winds, Welches, OR, June 28 – 30.

2006: April test train: preliminary CCLPS results, NCTA specials meeting, Denver, CO, June 21.

2006; Optimizing rail availability for PRB coal transport: summary of trends (G. D. Emmitt), NCTA special meeting, Denver, CO, June 21.

2006: Recommendations for the PRB coal loss mitigation program (G. D. Emmitt), NCTA special meeting, Denver, CO, June 21.

2006: Coal loss study update (G. D. Emmitt and E. D. Carre), NCTA workshop, St Louis, MO, February 21.

2006: CCLPS estimates of coal losses by wind erosion (G. D. Emmitt and E. D. Carre), NCTA workshop, St Louis, MO, February 21.

2006: Adaptive targeting schemes and their technology implications (G. D. Emmitt), Working Group on Space-Based Lidar Winds, Key West, FL, January 16.

2006: Latest simulations for a tropospheric wind sounder on NPOESS and beyond (G. D. Emmitt, S. A. Wood, B. Gentry and M. Kavaya), Working Group on Space-Based Lidar Winds, Key West, FL, January 16.

2006: NPOESS P3I and follow-on threshold operational mission (G. D. Emmitt and S. A. Wood), Working Group on Space-Based Lidar Winds, Key West, FL, January 16.

2006: Status of TODWL and GWOLF (G. D. Emmitt and C. O'Handley), Working Group on Space-Based Lidar Winds, Key West, FL, January 16.

2006: Adaptive targeting OSSEs for planning a space-based Doppler wind lidar (G. D. Emmitt, S. A. Wood, S. Greco, M. Matsutani, J. Woolen, Z. Toth and Y. Song), AMS annual meeting, IOAS-AOLS, January.

2005: Using airborne lidar data in models: an adaptive targeting approach (G. D. Emmitt), UAH, Huntsville, AL Seminar series, November 28.

2005: Coal losses from railcars: summary of data analyses (G. D. Emmitt, D. Carre, L.Wood and C. Palomares), NCTA special meeting, Ft. Worth, TX, November 15.

2005: OSSEs at GSFC (G. D. Emmitt and R. Atlas), Working Group on Space-based Lidar Winds, Welches, OR, June 28 – 30.

2005: OSSEs at NCEPm(M. Matsutani, J. Woolen, Z. Toth, G. D. Emmitt and S. Lord), Working Group on Space-based Lidar Winds, Welches, OR, June 28 – 30.

2005: Investigation of the utility of airborne DWL data in mesoscale models (G. D. Emmitt, S. A. Wood and S. Greco, Working Group on Space-based Lidar Winds, Welches, OR, June 28 – 30.

2005: Scaling TODWL and GWOLF performance to space (G. D. Emmitt and C. O'Handley), Working Group on Space-based Lidar Winds, Welches, OR, June 28 – 30.

2005: SNR issues: definitions, theory and practice (G. D. Emmitt and C. O'Handley), Working Group on Space-based Lidar Winds, Welches, OR, June 28 – 30.

2005: Simulating a dual technology DWL at 833 km (G. D. Emmitt, S. Wood, M. Kavaya and B. Gentry), Working Group on Space-based Lidar Winds, Welches, OR, June 28 – 30.

2005: Preliminary results of GLAS data base study of CFLOS statistics (G. D. Emmitt and S. Greco), Working Group on Space-Based Lidar Winds, Sedona, AZ, February 1 – 3.

2005: Mars related opportunities for DWL applications (G. D. Emmitt, G. Koch, M. Kavaya and U. Singh), Working Group on Space-based Lidar Winds,Sedona, AZ, February 1 – 3.

2005: Status of NCEP and GSFC OSSEs with DWLs (S. Lord, R. Atlas, G. D. Emmitt), Working Group on Space-based Lidar Winds,Sedona, AZ, February 1 – 3.

2005: Investigation of backscatter/wind correlations using an airborne 2-micron coherent Doppler wind lidar (G. D. Emmitt, C. O' Handley, D. Bowdle and H. Jonsson), Working Group on Space-based Lidar Winds,Sedona, AZ, February 1 – 3.

2005: Airborne WindSat Validation Program (Gasiewski, A. J, P. Gaiser, H.

Graber, and G. D. Emmitt), White paper submitted to NPOESS (Mango), January 11.

2004: Airborne Doppler lidar for WindSat Cal/Val (G. D. Emmitt, S. A. Wood, C. O'Handley, S Greco, H. Jonsson), WindSat Cal/Val and Science Meeting, Solomons Md, 17-18 November.

2004: The importance of CALIPSO to the design of follow-on lidars, inparticular, Doppler wind lidars (G. D. Emmitt), CALIPSO Workshop, NCEP, Silver Springs, Md., June 10.

2004: Comparison of measured and modeled aerosol backscatter during TODWL/2003 (D. Bowdle, G.D. Emmitt and C. O'Handley), Working Group on Space-based Lidar Winds, Sedona, AZ, January 27-29.

2004: Using surface returns to correct for aircraft motion induced errors (G.D. Emmitt and C. O'Handley), Working Group on Space-based Lidar Winds, Sedona, AZ, January 27-29.

2004: The DSLM on-line (S. Wood and G.D. Emmitt), Working Group on Space-based Lidar Winds, Sedona, AZ, January 27-29.

2004: GWOLF and VALIDAR comparisons (M. Kavaya, G. Koch, G.D. Emmitt, and S. Wood), Working Group on Space-based Lidar Winds, Sedona, AZ, January 27-29.

2004: Comparisons of TODWL soundings with MM5, microwave sounders, towers, and other wind sensors (G.D. Emmitt, S. Wood, S. Greco, and C. O'Handley), Working Group on Space-based Lidar Winds, Sedona, AZ, January 27-29.

2004: Status of IPO-funded hybrid feasibility and airborne testbed (G.D. Emmitt, B. Gentry, M. Hardesty, and M. Kavaya), Working Group on Space-based Lidar Winds, Sedona, AZ, January 27-29.

2004: OSSEs for realistic DWL concepts (G.D. Emmitt and R. Atlas), Working Group on Space-based Lidar Winds, Frisco, CO, June 29-July 1.

2004: Potential contribution of multiple Doppler wind lidars to a prospective CHEM/ CLOUD experiment in Huntsville, Alabama (G.D. Emmitt, M. Newchurch, and D. Bowdle), Working Group on Space-based Lidar Winds, Frisco, CO, June 29-July 1.

2004: Using TODWL and in situ particle probes to understand the backscatter signature of marine, boundary layer organized structures (D. Bowdle, G.D.

Emmitt, and S. Wood), Working Group on Space-based Lidar Winds, Frisco, CO, June 29-July 1.

2004: Using TODWL data to validate marine boundary layer models (R. Foster, R. Brown, C. O'Handley, and G.D. Emmitt), Working Group on Space-based Lidar Winds, Frisco, CO, June 29-July 1.

2004: Hybrid DWL simulations for OSSEs (G.D. Emmitt and S. Wood), Working Group on Space-based Lidar Winds, Frisco, CO, June 29-July 1.

2004: Accuracy of airborne Doppler lidar using threading and ground returns (G.D. Emmitt and C. O'Handley), Working Group on Space-based Lidar Winds, Frisco, CO, June 29-July 1.

2004: Status of TODWL and GWOLF activities and plans for future airborne DWL (G.D. Emmitt, B. Gentry, M. Hardesty, and M. Kavaya), Working Group on Space-based Lidar Winds, Frisco, CO, June 29-July 1.

2003: Simulating cloud and water vapor motion winds form a nature run (C. O'Handley and G. D. Emmitt), March 6.

2003: IPO Cal/Val for a space-based wind observing system (G.D. Emmitt and C. O'Handley), Working Group on Space-based Lidar Winds, Oxnard, CA, February 17-19.

2003: Status of Hybrid DWL study (G.D. Emmitt, S. Wood, and G.D. Spiers), Working Group on Space-based Lidar Winds, Oxnard, CA, February 17-19.

2003: GWOLF 2003 (G.D. Emmitt, C. O'Handley, M. Kavaya and G. Koch), Working Group on Space-based Lidar Winds, Bar Harbor, ME.

2003: IPO-funded airborne lidar experiments: TODWL 2003 (G.D. Emmitt, S. Greco, C. O'Handley, and S. Wood), Working Group on Space-based Lidar Winds, Bar Harbor, ME.

2003: Investigation of the marine boundary layer and validation of numerical models using an ONR/IPO airborne Doppler wind lidar (G.D. Emmitt), NRL seminar, Moneterey, CA, August.

2003: Airborne Doppler lidar for basic atmospheric research and calibration of space-based wind sensors (G.D. Emmitt , B. Bluth and H. Jonsson), NASA/MSFC seminar, Huntsville, AL.

2003: Airborne Doppler lidar investigation of flow within complex terrain and marine boundary layers (G.D. Emmitt), Invited talk, Arizona State University, November.

2002: Hybrid DWL: simulations of expected data products for use in OSSEs (D. Emmitt and S. Wood), Working Group on Space-based Lidar Winds, North Conway, NH, July 15-18.

2002: Status of IPO's Cal/Val study: the TODWL Spring 2002 checkout flights (D. Emmitt, C. O'Handley, and D. Bowdle), Working Group on Space-based Lidar Winds, North Conway, NH, July 15-18.

2002: Investigation of the marine LAS with an airborne Doppler wind lidar (D. Emmitt, C. O'Handley, D. Bowdle), Working Group on Space-based Lidar Winds, North Conway, NH, July 15-18.

2002: Nadir angle dependence of water surface return at 2 microns using TODWL (D. Emmitt and C. O'Handley), Working Group on Space-based Lidar Winds, North Conway, NH, July 15-18.

2002: TODWL: Between flight programs (D. Emmitt and P. Gatt), Working Group on Space-based Lidar Winds, North Conway, NH, July 15-18.

2002: Technology plan for the coherent subsystem of a space-based hybrid Doppler wind lidar (M. Kavaya, A. Amzajerdian, U. Singh, J. Yu, and D. Emmitt), Working Group on Space-based Lidar Winds, North Conway, NH, July 15-18.

2002: Technology roadmap for a direct detection Doppler lidar subsystem (B. Gentry, M. McGill, G. Schwemmer, B. Heaps, and D. Emmitt), Working Group on Space-based Lidar Winds, North Conway, NH, July 15-18.

2002: Status of the Doppler Lidar Simulation Model (DLSM) for GTWS (S. Wood and D. Emmitt), Working Group on Space-based Lidar Winds, North Conway, NH, July 15-18.

2002: A space-based coherent wind lidar point design for the NASA/NOAA Draft Science and Operational Data Requirements (M. Kavaya, D. Emmitt, R. Frehlich, F. Amzajerdian, U. Singh), Working Group on Space-based Lidar Winds, Key West, FL, January 23-25.

2002: Status of TODWL and other IPO funded activities (G.D. Emmitt et al.), Working Group on Space-based Lidar Winds, Key West, FL, January 23-25.

2002: A hybrid DWL concept for instrument and mission analyses (D.Emmitt, B. Gentry, and M. Kavaya), Working Group on Space-based Lidar Winds, Key West, FL, January 23-25.

2002: Discussion of the GTWS reference atmospheres and their use (D. Emmitt), Working Group on Space-based Lidar Winds, Key West, FL, January 23-25.

2001: Status of bracketing OSSEs at NCEP for several DWL notional concepts (G.D. Emmitt), Working Group on Space-based Lidar Winds, Oxnard, CA, February 7-9.

2001: Developing a CAL/VAL plan for a space-based Doppler wind lidar (G.D. Emmitt), Working Group on Space-based Lidar Winds, Oxnard, CA, February 7-9.

2001: IPO funded airborne DWL for CAL/VAL planning (G.D. Emmitt), Working Group on Space-based Lidar Winds, Oxnard, CA, February 7-9.

2001: Updated report on Hybrid technology DWLs (G.D. Emmitt), Working Group on Space-based Lidar Winds, Oxnard, CA, February 7-9.

2000: Adaptive targeting study for DWL operations (G.D. Emmitt, Z. Toth, E. Kalnay, R. Atlas). Working Group on Space-based Lidar Winds, Boulder, CO, June 21-23.

2000: Update on the feasibility study for a hybrid technology DWL (G.D. Emmitt). Working Group on Space-based Lidar Winds, Boulder, CO, June 21-23.

2000: Simulated DWL observations for the global OSSEs at NCEP: Coverage, accuracy, and systematic errors (G.D. Emmitt). Working Group on Space-based Lidar Winds, Boulder, CO, June 21-23.

2000: HYDROSAT: An opportunity for space-based Doppler lidar (G.D. Emmitt). Working Group on Space-based Lidar Winds, Boulder, CO, June 21-23.

2000: Update on IPO-funded wind lidar studies (G.D. Emmitt). Working Group on Space-based Lidar Winds, Daytona Beach, FL, January 26-28.

2000: Status of the Hybrid DWL feasibility study (G.D. Emmitt). Working Group on Space-based Lidar Winds, Daytona Beach, FL, January 26-28.

2000: HYDRA-SAT and the role of coherent Doppler lidar (G.D. Emmitt). Working Group on Space-based Lidar Winds, Daytona Beach, FL, January 26-28.

2000: The role of DWL OSSE's and appropriate metrics for a commercial wind data buy
(G.D. Emmitt). Working Group on Space-based Lidar Winds, Daytona Beach, FL, January

26-28.

1999: Recent results of IPO funded OSSE efforts at NCEP and GSFC (G.D. Emmitt). Working Group on Space-based Lidar Winds, Key West, FL, January 19-22.

1999: SPARCLE data product validation plan: Mission scientist's assessment (G.D. Emmitt, R. Menzies and D. Bowdle). Working Group on Space-based Lidar Winds, Key West, FL, January 19-22.

1999: SPARCLE "Challenges" B Pointing (G.D. Emmitt, T.Miller and G. Spiers). Working Group on Space-based Lidar Winds, Key West, FL, January 19-22.

1999: SPARCLE performance modeling (G. Spiers and G.D. Emmitt). Working Group on Space-based Lidar Winds, Key West, FL, January 19-22.

1999: Follow on mission(s) for SPARCLE (M. Kavaya, G.D. Emmitt and T. Miller). Working Group on Space-based Lidar Winds, Key West, FL, January 19-22.

1999: Status of OSSEs at NCEP (R. Atlas and G.D. Emmitt). Working Group on Space-based Lidar Winds, Key West, FL, January 19-22.

1999: Review of observational requirements for global DWL winds (G.D. Emmitt). Working Group on Space-based Lidar Winds, Key West, FL, January 19-22.

1999: Adaptive targeting with a space-based DWL (G.D. Emmitt and R. Atlas). Working Group on Space-based Lidar Winds, Key West, FL, January 19-22.

1999: Update of LITE analyses of cloud and aerosol backscatter statistics (D. Winker and G.D. Emmitt). Working Group on Space-based Lidar Winds, Key West, FL, January 19-22.

1999: SPARCLE Science Team Meeting (G.D. Emmitt). Working Group on Space-based Lidar Winds, Key West, FL, January 19-22.

1999: Status of the NASA New Millennium Program. Presented for C. Raymond by G.D. Emmitt. Working Group on Space-based Lidar Winds, Mt. Hood, OR, July 6-9.

1999: Status of wind lidar OSSEs at NCEP (G.D. Emmitt and R. Atlas). Working Group on Space-based Lidar Winds, Mt. Hood, OR, July 6-9.

1999: SPARCLE: What happened, lessons learned, what next (T. Miller and G.D.

Emmitt). Working Group on Space-based Lidar Winds, Mt. Hood, OR, July 6-9.

1999: Results of the ALADIN (ISS) impact study. Presented for W. Wergen et al. By G.D. Emmitt, Working Group on Space-based Lidar Winds, Mt. Hood, OR, July 6-9.

1999: A notional hybrid DWL on the roadmap to an operational system (G.D. Emmitt). Working Group on Space-based Lidar Winds, Mt. Hood, OR, July 6-9.

1999: Data requirements and specifications (G.D. Emmitt). Working Group on Space-based Lidar Winds, Mt. Hood, OR, July 6-9.

1999: OSSEs and impact metrics definitions (G.D. Emmitt). Working Group on Space-based Lidar Winds, Mt. Hood, OR, July 6-9.

1999: Benefits of a pre-data buy DWL demo mission (G.D. Emmitt). Working Group on Space-based Lidar Winds, Mt. Hood, OR, July 6-9.

1999: An overview of the potential space-based application of coherent Doppler lidar to measure the surface velocity of rivers (G.D. Emmitt). NASA-USGS Workshop on Remote Sensing of River Stage and Discharge, Herndon, VA, September 23-24.

1999: Airborne Doppler lidar observations of river transects (MACAWS) (G.D. Emmitt and J. Rothermel). NASA-USGS Workshop on Remote Sensing of River Stage and Discharge, Herndon, VA, September 23-24.

1998: SPARCLE mission science plan (G.D. Emmitt). NOAA Working Group on Space-based Lidar Winds, Key West, FL, January 20-22.

1998: Pointing knowledge: GPS/INS (G. Kamerman and G.D. Emmitt). NOAA Working Group on Space-based Lidar Winds, Key West, FL, January 20-22.

1998: Velocity error budget (G. Spiers and G.D. Emmitt). NOAA Working Group on Space-based Lidar Winds, Key West, FL, January 20-22.

1998: Simulated performance of SPARCLE and follow-on missions (G.D. Emmitt). NOAA Working Group on Space-based Lidar Winds, Key West, FL, January 20-22.

1998: Simulating coherent and direct detection DWLs for IPO OSSEs (G.D. Emmitt). NOAA Working Group on Space-based Lidar Winds, Key West, FL, January 20-22.

1998: The validation program. OSSEs (G.D. Emmitt). NOAA Working Group on Space-based Lidar Winds, Key West, FL, January 20-22.

1998: Calibration of the GPS/INS (G.D. Emmitt and G. Spiers). NOAA Working Group on Space-Based Lidar Winds, Boulder, CO, July 13-16.

1998: Cloud statistics from LITE and relevance to wind lidar performance (D. Winker and G.D. Emmitt). NOAA Working Group on Space-Based Lidar Winds, Boulder, CO, July 13-16.

1998: An approach to evaluating the merits of a hybrid technology Doppler wind lidar (G.D. Emmitt). NOAA Working Group on Space-Based Lidar Winds, Boulder, CO, July 13-16.

1998: Update of target atmospheres for use in DWL concept studies (S. Wood and G.D. Emmitt). NOAA Working Group on Space-Based Lidar Winds, Boulder, CO, July 13-16.

1998: Inverted quasi-conical partial VAD processing of MACAWS data taken during turns (G.D. Emmitt, S. Wood and S. Greco). NOAA Working Group on Space-Based Lidar
Winds, Boulder, CO, July 13-16.

1998: Update on recent OSSEs (R. Atlas, S. Wood and G.D. Emmitt). NOAA Working Group on Space-Based Lidar Winds, Boulder, CO, July 13-16.

1998: What is a useful wind measurement? (G.D. Emmitt). NOAA Working Group on Space-Based Lidar Winds, Boulder, CO, July 13-16.

1998: Review of the lidar working group data requirements (G.D. Emmitt). NOAA Working Group on Space-Based Lidar Winds, Boulder, CO, July 13-16.

1997: Status of performance simulations in support of the shuttle and NPOESS missions (G.D. Emmitt), NOAA Working Group on Space-based Lidar Winds, Daytona, FL, January 21-23.

1997: Issues related to the comparison of DWL technologies and the simulation of their performance (e.g., wallplug efficiences and beta vs. wavelength) (G.D. Emmitt), NOAA Working Group on Space-based Lidar Winds, Daytona, FL, January 21-23.

1997: Proposed role of OSSEs for CAMEX III (G.D. Emmitt), NOAA Working Group on Space-based Lidar Winds, Daytona, FL, January 21-23.

1997: Relevance of LITE data analysis to space-based DWL performance (G.D. Emmitt and D. Winker), NOAA Working Group on Space-based Lidar Winds, Northglenn, CO, July 15-17.

1997: Update on OSSEs for NPOESS and CAMEX III (G.D. Emmitt, S. Wood, L. Wood, and S. Greco), NOAA Working Group on Space-based Lidar Winds, Northglenn, CO, July 15-17.

1997: Status report on NASA's DWL shuttle mission -- The science/data perspective (G.D. Emmitt, S. Wood, and M. Kavaya), NOAA Working Group on Space-based Lidar Winds, Northglenn, CO, July 15-17.

1997: Issues related to DWL scanning, sampling and LOS co-processing (G.D. Emmitt, S. Wood, B. Rye), NOAA Working Group on Space-based Lidar Winds, Northglenn, CO, July 15-17.

1996: Use of MACAWS data to address issues related to a space-based DWL (G.D. Emmitt, S. Greco and J. Rothermel) Paper presented at the NOAA Working Group on Space-Based Lidar Winds, Daytona Beach, FL, February 6-9.

1996: Figures of Merit for DWL OSSEs (G.D. Emmitt and R. Atlas) Paper presented at the NOAA Working Group on Space-Based Lidar Winds, Daytona Beach, FL,February 6-9.

1996: Effects of wind shear on signal processing (G.D. Emmitt) Paper presented at the NOAA Working Group on Space-Based Lidar Winds, Daytona Beach, FL,February 6-9.

1996: Data volume issues for a 2□m small-sat mission (G.D. Emmitt and S.A. Wood) Paper presented at the NOAA Working Group on Space-Based Lidar Winds, Daytona Beach, FL, February 6-9.

1996: Preliminary cloud and cloud porosity statistics from LITE (G.D. Emmitt and D. Winker) Paper presented at the NOAA Working Group on Space-Based Lidar Winds, Daytona Beach, FL, February 6-9.

1995: Use of NASA/NOAA ground-based lidar data to evaluate several signal processing strategies (G.D. Emmitt) Paper presented at the NOAA Working Group on Space-based Lidar Winds, Clearwater, FL, January 31-February 2.

1995: Revised outlook for mid/upper tropospheric returns for a small-satellite wind lidar (G.D. Emmitt) Paper presented at the NOAA Working Group on Space-based Lidar Winds, Clearwater, FL, January 31-February 2.

1995: OSSEs in support of a small-satellite mission (G.D. Emmitt) Paper presented at the NOAA Working Group on Space-Based Lidar Winds, Clearwater, FL,January 31-February 2.

1995: Status of efforts by the U.S.A. Working Group on Space-Based Lidar Winds (G.D. Emmitt and W.E. Baker) Paper presented at the ESA Doppler Wind Lidar Workshop, Noordwijk, The Netherlands, September 20-22.

1993: Update on LAWS data simulations (G.D. Emmitt). Paper presented at the LAWS Science Team Meeting, January, Clearwater Beach, FL.

1993: Design considerations for a Quick LAWS (G.D. Emmitt). Paper presented at the LAWS Science Team Meeting, January, Clearwater Beach, FL.

1993: Update on ground-based lidar observations (G.D. Emmitt). Paper presented at the LAWS Science Team Meeting, January, Clearwater, FL.

1992: Simulated LAWS performance profiles (G.D. Emmitt). Paper presented at the LAWS Science Team Meeting, July, Cape Cod, MA.

1992: LAWS power budget simulations (G.D. Emmitt). Paper presented at the LAWS Science Team Meeting, July, Cape Cod, MA.

1992: Review of mission science objectives for LAWS (G.D. Emmitt). Paper presented at the LAWS Science Team Meeting, July, Cape Cod, MA.

1991: LAWS, a career in global transports. Seminar given at Florida State University, Tallahassee, FL, January 14-18.

1990: Shot management for LAWS. LAWS Simulation Workshop, March, Goddard Space Flight Center, Greenbelt, MD.

1990: Optimal scanning pattern in partly cloudy regions. LAWS Science Team Meeting, August 1-3, Boulder, CO.

1990: Optimal sampling strategies for space-based laser wind sounders. Seminar at Laboratoire de Météorologie Dynamique, June 8, Ecole Polytechnique, Palaiseau, France.

1990: Preliminary estimates of LAWS global observation opportunities below 15 km. GLOBE Meeting, March 7-8, Huntsville, AL.

1990: Optimal sampling strategies in partly cloudy regions for space-based laser wind sounders. Seminar at Laboratoire de Météorologie Dynamique, Ecole Normal Supérieure, September, Paris, France.

1990: Role of OSSEs in the design of a space-based lidar wind sounder. Seminar at European Center for Medium Range Forecasts, September 4, Reading, England.

1989: LAWS - Can it provide more than just winds? Seminar at NASA Langley Research Center, Hampton, VA, October.

1987: Windstorms: site-specific risk assessment. American International Group's Fall 1987 Seminar on Geophysical Hazards, New York, N.Y., December.

1980: Nocturnal boundary layer measurements made with a tethered balloon. SESAME 1979 Data Users Workshop, January, Boulder, CO.

1979: Seminar on hail suppression and its implications. Departmental Seminar, University of Virginia, April.

1977: Use of direct and indirect estimates of cumulus transports to estimate total active cloud cover. Seminar paper given at MPI fur Meteorologie, Hamburg, West Germany.

1977: Elected to present final report of the GATE Workshop Boundary Layer Group at the International Conference on the energetics of the tropical atmosphere, Tashkent, U.S.S.R., September; report published in proceedings of the conference.

1977: Invited participant at the GATE summer workshop (3 papers), Boulder, Colorado, July 29-August 12.

1977: Technical aspects of tethered balloon operations. Seminar paper given at the Danish Atomic Energy Laboratories, RISϕ, Denmark.

1977: Cumulus convection below cloud base. Seminar paper given at the Danish Atomic Energy Laboratories, RISϕ, Denmark.

1976: Tropical cumulus activity below cloud base. Seminar paper given at MPI fur Meteorologie, Hamburg, West Germany.

1974: Opportunities for physicists in a Department of Environmental Sciences (G.D. Emmitt). Given at Eastern Nazarene College, Wollaston, MA.

RESEARCH

Principal Investigator: NOAA's Integrated Program Office's (IPO) feasibility study for hybrid Doppler wind lidars

Principal Investigator: NOAA's IPO observing system simulation experiments for space-based DWLs

Principal Investigator: NOAA's IPO targeted observing strategies for wind lidars

Principal Investigator: NOAA's IPO calibration/validation plan for space-based DWLs

Principal Investigator: NOAA's IPO twin otter Doppler wind lidar (TODWL) for cal/val strategy development

Principal Investigator: NASA LaRC, Modification of the Doppler lidar simulation model

Principal Investigator: Provincial Energy Ventures Dust Suppression System Design

Principal Investigator: NASA GSFC – GTWS Science Definition efforts

Principal Investigator: Storm top divergence studies using the LAWS, NASA/Marshall Space Flight Center.

Principal Investigator: Cloud top and planetary boundary layer wind measurements using a space-based lidar, SBIR, U.S. Air Force.

Principal Investigator: Simulation experiments to assess LAWS' impact on global climate change modeling, NASA.

Principal Investigator: Vertical velocity structures significant to space-based and ground- based lidar anemometry, CNES, France.

Principal Investigator: Norfolk Southern Rail Study.

Co-Principal Investigator: Interdisciplinary research scenario - Version Ø, NASA.

Principal Investigator: EOS Laser atmosphere wind sounder (LAWS) investigation, NASA.

Principal Investigator: Space-based Doppler lidar sampling strategies -- algorithm development and simulated observation experiments, NASA.

Principal Investigator: PLACEM, Pier IX Terminal Company/Shell Mining.

Principal Investigator, Interdisciplinary research scenario - Version 0, NASA.

Principal Investigator, Airborne/space-based Doppler lidar wind sounders: Sampling the PBL and other regions of significant B and u inhomogeneities, NASA.

Principal Investigator, Lidar mapping of cloud tops and cloud top winds, SBIR, AFGL.

Principal Investigator: Tropospheric wind observations with Doppler lidars: SPARCLE and follow-on missions, NASA.

Principal Investigator: CAMEX-3, NASA.

Principal Investigator, DTA Pile Moisture Modeling project.

Fugitive coal dust emission project at Elk Run Coal Company

Fugitive coal dust emission project for Norfolk Southern

Design of Procontrol System for SINCOR, Jose, Venezuela

VERIFIED STATEMENT OF EROL TUTUMLUER

BEFORE THE
SURFACE TRANSPORTATION BOARD

STB Finance Docket No. 35305

PETITION OF ARKANSAS ELECTRIC COOPERATIVE CORPORATION FOR A DECLARATORY ORDER

VERIFIED STATEMENT OF EROL TUTUMLUER IN SUPPORT OF BNSF RAILWAY COMPANY'S OPENING EVIDENCE

My name is Erol Tutumluer. I am Professor of Civil and Environmental Engineering at the University of Illinois at Urbana-Champaign where I have studied and published papers regarding the effect of fugitive coal dust upon railroad ballast. The purpose of my Verified Statement is to describe for the Board my findings that coal dust has a pernicious effect upon railroad ballast.

Introduction

Fouling of the railroad ballast occurs when spaces or voids in this unbound aggregate layer are filled with finer sized materials. As a fouling agent, coal dust from coal trains accumulating in the ballast has become a major concern. I have studied the most probable adverse impacts of coal dust on railroad ballast on drainage and load carrying function, which were previously unknown because of the lack of technical data. As summarized below in my Verified Statement, the physical and mechanical properties of coal dust and other laboratory tests indicate that coal dust is one of the worst fouling agents when compared to mineral filler produced from aggregate breakdown and the fine-grained cohesive subgrade soils. Coal dust particles are mainly sand sized, however, they have lower density and greater plasticity, meaning that they have much greater water holding ability than subgrade soil fines, which are silty and clayey and often plastic (i.e., they possess high moister affinity). As compared to sand particles, coal dust particles greatly reduce the ballast strength, stability, resistance to settlement under unit trains, and ultimately the load-bearing ability of fouled ballast layers. My two major papers concerning fouled ballast are attached hereto as Exhibits 3 and 4. Exhibit 3 is Tutumluer, E., Dombrow, W., and Huang, H., "Laboratory Characterization of Coal Dust Fouled Ballast Behavior," In Proceedings of the AREMA 2008 Annual Conference, Salt Lake City, Utah, September 21-24, 2008. Exhibit 4 is Huang, H., Tutumluer, E., and Dombrow, W., "Laboratory Characterization of Fouled Railroad Ballast Behavior," Transportation Research Record 2117: Journal of the Transportation Research Board, National Research Council, Washington, D.C., 2009, pp. 93-101.

Exposure of coal dust to moisture significantly reduces the friction component of the shear strength and can cause significant reduction in load-bearing capacity. Even more drastic strength reductions can be realized when dry coal dust, never before saturated or soaked in the field and therefore having a high suction potential, is subjected to inundation and 100% saturation. This was exactly the case in 2005 when two derailments occurred on the BNSF/UP Joint Line—there was heavy precipitation after a relatively low level of precipitation for an extended period of time in the region, and in both places where the derailments happened, the ballast was heavily fouled by coal dust. The coal dust caused moisture to accumulate and caused the loss of strength of the track, resulting in the derailments, which threatened to interrupt the supply of coal to power plants.

Education and Experience

My educational background is in Civil Engineering. In 1995, I earned a Ph.D. in Civil Engineering from the Georgia Institute of Technology in Atlanta, Georgia. In 1993, I earned a

M.S. in Civil Engineering from the Georgia Institute of Technology in Atlanta, Georgia. In 1991, I earned a M.S. in Civil Engineering from Duke University in Durham, North Carolina. In 1989, I earned a B.S. in Civil Engineering from the Bogazici University in Istanbul, Turkey.

I am a transportation and geotechnical engineer and serve as Professor of Civil and Environmental Engineering at University of Illinois at Urbana-Champaign ("UIUC"). In October 2006, I was recognized with the Endowed Paul F. Kent Faculty Scholarship for my research accomplishments. In August 2008, I was promoted to full professor position in the Department of Civil and Environmental Engineering. In October 2009, the Department of Civil and Environmental Engineering extended for a new 3-year term my recognition and title of the Endowed Paul F. Kent Faculty Scholar. I have taught graduate and undergraduate courses in transportation soils engineering, subgrade soil and aggregate behavior and stabilization, introduction to transportation engineering, and pavement analysis and design at the UIUC since 1996.

I am an affiliate of the Transportation Research Board, and I have chaired its AFS50(1) subcommittee on "Applications of Nontraditional Computing Tools Including Neural Nets" for the past six years. I currently serve on committees AFP70, AFP30, AFS50, and AFD80 of the Transportation Research Board. I am a member of the AREMA Committee 1 on "Ballast," and I am currently the chair of the Pavements Committee of the American Society of Civil Engineering's Geo-Institute, which has been just recently recognized with the 2010 Committee of the Year Award from the American Society of Civil Engineering ("ASCE") Geo-Institute.

I am currently an Associate Editor for both the ASCE Journal of Computing in Civil Engineering (http://pubs.asce.org/journals/computing/default.htm) and the International Journal of Pavement Research and Technology (http://www.ijprt.org.tw). I also serve as an Editorial

Board Member for the International Journal of Pavement Engineering (Taylor and Francis Group, http://www.tandf.co.uk/journals) and the ASCE International Journal of Geomechanics (http://pubs.asce.org/journals/geomechanics/default.htm). I was the Conference Chair and Proceedings Co-Editor of the Eighth International Conference on the Bearing Capacity of Roads, Railways and Airfields, which was held at the University of Illinois, Champaign, Illinois on June 29-July 2, 2009 (http://www.BCR2A.org). My *curriculum vitae* is attached to this statement as Exhibit 1.

My research areas and expertise include testing and modeling railroad track geo-material (i.e., subgrade soils and ballast/subballast unbound aggregates); use of geosynthetics in railroad track and pavement substructure; shape, texture, angularity characterization of aggregates using video-imaging techniques; modeling of particulate media using discrete and finite element methods; and mechanistic based railroad track and pavement designs. I have authored or co-authored more than 150 technical papers in these areas.

I have extensive experience in studying the effect of coal dust on ballast behavior. I have also studied the potential for developing ground penetrating radar ("GPR") based railway track subsurface condition indices from estimates of track bed materials' physical properties and the recent BNSF project on the characterization of fouled ballast behavior. To study ballast fouling through the use of GPR scanning, I traveled to Gillette, Wyoming on July 22-25, 2007 to collect ballast aggregate samples from the Joint Line. During this visit to the Joint Line, I had a chance to personally observe the coal dust accumulation.

I have also recently studied the effects of accumulation of coal dust in the aggregate ballast layer of the railroad track structure on the BNSF/UP Joint Line and have published two major papers concerning the effect of coal dust upon fouled ballast. The research study focused on large direct shear laboratory tests to measure strength and deformation characteristics of both clean (new) and fouled ballast aggregates at various stages of fouling with (1) non-plastic mineral filler, (2) plastic clayey soil, and (3) coal dust. This study determined material properties that could be used for modeling the ballast behavior and evaluating reductions in strength and stability. The tests were conducted at the University of Illinois on granite and limestone ballast samples. The coal dust was provided by the BNSF from the Joint Line. From the research findings, the two major papers that I previously identified were published. The first of these papers, Exhibit 3 to this statement, presents the test results on coal dust and fouling of granite type ballast material. The second of these papers, Exhibit 4 to this statement, documents the effects of three types of fouling agents: coal dust, non-plastic mineral filler, and plastic clayey subgrade soils. We found that coal dust caused the worst fouling effects and the greatest shear strength loss while non-plastic mineral filler and plastic clayey subgrade soils caused less detrimental effects as fouling agents.

I have extensive experience on other issues relating to railroad track substructure, and that experience is described in Exhibit 2 attached hereto.

Coal Dust Problem

Based upon my specific research regarding coal dust and its impact upon ballast, I have found that coal dust is one of the worst fouling agents when compared to mineral filler produced from aggregate breakdown and the fine-grained cohesive subgrade soils.

Let me start by describing ballast and its purpose. Railroad ballast is uniformly-graded coarse aggregate placed between and immediately underneath the crossties and the rail. The purpose of ballast is to provide drainage and structural support for the heavy weight applied by loaded trains. Proper functioning ballast is critical to maintain operations on high volume tracks, such as the tracks on the Joint Line. For a proper functioning ballast, superior ballast aggregate shape properties, such as an angular crushed stone, and size distribution (gradation) are critical to provide ballast strength and stability. Proper functioning ballast gradation requires large enough spaces or voids between the aggregate to provide adequate drainage. Therefore, for ballast to function properly, it must have sufficiently large voids for drainage and structural stability.

As a section of ballast on the Joint Line ages, it is progressively fouled with fine-grained materials, such as mineral filler, plastic soil fines, and coal dust from coal trains. These materials can fill the voids and cause ballast fouling. The most commonly used method to assess track ballast condition is to check visually for evidence of fouling, pumping, or water accumulation (ponding) at ditches and shoulders. However, the surface of a ballast layer generally has a clean appearance most of the time, and it is often not possible to detect the amount of ballast fouling through visual inspection alone as the clean appearance of the surface of a ballast layer may nonetheless conceal fouled ballast. Another method for testing ballast fouling is ballast sampling and testing through laboratory sieve analyses. This laboratory method can provide some insight into the compositions of the larger aggregate particles and the amount of fines in a particular ballast section. Finally, the use of ground penetrating radar ("GPR") can also indicate the amount of ballast fouling. GPR is a nondestructive means of testing because it scans existing railroad track. The use of GPR, however, is currently at a research stage for future implementation, and it is not yet a standard practice.

Regardless of the method used to test the ballast, fouled ballast occurs when there is the loss of aggregate to aggregate contact because the voids are filled with finer sized materials. In a clean ballast sample, almost all aggregates are supposed to establish contact with each other at the aggregate surface to carry the load (as shown in Exhibit 3, at 21 Figure 2a). As shown in

Exhibit 3, page 21 Figure 2b, dirty or partially fouled ballast has the voids in between contacting aggregates filled with fine particles, but still maintains aggregate to aggregate contact. By contrast, fouled ballast has an excessive amount of fine particles, and the aggregate to aggregate contacts are mostly eliminated (as shown in Exhibit 3, page 21 Figure 2c). The aggregate particle movements are then only constrained by the fine particles filling the matrix or voids between the particles. In regards to excessive fouling conditions, for example, as in the case of 2005 Joint Line derailments when wet coal dust completely filled all voids in ballast and pumping was observed on the surface of railroad track, the low strength of the fouling agent would govern for carrying the wheel load. Hence, train derailments may occur due to unstable support under the crossties.

My research showed that different fouling agents have different effects on ballast based upon the physical and mechanical properties of the fouling agents. There are mainly three types of ballast fouling agents: (1) nonplastic mineral filler; (2) fine-grained and plastic subgrade soils; and (3) coal dust. Plasticity index refers to a certain range of gravimetric moisture content in soils determined in the laboratory as the difference between the liquid limit (at which soil behaves as a viscous fluid) and the plastic limit (lower moisture content at which a thin 1/8-inch soil thread crumbles upon rolling under your palm), and it is obtained from conducting these Atterberg limit tests on soils. The term "nonplastic" therefore refers to the low affinity and moisture absorption or holding ability of mineral fillers. Subgrade soils are fine-grained, i.e., silty, clayey, and are often plastic, meaning that they possess high moisture affinity. In our research study attached as Exhibit 3, coal dust was found to be highly plastic, meaning it has the potential to absorb water like a sponge, and was even more plastic than most commonly found plastic natural clays. Although 76% of coal dust was found to have sand-sized particles with only 24% silt of clay sized, the high plasticity of coal dust is expected to have the most detrimental effects on mechanical properties and impact differently the engineering behavior when they foul clean ballast layers. Our research shows that in rail lines where the ballast is not exposed to coal dust, ballast fouling is due to ballast aggregate gradually powdering, i.e., breaking down, over a period of years. By contrast, in rail lines where the ballast is exposed to coal dust, the ballast is fouled very quickly by coal dust particles that accumulate in the ballast void spaces and have high potential to absorb moisture.

Research Shows That Coal Dust Is One of the Worst Ballast Fouling Agents That Has Been Studied.

I will briefly describe the test protocol we used in our research. We obtained coal dust samples from the Joint Line. In March 2007, BNSF provided four buckets of coal dust samples collected from Milepost 62.4 of the Joint Line. To determine the physical and mechanical properties of the coal dust samples, laboratory tests conducted at the University of Illinois included both dry and wet sieve analyses of the coal dust in compliance with ASTM C 136 and ASTM C 117 test procedures for determining grain size distributions, Atterberg limits, specific gravity, moisture-density compaction relationships, and shear strength properties. We compared the properties of coal dust to the physical and mechanical properties of fine-grained silty and clayey soils to identify coal dust's potential negative impact on railroad track ballast strength characteristics.

In the summer of 2007, BNSF Railway Company representatives in Gillette, Wyoming shipped to the University of Illinois approximately 2 tons of granite aggregate commonly used in the Joint Line railroad track structures as the ballast layer. To determine the physical properties of these granite aggregate materials, laboratory tests conducted at the University of Illinois included grain size distributions, specific gravity, and unit weight properties of the granite aggregate. Using a large direct shear (shear box) testing machine, both clean and coal dust fouled granite ballast samples were then prepared and tested under dry and wet conditions in an effort to investigate shear strength properties in relation to the mechanical functions of railroad ballast.

Several laboratory tests were conducted on the Wyoming coal dust samples obtained from the Joint Line as reported in Exhibit 3. First, mechanical properties of representative coal dust samples were determined for the first time at the University of Illinois through laboratory tests, such as, grain size distribution, Atterberg limits, specific gravity, moisture-density compaction relationships, and shear strength properties. The summary of the test results are as follows:

- Coal dust Liquid Limit ("LL") = 91% – *much* higher than typical weak soils.
- Coal dust Optimum Moisture Content ("OMC") = 35% – *much* higher than typical weak soils.
- Coal dust can absorb and hold a lot of water when compared to typical weak soils such as clays and silts.
- Triaxial shear strength of coal dust at OMC = 3 psi – *very low*.
- Coal dust friction angle at OMC = 33.5 degrees obtained from direct shear tests indicated a large reduction with increasing moisture content.

Then, granite type aggregates—also received from the Joint Line near Gillette, Wyoming and commonly used in the railroad track as the ballast layer—were added coal dust at different percentages by weight and moisture contents to represent coal dust fouling in the field. When fouled samples were tested in large direct shear (shear box) equipment, we found that 25% coal dust by weight of aggregates were enough to fill up all the voids in ballast corresponding to 43% of the total volume. The summary of the test results are as follows:

- The highest shear strength values were obtained from the clean ballast at all applied normal stress levels.

- When ballast samples were fouled, the shear strength always decreased. Wet (35% OMC) coal dust fouling resulted in the lower ballast shear strengths than dry coal dust fouling.
- For the fully fouled case with 25% wet coal dust by weight of ballast, internal friction angle and cohesion obtained were equivalent to those properties of the wet coal dust itself. This implies that individual aggregate particles within ballast layer would then be completely separated by coal dust to most likely cause the worst track instability problems in the field.

These laboratory findings outlined in Exhibit 3 are the first detailed examination of the mechanical properties of coal dust. Accordingly, when subjected to precipitation, coal dust can hold excessive amounts of moisture to prevent free draining of the ballast, can keep ballast wet and saturated, and act as a lubricant between the ballast stones, enabling much greater movement within the ballast layer. While the fines' content (silt and clay size) of the coal dust was lower than that of most silty and clayey soils, the optimum moisture content of the coal dust found from standard Proctor compaction test was remarkably higher than that of some of the weak cohesive soils, which highlights its ability to hold much greater amounts of moisture than other weak soils. As Exhibit 3 explains in more detail, we concluded that the coal dust's high moisture holding capacity and the extremely low strength properties made coal dust the worst ballast fouling agent for its impact on track substructure and roadbed when compared to even the highly plastic type clayey soil fines.

I would also like to explain our test protocol for the research published in Exhibit 4. For this research, we conducted direct shear (shear box) laboratory tests at the University of Illinois on granite ballast samples to measure strength and deformation characteristics of both clean (new) and fouled ballast aggregates at various stages of fouling. Effects of the different fouling agents on ballast aggregate shear strength were studied when three types of fine materials, i.e., coal dust, plastic clayey soil and mineral filler, were added to clean ballast samples at various percentages by weight of ballast under both dry and wet (mostly optimum moisture content) conditions. Realistic sample preparation procedures were conducted to closely simulate field fouling scenarios. The coal dust was also used as the fouling agent and mixed with clean aggregates for achieving fouling levels of 5%, 15%, and 25% by weight of ballast under dry and wet (at 35% optimum moisture content or OMC) conditions. Test results showed that when the coal dust fouling percentage increased, the ballast shear strength steadily decreased. Wet fouling was found to exacerbate this trend. Results of ballast samples fouled with clay and mineral filler also showed decreasing trends in strength properties; however, coal dust was by far the worst fouling agent for its impact on track substructure and roadbed. Approximately 15% coal dust fouling by weight of ballast caused considerable strength reductions in the ballast. In the case of ballast fully fouled with wet coal dust at 35% optimum moisture content, the friction angles obtained were as low as the friction angle of coal dust itself.

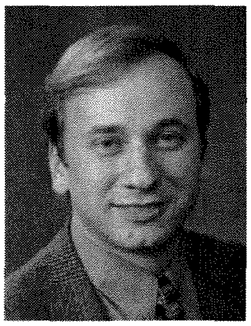
Exposure of coal dust to moisture significantly reduces the friction component of the shear strength and can cause significant reduction in load bearing capacity. Note that even more drastic strength reductions can be realized when dry coal dust that has never been saturated or soaked in the field and therefore has a high suction potential, is subjected to inundation and 100% saturation. This was exactly the case with the 2005 derailments that occurred on the BNSF/UP Joint Line, which threatened to interrupt the supply of coal to power plants. These derailments occurred as a result of heavy precipitation after a relatively low level of precipitation for an extended period of time in the region. Both of the derailments were suspected to be attributable to coal dust fouling, where coal dust spilled over the ballasts and accumulated moisture, allegedly resulting in the loss of strength of the track. In both places where derailments happened, the ballast was heavily fouled by coal dust.

I declare under penalty of perjury that the foregoing is true and correct. Further, I certify that I am qualified and authorized to file this Verified Statement.

Executed on March 15, 2010

Erol Tutumluer

EXHIBIT 1



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Education

Ph.D., Civil Engineering, Civil Engineering, Georgia Tech, 1995
M.S., Civil Engineering, Georgia Tech, 1993
M.S., Civil Engineering, Duke University, 1991
B.S., Civil Engineering, Bogazici University, 1989

Professional Experience

8/2008-present	Professor, University of Illinois at Urbana–Champaign (UIUC)
2002-2008	Associate Professor, UIUC
8/1996-2002	Assistant Professor, UIUC
1/1996-8/1996	Post Doctoral Research Associate, UIUC

Academic Courses Taught

CEE 310 – Introduction to Transportation Engineering - undergraduate, UIUC
CEE 406 – Pavement Analysis and Design - undergraduate/graduate, UIUC
CEE 407 – Airport Facilities Design - undergraduate/graduate, UIUC
CEE 509 – Transportation Soils Engineering - graduate, UIUC
CEE 598 – Transportation Soil Stabilization - graduate, UIUC

Research Areas

Dr. Tutumluer has research interests in testing and modeling of pavement and railroad track geo-materials, use of geosynthetics in transportation facilities, characterization of aggregates using video-imaging techniques, modeling of particulate media using discrete and finite element methods, artificial intelligence in the form of neural network modeling, and mechanistic based pavement design. He has conducted several studies on anisotropy and stress dependency of aggregates affecting structural response and performance of flexible pavements with unbound aggregate layers sponsored by the Federal Aviation Administration (FAA), US Army Corps of Engineers, and the International Center for Aggregates Research (ICAR). He has also been working on size, shape, and angularity characterization of aggregates using video-imaging techniques sponsored jointly by the Federal Highway Administration (FHWA), the Illinois Department of Transportation (IDOT), and by the National Cooperative Highway Research Program (NCHRP).

Dr. Tutumluer's recent and currently ongoing research efforts include the Caterpillar, Inc. project on characterizing deformation behavior of oil sands mined in Canada, Association of American Railroads (AAR) project on discrete element modeling of railway ballast behavior, the Federal Railroad Administration (FRA) funded Ground Penetrating Radar based railroad track ballast condition assessment, Burlington Northern Santa Fe (BNSF) railroad gift grant to study characterization of fouled ballast behavior, railroad track substructure research jointly sponsored by FRA and AAR, O'Hare Modernization Program (OMP) project on subgrade support and stabilization of airport pavements, FAA project on granular layer deformation analyses of National Airport Pavement Test Facility of full-scale test sections under trafficking, NCHRP 4-34 project on laser based aggregate characterization, Tensar International, Inc. project on modeling and design of geogrid reinforced flexible pavements, investigating effects of aggregate type and quality including recycled asphalt product (RAP) used as aggregate in pavement working platforms and base layers supported by IDOT, and nondestructive pavement evaluation using artificial intelligence in the form of modeling with neural networks and genetic algorithms supported by IDOT and NEXTRANS US DOT Region 5 University Transportation Center.

Honors and Awards

Best Paper Award, Geology and Properties of Earth Materials Section, Transportation Research Board, National Academy of Sciences, January 2009
Paul F. Kent Endowed Faculty Scholar, Civil and Environmental Engineering, UIUC, 2006
Listed in the "Incomplete List of Teachers Ranked as Excellent By Their Students," UIUC, 2003 & 2008
TRB Fred Burgraff Award for Excellence in Transportation Research, 2000
Collins Fellow, Academy of Excellence in Engineering Education, UIUC, 2000
General Electric Fellow, Academy of Excellence in Engineering Education, UIUC, 1999
General Electric Scholar, UIUC, 1997
Engineering Education Scholar, National Science Foundation, 1997

Professional Societies

Member of the American Society of Civil Engineers (ASCE)
Chair of the ASCE Geo-Institute's Pavements Committee
Affiliate of the Transportation Research Board (TRB)
Serves on TRB committees AFP70, AFP30, AFS50, AFS70(2), AFD80
Chair of TRB's AFS50(1) subcommittee on "Applications of Nontraditional Computing Tools Including Neural Nets"
Member of the American Railway Engineering and Maintenance of Way Association (AREMA)
Member of the Association of Asphalt Paving Technologists (AAPT)
Member of the American Society of Engineering Education (ASEE)
Member of the International Society of Soil Mechanics and Geotechnical Engineering (ISSMGE)
- ISSMGE TC 3, Geotechnics of Pavements
- ISSMGE TC 29, Laboratory Stress Strain Strength Testing of Geomaterials

Member of the International Association for Computer Methods and Advances in Geomechanics
Voting Member of the International Society for Asphalt Pavements (ISAP)
Voting Member of the International Society for Concrete Pavements (ISCP)

Books Authored or Co-Authored, Original Editions

The Design Theory and Methodology of Asphalt Pavement Based on the Cross-Anisotropy, Co-authored by Zhenfeng Li and Erol Tutumluer, Water Publishers, China (www.waterpub.com.cn) (ISBN: 978-75084-4328-7, pages: 169, 2007)

Books Edited or Co-Edited

ASCE Geotechnical Special Publication No. 89, entitled, Recent Advances in the Characterization of Transportation Geomaterials, Proceedings Book of the Third National Conference of the Geo-Institute of ASCE, Geo-Engineering for Underground Facilities, University of Illinois at Urbana-Champaign, June 13-17, 1999. Edited by E. Tutumluer and A.T. Papagiannakis (ISBN: 0-7844-0437-2, pages: 72, 1999)

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2002. Edited by Erol Tutumluer, Yacoub M. Najjar, and Eyad Masad (ISBN: 0-7844-0709-6, pages: 241, 2004)

ASCE Geotechnical Special Publication No. 130, entitled, Advances In Pavement Engineering, Proceedings CD-ROM of the ASCE Geo-Institute Geo-Frontiers Conference, held in Austin, Texas, on January 24-26, 2005. Sponsored by the Pavements Committee, Edited by Charles W. Schwartz, Erol Tutumluer, and Laith Tashman (ISBN: 0-7844-0769-X, 2005)

ASCE Geotechnical Special Publication No. 154, entitled, Pavement Mechanics and Performance, Proceedings Book of the ASCE Geo-Institute GeoShanghai Conference, held in Shanghai, China, on June 6-8, 2006. Sponsored by the Pavements Committee and Edited by Baoshan Huang, Roger Meier, Jorge Prozzi, and Erol Tutumluer (ISBN: 0-7844-0866-1, pages: 300, 2006)

ASCE Geotechnical Special Publication No. 169, entitled, Soil and Material Inputs for Mechanistic-Empirical Pavement Design, Proceedings CD-ROM of the ASCE Geo-Institute GeoDenver Congress, New Peaks in Geotechnics, held in Denver, Colorado, on February 18-21, 2007. Sponsored by the Pavements Committee and Edited by Erol Tutumluer, Laith Tashman, and Halil Ceylan (ISBN-13 978-0-7844-0897-1, 2007)

Bearing Capacity of Roads, Railways and Airfields, Two-Volume Hardcover and CD-ROM Proceedings of the 8th International Conference on the Bearing Capacity of Roads, Railways and Airfields, Champaign, Illinois, USA, June 29–July 2, 2009; Edited by Erol Tutumluer and Imad Al-Qadi, 1600 pages (ISBN: 978-0-415-87199-0, 2009)

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Tutumluer, E., Seyhan, U., and Garg, N., "Characterization of Anisotropic Aggregate Behavior Under Variable Confinement Conditions," In ASCE Geotechnical Special Publication (GSP) No. 85, entitled, Application of Geotechnical Principles in Pavement Engineering, October 1998, pp. 1-12.

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Roberts, R., Al-Qadi, I.L., and Tutumluer, E., "Railroad Structure Characterization using GPR in Alaska: A Case History," In Proceedings of the 12th International Conference on Ground Penetrating Radar, Birmingham, UK, June 16-19, 2008.

Donovan, P., and Tutumluer, E., "Anti-Shakedown of Unbound Aggregate Pavement Layers Subjected to Traffic Loading with Wander," In Proceedings of the 1st International Conference on Transportation Geotechnics and the 7th Unbound Aggregates in Roads Symposium (UNBAR7), Nottingham, UK, August 25-27, 2008.

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Pekcan, O., Tutumluer, E., and Thompson, M.R., "Quantifying Effects of Lime Stabilized Subgrade on Conventional Flexible Pavement Responses," In Proceedings of the 1st International Conference on Transportation Geotechnics and the 7th Unbound Aggregates in Roads Symposium (UNBAR7), Nottingham, UK, August 25-27, 2008.

Kim, M., Tutumluer, E., and Mishra, D., "Flexible Pavement Response to Multiple Wheel Loading Using Nonlinear Three-dimensional Finite Element Analysis," 12th International Conference of International Association for Computer Methods and Advances in Geomechanics (IACMAG), Goa, India, October 1-6, 2008.

Pekcan, O., Tutumluer, E., and Thompson, M.R., "Artificial Neural Network Based Backcalculation of Conventional Flexible Pavements on Lime Modified Soils," 12th International Conference of International Association for Computer Methods and Advances in Geomechanics (IACMAG), Goa, India, October 1-6, 2008.

Donovan, P. and Tutumluer, E., "Effect of Aircraft Load Wander on Unbound Aggregate Pavement Layer Stiffness and Deformation Behavior," ASCE Transportation and Development Institute (T&DI) Airfield and Highway Pavement Specialty Conference, Bellevue, Washington, October 15-18, 2008.

Kim, M. and Tutumluer, E., "Implications of Complex Axle Loading and Multiple Wheel Load Interaction in Low Volume Roads," ASCE Transportation and Development Institute (T&DI) Airfield and Highway Pavement Specialty Conference, Bellevue, Washington, October 15-18, 2008.

Anochie-Boateng, J. and Tutumluer, E., "Resilient Behavior Characterization of Naturally Occurring Bituminous Sands," In Preprint CD-ROM Proceedings of the 88th Annual Meeting of the Transportation Research Board (TRB), January 11-15, 2009.

Anochie-Boateng, J. and Tutumluer, E., "Characterizing Volumetric Deformation Behavior of Naturally Occurring Bituminous Sand Materials," In Proceedings of the 7th International RILEM Symposium on Advanced Testing and Characterization of Bituminous Materials (ATCBM09), Rhodes, Greece, May 27-29, 2009.

Mishra, D., Tutumluer, E., Kern, J., and Butt, A.A., "Characterizing Aggregate Permanent Deformation Behavior based on Types and Amounts of Fines," In Proceedings of the 8th International Conference on the Bearing Capacity of Roads, Railways and Airfields, Champaign, Illinois, USA, June 29–July 2, 2009; Edited by E. Tutumluer and I.L. Al-Qadi, ISBN: 978-0-415-87199-0, 2009.

Donovan, P.R., Tutumluer, E., and Huang, H., "Use of 3-dimensional Discrete Element Model to Examine Aggregate Layer Particle Movement due to Load Wander," In Proceedings of the 8th International Conference on the Bearing Capacity of Roads, Railways and Airfields, Champaign, Illinois, USA, June 29–July 2, 2009; Edited by E. Tutumluer and I.L. Al-Qadi, ISBN: 978-0-415-87199-0, 2009.

Pekcan, O., Tutumluer, E., and Ghaboussi, J., "SOFTSYS for Backcalculation of Full-depth Asphalt Pavement Layer Moduli," In Proceedings of the 8th International Conference on the Bearing Capacity of Roads, Railways and Airfields, Champaign, Illinois, USA, June 29–July 2, 2009; Edited by E. Tutumluer and I.L. Al-Qadi, ISBN: 978-0-415-87199-0, 2009.

Anochie-Boateng, J. and Tutumluer, E., "Shear Strength Properties of Naturally Occurring Bituminous Sands," In Proceedings of the 8th International Conference on the Bearing Capacity of Roads, Railways and Airfields, Champaign, Illinois, USA, June 29–July 2, 2009; Edited by E. Tutumluer and I.L. Al-Qadi, ISBN: 978-0-415- 87199-0, 2009.

Dombrow, W., Huang, H., and Tutumluer, E., "Comparison of Coal Dust Fouled Railroad Ballast Behavior – Granite vs. Limestone," In Proceedings of the 8th International Conference on the Bearing Capacity of Roads, Railways and Airfields, Champaign, Illinois, USA, June 29–July 2, 2009; Edited by E. Tutumluer and I.L. Al- Qadi, ISBN: 978-0-415-87199-0, 2009.

Huang, H., Tutumluer, E., Hashash, Y.M.A., and Ghaboussi, J., "Discrete Element Modeling of Aggregate Behavior in Fouled Railroad Ballast," In Proceedings of the GeoHunan International Conference – Challenges and Recent Advances in Pavement Technologies and Transportation Geotechnics, Hunan, China, August 3-6, 2009.

Selected Recent Invited Lectures

"Mechanistic-Empirical Pavement Design," Workshop Lecture Jointly Presented with Dr. Dallas N. Little, Texas A&M University, at the 11th Annual Symposium of the International Center for Aggregate Research (ICAR), Austin, Texas, April 28, 2003.

"ICAR Structural Model and Mechanistic-Empirical Pavement Design," Workshop Lecture Jointly Presented with Dr. Dallas N. Little, Texas A&M University, at the 11th Annual Symposium of the International Center for Aggregate Research (ICAR), Austin, Texas, April 28, 2003.

University Invitation: "Soil Trafficability and Subgrade Stability," Invited Speaker, Department of Civil Engineering, University of Costa Rica, San Jose, Costa Rica, November 2003.

University Invitation: "Soil and Aggregate Characterization," Invited Speaker, Department of Civil Engineering, University of Costa Rica, San Jose, Costa Rica, November 2003.

University Invitation: "Mechanistic-Empirical Pavement Design," Invited Speaker, Department of Civil Engineering, University of Costa Rica, San Jose, Costa Rica, November 2003.

"Mechanistic Based Pavement Design," Invited Speaker, Seminar Lecture Jointly Presented with Dr. D.N. Little, Texas A&M University, at the 12th Annual Symposium, International Center for Aggregate Research (ICAR), Denver, Colorado, April 5, 2004.

"State-of-the-Art of Aggregate Shape Analysis Using Imaging Techniques," Invited Speaker, Seminar Lecture Jointly Presented with Dr. E. Masad, Texas A&M University, at the 12th Annual Symposium, International Center for Aggregate Research (ICAR), Denver, Colorado, April 6, 2004.

"Stress Rotations Due to Moving Wheel Loads and Their Effects on Pavement Materials Characterization," Invited Speaker, Workshop on "Pavement Engineering from a Geotechnical Perspective," 57th Canadian Geotechnical Conference GeoQuebec 2004, Quebec City, October 24, 2004.

University Invitation: "Stress Rotations Due to Moving Wheel Loads and Their Effects on Pavement Materials Characterization," Invited Speaker, Civil, Construction and Environmental Engineering Department, Iowa State University, Ames, Iowa, November 15, 2004.

University Invitation: "Imaging Based Aggregate Shape Analysis and Its Applications In Mechanics of Pavement Materials," Invited Speaker, Civil Engineering Department Seminar Series, Louisiana State University, Baton Rouge, LA, November 23, 2004.

University Invitation: "Stress Rotations Due to Moving Wheel Loads and Their Effects on Pavement Materials Characterization," Invited Speaker, Department of Civil Engineering, Bogazici University, Istanbul, Turkey, January 4 AM hours, 2005.

University Invitation: "Stress Rotations Due to Moving Wheel Loads and Their Effects on Pavement Materials Characterization," Invited Speaker, Department of Civil Engineering, Kocaeli University, Izmit, Turkey, January 4 PM hours, 2005.

"Subgrade Stability and Pavement Foundation Requirements," Invited Keynote Speaker, 15th Colombian Symposium of Pavement Engineering, Sponsored by the Pontificia Universidad Javeriana in Bogota, Melgar, Colombia, March 11, 2005.

"Imaging Based Evaluation of Course Aggregate Used in the NCAT Pavement Test Track Asphalt Mixes," Invited Speaker, 2005 Asphalt Pavements Innovations Conference, Organized by the Center for Emerging Technologies in Infrastructure at Bradley University, Peoria, April 12, 2005.

"Measurement of Particle Shape, Form, and Texture Characteristics," Invited Speaker, TRB Mid-Year Meeting on Aggregates for Highway Construction: Characterization and Performance, held during the 56th Annual Highway Geology Symposium, May 3, 2005.

"A Mechanistic Response Model for Geosynthetic Reinforced Road Pavements," Invited Speaker, 2nd Technical Textiles Conference, Sponsored by Dokuz Eylul University, Istanbul International Technical Textile and Nonwoven Fair and Exhibition - HIGHTEX, July 14, 2005.

"Building Long Lasting Pavements with Unbound Aggregate Bases," Invited Speaker, Aggregate Base Symposium, Sponsored by the Oklahoma Aggregate Association, Oklahoma City, October 4, 2005.

University Invitation: "Characterization of the Anisotropic Behavior of Unbound Aggregate Bases," Invited Speaker, Taiyuan University of Science and Technology, Taiyuan, P.R. of China, June 12, 2006.

"Geogrid Base Reinforced Asphalt Pavements: Analysis Approach and Benefits," Invited Keynote/Opening Speaker, 2nd National Geosynthetics Conference of the Turkish Chapter of International Geosynthetics Society (IGS), Bogazici University, Istanbul, Turkey, November 16, 2006.

University Invitation: "Aggregate Testing and Characterization for Transportation Facilities Design," Invited Speaker, 35th Geomechanics Colloquium, Technical University (TU) Bergakademie, Freiberg, Germany, November 17, 2006.

"Influence of Coarse Aggregate Morphology on Hot Mix Asphalt Behavior," Invited Speaker, Mini-Symposium on Pavement Modeling and Damage Mechanics held in honor Professor Samuel H. Carpenter's Accomplishments, ICAMEM Conference, Hammamet, Tunisia, December 18, 2006.

"Essentials of Mechanistic-Empirical Pavement Design and 2002 MEPDG Overview," Invited Seminar Speaker, General Directorate of Turkish Highway Agency, Ankara, Turkey, December 26, 2006.

"Geogrid Base Reinforced Asphalt Pavements: Analysis Approach, Field Validations and Benefits," Invited Speaker, Tensar Mechanistic-Empirical Pavement Design Overview, Tensar Hospitality Suite, 86th Annual Meeting of the Transportation Research Board (TRB), January 21, 2007.

"Validation of Unbound Aggregate Base Anisotropic Stiffness Characterization from Instrumented Full Scale Pavement Tests," Invited Speaker, 15th Annual Symposium, International Center for Aggregate Research (ICAR), Austin, Texas, April 10, 2007.

"Building Long Lasting Pavements with Unbound Aggregate Bases," Invited Speaker, MO/KS Aggregate Base Symposium, Sponsored by Missouri Aggregate Association and Kansas Aggregate Association, Kansas City, May 3, 2007.

University Invitation: "Geogrid Base Reinforced Asphalt Pavements: A Mechanistic-Empirical Analysis and Design Approach," Invited Speaker, Seminar Series of the Civil Engineering Department, University of Wisconsin, Madison, WI, May 21, 2007.

University Invitation: "Geogrid Base Reinforced Asphalt Pavements: A Mechanistic-Empirical Analysis and Design Approach," CCEE Distinguished Lecture, Department of Civil, Construction and Environmental Engineering (CCEE), Iowa State University, Ames, Iowa, September 28, 2007.

"Tensar Mechanistic Based Design for Geogrid Base Reinforced Flexible Pavements," Invited Keynote Speaker, 13th International Meeting on Tensar Geosynthetics, Guatemala City, Guatemala, October 15, 2007.

"Unbound Aggregate Bases," Invited Speaker, IAAP / ICAR / MLPA / NSSGA Regional Technology Transfer Seminar, Sponsored by Illinois Aggregate Association Missouri Lime Producers Association, and Illinois and Missouri Departments of Transportation, Collinsville, Illinois, October 30, 2007.

"Geosynthetics in Pavements," and "Thin Asphalt Pavements," Invited Seminar Speaker, Istanbul Asphalt Plants Industry and Trading, Inc. (ISFALT), Istanbul, Turkey, January 3 and 4, 2008.

"Overview of Current Design Techniques for Flexible Pavements with Unbound Aggregate Bases," Invited Speaker, National Aggregate Base Conference, Austin, Texas, May 14, 2008.

"State of the Art: Anisotropic Characterization of Unbound Aggregate Layers in Flexible Pavements," Invited Keynote/Opening Speaker, Symposium of Pavement Mechanics and Materials, International Conference of the ASCE Engineering Mechanics Institute (EM08), Minneapolis, Minnesota, May 18, 2008.

"Pavement Management," Invited Seminar Speaker, Istanbul Asphalt Plants Industry and Trading, Inc. (ISFALT), Istanbul, Turkey, May 29, 2008.

"Experiences with Alternative Bases," Invited Speaker, 2nd Annual National Aggregate Base Conference, National Stone, Sand and Gravel Association Annual Convention and AGG1 Forum & Expo, Orlando, Florida, March 9, 2009.

"Types and Amounts of Fines Affecting Unbound Aggregate Behavior," Invited Speaker, 17th Annual Symposium, International Center for Aggregate Research (ICAR), Austin, Texas, May 4, 2009.

"Recent Research into the Actual Behavior of Geogrids in Stabilization Applications" Invited Speaker, Jubilee Symposium on Polymer Geogrid Reinforcement, Institution of Civil Engineers, London, UK, September 8, 2009.

Selected Recent Reports

Thompson, M.R., Tutumluer, E., and Bejarano, M., "Granular Material and Soil Moduli," Final Report No. 1, FAA Center of Excellence for Airport Pavements, Civil Engineering, University of Illinois at Urbana-Champaign, 1997.

Tutumluer, E. and M.R. Thompson, "Anisotropic Modeling of Granular Bases," Final Report No. 2, FAA Center of Excellence for Airport Pavements, Civil Engineering, University of Illinois at Urbana-Champaign, 1998.

Tutumluer, E. and U. Seyhan, "Characterization of Unbound Aggregates Using the University of Illinois FastCell," Technical Report, Submitted to Applied Research Associates for Inclusion in the Final Report of the NCHRP Project 4-23, Civil and Environmental Engineering, University of Illinois at Urbana-Champaign, 1999.

Tutumluer, E., Rao, C., and Stefanski, J., "Video Image Analysis of Aggregates," Final Project Report, FHWA-IL-UI-278, Civil Engineering Studies UILU-ENG-2000-2015, University of Illinois Urbana-Champaign, Urbana, IL, July 2000.

Tutumluer, E., Adu-Osei, A., Little, D.N., and Lytton, R.L., "Field Validation of the Cross-Anisotropic Behavior of Unbound Aggregate Bases," Research Report 502-2, A Deliverable of the International Center for Aggregates Research (ICAR) 502 Project: Structural Characteristics of Unbound Aggregate Bases to Meet AASHTO 2002 Design Requirements, March 2001.

Seyhan, U. and E. Tutumluer, "Characterization of Anisotropic Granular Layer Behavior of Flexible Pavements," Final Report No. 18, FAA Center of Excellence for Airport Technology, Civil Engineering, University of Illinois, February 2002.

Kwon, J. and E. Tutumluer, "Geosynthetic Reinforcement of Pavement Structures," Summary Technical Report, Project IHR-R30, Submitted to the Illinois Department of Transportation, University of Illinois, Urbana, IL, August 2002.

Masad, E., Al-Rousan, T., Pascual, J., Button, J., Little, D.N., and Tutumluer, E., "Test Methods for Characterizing Aggregate Shape, Texture, and Angularity," Interim Report, Project 4-30, National Cooperative Highway Research Program, Transportation Research Board, National Research Council, Washington, D.C., October 2002.

Kwon, J. and E. Tutumluer, "Use of Geosynthetics In Working Platform and Pavement Construction," Final Report, Project IHR-R30, Submitted to the Illinois Department of Transportation, University of Illinois, Urbana, IL, June 2003.

Tutumluer, E., Pan, T., and Carpenter, S.H., "Investigation of Aggregate Shape Effects on Hot Mix Performance Using An Image Analysis Approach," Final Technical Report, Pooled Fund Study TPF-5(023), UILU-ENG-2005-2003, Federal Highway Administration IL Division, University of Illinois, Urbana, IL, Feb., 2005.

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Other Professional Service

Contributor/Co-Editor, Transportation Research Board (TRB) Circular E-C012 on "Use of Artificial Neural Networks Geomechanical and Pavement Systems," 79th Annual TRB Meeting, January 8-13, 2000 (http://www4.nationalacademies.org/trb/onlinepubs.nsf/web/circular)

Program Committee Member, 2nd International Workshop on Artificial Intelligence and Mathematical Methods in Pavement and Geomechanical Engineering Systems, University of Delaware, Newark, Delaware, August 11-12, 2000.

Planning Committee Member, ASCE Airfield Pavement Specialty Conference, Advancing Airfield Pavements, Chicago, Illinois, August 5-8, 2001.

Planning Committee Chair, "Recent Advances in Materials Characterization and Modeling of Flexible Pavements" A Symposium Sponsored by the ASCE Geo-Institute Pavements Committee at the 15th ASCE Engineering Mechanics Division Conference (EM2002) at Columbia University, New York, NY, June 2-5, 2002.

Scientific Committee Member, 6th International Conference on the Bearing Capacity of Roads, Railways and Airfields, BCRA 2002, Technical University of Lisbon, Lisbon, Portugal, 24-26 June, 2002.

Planning Committee Member, A Special Pavements Symposium at the GeoFrontiers 2005 Conference organized by the ASCE Geo-Institute, Austin, TX, January 24-26, 2005.

Scientific Committee Member, 7th International Conference on the Bearing Capacity of Roads, Railways and Airfields, BCRA 2005, Norwegian University of Science and Technology, Trondheim, Norway, June 27-29, 2005.

Planning Committee Member, Pavement Foundations Sessions at the GeoShanghai Conference organized by the ASCE Geo-Institute, Shanghai, China, June 6-8, 2006.

Technical Committee Member, ASCE Geo-Institute GeoShanghai Conference, Shanghai, China, June 6-8, 2006.

Planning Committee Chair, Pavements Track Symposium on Soil and Material Inputs for Mechanistic-Empirical Pavement Design at the GeoDenver 2007 Conference organized by the ASCE Geo-Institute, Denver, CO, February 18-21, 2007.

Scientific Committee Member, International Conference on Advanced Characterization of Pavement and Soil Engineering Materials, National Technical University of Athens (NTUA), Athens, Greece, June 20-22, 2007.

Planning Committee Chair, Pavements Track Sessions at the GeoCongress 2008 Conference organized by the ASCE Geo-Institute, New Orleans, LA, March 9-12, 2008.

Scientific Committee Member, 10th International Conference on Application of Advanced Technologies in Transportation (AATT 2008), National Technical University of Athens (NTUA), Athens, Greece, May 27-31, 2008.

Organizing Committee Member, 6th RILEM International Conference on Pavement Cracking, Chicago, Illinois, June 16-19, 2008.

International Advisory Committee Member, 1st ISSMGE International Conference on Transportation Geotechnics, University of Nottingham, United Kingdom, September 8-10, 2008.

International Advisory Committee Member, 12th International Conference of the Association for Computer Methods and Advances in Geomechanics (IACMAG), Goa, India, October 1-6, 2008.

Conference Chair, 8th International Conference on the Bearing Capacity of Roads, Railways, and Airfields (BCR^{2}A), University of Illinois at Urbana-Champaign, Champaign, Illinois, June 29-July 2, 2009.

International Advisory Committee Member, GeoHunan International Conference on Challenges and Recent

Advances in Pavement Technologies and Transportation Geotechnics, Hunan, China, August 3-6, 2009.

Organizing Committee Member, GeoShanghai International Conference 2010 organized by the ASCE Geo-Institute, Shanghai, China, June 3-5, 2010.

International Advisory Committee Member, GeoHunan International Conference II: Emerging Technologies for Design, Construction, Rehabilitation, and Inspections of Transportation Infrastructures, Zhangjiajie (Hunan Province), China, June 6-8, 2011.

International Advisory Committee Member, 2nd International Conference on Transportation Geotechnics, Sapporo, Hokkaido, Japan, September 10-12, 2012.

Reviewer of technical papers/books submitted for publication:

- Transportation Research Board (TRB) Research Record Series
- Geotechnical Testing Journal, ASTM
- ASTM Journal of Testing and Evaluation
- Journal of Transportation Engineering, ASCE
- Journal of Geotechnical and Geoenvironmental Engineering, ASCE
- Canadian Journal of Geotechnical Engineering

- Journal of Materials in Civil Engineering, ASCE
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- International Journal of Pavement Research and Technology, Editors-in-Chief Prof. Deng-Fong Lin, I-Shou University, Taiwan and Dr. Chung Wu, Virginia DOT, USA
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EXHIBIT 2

Erol Tutumluer's Additional Experience

My major research focus in railroad engineering has been primarily on the aspects of track substructure. My first railroad project in 2001 was jointly funded by the AAR affiliated laboratory established at UIUC and Burlington Northern Santa Fe Railroad Company. The project involved an industry survey and review of performance and remediation methods for track substructure, including ballast, subballast, and subgrade. Specifically, the industry survey provided information for AAR members on (1) general track substructure statistics, inspection, and maintenance; (2) subgrade soil problems and railroad remedial practices; and (3) ballast/subballast related problems and railroad remedial practices.

Another railroad project funded by the Federal Railroad Administration ("FRA") involved the development of ground penetrating radar ("GPR") to evaluate railway track subsurface condition and estimate track bed materials' physical properties. The objective of the project was to test previous methods of collecting GPR data. The UIUC team was responsible for evaluating the modified common midpoint GPR technique and developing ballast thickness algorithm and quantitative assessment of the ballast and sub-ballast condition, including accurate assessment of its physical state and indications of the degree of ballast fouling, which is the main indicator of ballast degradation.

I am currently working on four research projects concerning railroads: (1) Discrete Element Modeling ("DEM") of Ballast funded by the AAR-affiliated laboratory at UIUC, (2) Railroad Track Substructure Evaluation jointly funded by AAR and the FRA, (3) Investigation of Fouled Ballast Behavior funded by BNSF Railroad Company, and finally, (4) Testing of Polyurethane Elastomer Coated Railroad Ballast funded by BASF The Chemical Company. I have presented and published several papers and AAR Technology Digests related to these railroad projects, including at the American Railway Engineering and Maintenance of Way Association ("AREMA") conferences held from 2006 to 2009 and at the Transportation Research Board annual meetings since 2008.

The current AAR project focuses on the development of a combined image analysis and DEM approach for analyzing ballast aggregate behavior and improving ballast strength and stability and manufactured crosstie designs. This project also deals with the selection of proper ballast aggregate shape and angularity characteristics for mitigating track problems and failures due to ballast breakdown, powdering, and fouling; ballast deformation and degradation due to compaction and repeated loading; and ballast lateral movement and instability causing track buckle. In this project, we developed a validated image-aided DEM model to evaluate the size and shape properties of ballast aggregate to eventually engineer ballast track designs. In our ongoing efforts, we will use the developed DEM model to adequately predict field ballast deformation behavior obtained from settlement records of full-scale test sections, as well as bridge approaches and transition zones in the AAR Transportation Technology Center, Inc. ("TTCI") test track in Pueblo, Colorado.

BNSF Railway Company has funded a research project at UIUC with a focus on conducting large direct shear laboratory tests to measure strength and deformation characteristics of both clean (new) and fouled ballast aggregates at various stages of fouling with different type fine-grained materials (plastic subgrade soils, mineral filler, coal dust, etc.). This laboratory study also included studying the effects of coal dust fouling on the granite-type and limestone-type ballast aggregate behavior and evaluating reductions in strength and stability. This study resulted in important findings on the effects of coal dust and other ballast foulants.

My railroad track research program at UIUC was selected as the university research partner to collaborate with the AAR's TTCI for the "Track Substructure" cooperative research program established in 2009 and now jointly funded by the AAR and FRA. Under this multi-year track infrastructure research partnership program, the primary objectives are to determine the effects of heavy axle load traffic on track infrastructure; investigate root causes of mud holes and quantify their effects on track and track components; and finally, develop guidelines for track substructure diagnostics, remedy, design, and construction.

My other projects include stress dependency and anisotropy of aggregate behavior affecting structural response and performance of unbound aggregate layers in the transportation infrastructure sponsored by the Federal Aviation Administration ("FAA"), U.S. Army Corps of Engineers, and the International Center for Aggregates Research ("ICAR"). I have also studied the size, shape, and angularity characterization of aggregates using video-imaging and more recently Laser Detection and Ranging techniques sponsored throughout the last nine years by the Federal Highway Administration ("FHWA"), the Illinois Department of Transportation ("IDOT"), and by the National Cooperative Highway Research Program ("NCHRP"). In addition, I recently have researched establishing subgrade/subbase support, stability, and working platform requirements with virgin and recycled aggregates, including evaluating their expansive characteristics, for highway pavements, which was funded by IDOT. I have also researched airport pavements in a project funded by the O'Hare Modernization Program for Chicago's O'Hare Airport and the best value granular material for road foundation in a project funded by Minnesota Department of Transportation. In addition, I have been working on laboratory subgrade soils testing for Caterpillar, Inc., related to the mobility of some of its construction and compaction equipment on problematic soils, such as tar sands or oil sands. I am also working to model geogrid reinforced unbound aggregate roadway, railroad base, and ballast layers for a leading geosynthetic producer, Tensar International, Inc.

My research has resulted in high-quality peer-reviewed journal papers, an invention disclosure for U.S. patent application, a co-authored book on anisotropic behavior of aggregate materials, co-edited a two-volume hardcover Eighth International Conference Proceedings book on the Bearing Capacity of Roads, Railways and Airfields in 2009, and co-edited five ASCE Geotechnical Special Publications in relation to my involvement, including my current chair role of the ASCE Geo-Institute's Pavements Committee. To support my research programs, I have received grants from federal agencies including FRA, FHWA, FAA, U.S. Army Corps of Engineers, NCHRP and NSF; state agencies, including single grants from Illinois, Minnesota and Indiana DOTs and pool-funded research contributions from six other state DOTs; and grants from the private sector, including companies such as AAR, BNSF Railway Company, Caterpillar, Inc., BASF The Chemical Company, International Center for Aggregates Research, Chicago O'Hare Airport O'Hare Modernization Program, and Tensar International, Inc.

I have been recognized for my teaching and scholarly service. In 1997, I was named a General Electric Scholar by the UIUC College of Engineering in 1997 and also received a certificate of recognition as an Engineering Education Scholar by the National Science Foundation ("NSF"). I was named General Electric Fellow (1999) and Collins Fellow (2000) by the Academy of Excellence in Engineering Education program administered by the College of Engineering. In 2000, I was the recipient of the Transportation Research Board's Fred Burgraff award for Excellence in Transportation Research. In 2001, I was elected as a Campus Honors Program faculty member by the Chancellor of UIUC. In 2003 and 2008, my students ranked me as excellent on the list of teachers at UIUC. In January 2009, my paper entitled the "Use of

Falling Weight Deflectometer Testing to Determine Relative Damage in Asphalt Pavement Unbound Aggregate Layers" received the Best Paper Award from the Geology and Properties of Earth Materials Section of the Transportation Research Board, National Academy of Sciences.

EXHIBIT 3

Laboratory Characterization of Coal Dust Fouled Ballast Behavior

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Laboratory Characterization of Coal Dust Fouled Ballast Behavior

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ABSTRACT

Fouling refers to the condition of railroad ballast when voids in this unbound aggregate layer are filled with finer materials. As a fouling agent, coal dust coming from coal trains and accumulating in the ballast has become a major concern for railroads. This paper aims to provide a better understanding of adverse impacts of coal dust on railroad ballast drainage and load carrying functions. First, mechanical properties of coal dust were investigated at the University of Illinois through laboratory tests such as grain size distribution, Atterberg limits, specific gravity, moisture-density compaction relationships, and shear strength properties. Then, ballast aggregates were added coal dust at different percentages by weight and moisture contents to represent coal dust fouling in the field. When fouled samples were tested in large direct shear (shear box) equipment, it was found that 25% coal dust by weight of aggregates were enough to fill up all the voids in ballast corresponding to a void ratio of 43%. When the coal dust percentage in ballast samples increased, the ballast shear strength steadily decreased. In the case of ballast fully fouled with wet coal dust at 35% moisture content, the friction angles obtained from the direct shear equipment were close to the friction angle of coal dust itself. This implies that individual aggregate particles within ballast layer would be completely separated by coal dust to most likely cause the worst track instability problems in the field.

Key Words: Railroad track, ballast, fouling, coal dust, shear strength, laboratory testing

INTRODUCTION

Railroad ballast is uniformly-graded coarse aggregate placed between and immediately underneath the crossties. The purpose of ballast is to provide drainage and structural support for the heavy loading applied by trains. As ballast ages, it is progressively fouled with fine-grained materials filling the void spaces. Methods specifically used to assess track ballast condition only deal with checking visually for evidence of fouling, pumping and water accumulation (ponding) at ditches and shoulders. Additionally, ballast sampling and testing for fouling through laboratory sieve analyses generally provide some insight into the compositions of the larger aggregate particles and the amount of fines. Nonetheless, for a better evaluation of the serviceability and proper functioning of the existing ballast layer, ballast strength and deformation behavior needs to be characterized for different percentages of fine-grained materials, such as plastic soil fines, mineral filler, and more recently coal dust coming from coal trains, which can fill the voids and cause ballast fouling.

For hundreds of years, coal has been a major energy source in the United States. Indeed, there has been a historical link between the economic progress of the U.S. and the use of coal for numerous basic needs of the country, ranging from energy for domestic purposes to industrial applications and electricity generation. As the demand for coal transportation increases with the growing energy need, the coal transportation in the U.S. strongly relies on rail transport. Since rail transport, particularly a unit train, provides the most efficient means of transporting bulk commodities such as coal (Morrison, 1985), the role of rail lines in coal transport has always been predominant.

Today, Powder River Basin (PRB) coal is the largest source of incremental low-sulfur coal supplies in the U.S. (Gaalaas, 2006). From 2000 to 2005, the 5.6 percent increase in nationwide coal production chiefly stemmed from the concurrent expansion in PRB coal production, and the Burlington Northern Santa Fe/Union Pacific (BNSF/UP) joint line provided for over 60 percent of the total increase in PRB coal production (42 million tons of 69 million tons) from 2000 to 2005. However, while the National Coal Transportation Association forecast of the corresponding total coal shipments was 348 million tons, the joint line was able to achieve 325 million tons of the total forecast value because of major operating problems on the joint line (Gaalaas, 2006). In 2005, two derailments occurred in the BNSF/UP joint coal line in PRB which threatened to interrupt the supply of coal to power plants. Both of the derailments were suspected to be attributed by coal dust fouling, where coal dust spilled over the ballasts and accumulated moisture, allegedly resulting in the loss of strength of the track. In both places where derailments happened, ballast was heavily fouled by coal dust.

This paper presents findings from a comprehensive laboratory-testing program recently initiated at the University of Illinois to study effects of coal dust fouling on railroad ballast strength. Using large direct shear (shear box) tests, strength and deformation characteristics of granite type ballast material were investigated for both clean and coal dust fouled aggregates at various stages of fouling under both dry and wet conditions. The shear strength properties, i.e., cohesion intercept and friction angle, and the stress-strain response are linked to field ballast fouling levels to better assess the impact of coal dust fouling on track instability and ultimately loss of track support leading to derailments.

BALLAST FOULING

Selig and Waters (1994) proposed two indices to describe ballast fouling: (1) *fouling index* is the sum of the percent by weight of ballast sample passing the No. 4 (4.75 mm) sieve plus the percent passing the No. 200 sieve and (2) *percentage of fouling* is the ratio of the dry weight of material passing 3/8 in. (9.5 mm) sieve to the dry weight of total sample. Figure 1 shows grain size distributions obtained for both clean and fouled materials. The fouled ballast material was collected from a location of derailed (track had buckled out) section of the BNSF railroad line near milepost 43 in Utica, Nebraska in spring of 2006. As indicated, these clean and fouled samples have 1.5% and 14.0% passing the No. 200 sieve (0.075mm), respectively. Although the fines content (% passing the No. 200 sieve) of the fouled sample is not very high, the *fouling index* values computed for the clean and fouled samples were 6.9 and 45.7, respectively. In this case, a *fouling index* of 45.7 corresponds to a *percentage fouling* of nearly 38% (see Figure 1).

In a clean ballast sample, almost all aggregates are supposed to establish contact with each other at the aggregate surface to carry the load (see Figure 2a). As shown in Figure 2b, dirty or partially fouled ballast will have the voids in between contacting aggregates filled with fine particles, however, still maintaining aggregate to aggregate contact. Whereas, in a fouled ballast, due to the excessive amount of fine particles, aggregate to aggregate contacts are mostly eliminated and the aggregate particle movements are then only constrained by the fine particles filling the matrix or voids between the particles (see Figure 2c). In regards to excessive fouling conditions, for example, as in the case of 2005 PRB joint line derailments with wet coal dust completely filling all voids in ballast and pumping on the surface of railroad track, the low strength of the fouling agent will govern for carrying the wheel load. Hence, train derailments may take place due to unstable support under the crossties.

MECHANICAL PROPERTIES OF COAL DUST

Coal dust sample tested in this study was collected from the PRB Orin line milepost 62.4 and was sampled on March 10, 2007. Figures 3 and 4 depict the received coal dust sample in its loose state and close-up view, respectively. To investigate first the mechanical behavior of coal dust itself, several laboratory tests were conducted at the Advanced Transportation Research Laboratory (ATREL) of the University of Illinois at Urbana-Champaign (UIUC). The following sections briefly describe the conducted laboratory tests and present the coal dust test results.

Grain Size Analysis (ASTM C 136, ASTM C 117)

To begin with, dry and wet sieve analyses of the coal dust were performed in compliance with ASTM C 136 and ASTM C 117 test procedures. As Figure 5 indicates from the more accurate wet sieve analyses, the fines content of the coal dust sample was found to be 24%, which means 76% of the coal dust particles were primarily sand sized, coarser than 0.00295 in. (0.075 mm) or retained on No. 200 sieve. The top size (D_{max}) of the coal dust sample is 0.187 in. (4.75 mm), and the particle size corresponding to 50 percent finer by weight (D_{50}) is 0.03 in. (0.76 mm).

Atterberg Limits

The Atterberg limits tests performed indicated that the coal dust sample had a plastic limit (PL) of 50%, a considerably high liquid limit (LL) of 91% thus resulting in a plasticity index (PI) of 41%. This means, at 50% water content, the coal dust starts to exhibit plastic behavior whereas at 91% water content or higher, it behaves like a viscous liquid. Note that the LL of the coal dust is significantly higher than some known weak soils, such as Panama Organic Silt (55%), Georgia Kaolinite (48%), Venezuela Clay (40%), mica powder (75%) from Terzaghi et al. (1996).

Similarly, the PI of the coal dust also exceeds typical values for weak soils, such as Panama Organic Silt (17%), Georgia Kaolinite (16%), Venezuela Clay (25%) and mica powder (20%) (after Terzaghi et al., 1996). Therefore, the high LL and PI of the coal dust sample clearly highlighted its much higher moisture holding capability compared to many silty and clayey subgrade soils.

Specific Gravity

The specific gravity of the coal dust sample was found to be 1.28, which simply meant the density of the coal dust solids was a rather low 79.9 pcf (1.28 g/cm^3) when compared to solid densities of typical soils and aggregates. These results were in accordance with the findings of Fitch (2005), who gave a specific gravity range for coal dust from 1.3 to 1.5. On the other hand, the specific gravities of clay particles typically vary from 2.5 to 2.9 with a statistical average of 2.7 whereas the average specific gravity of sand grains is about 2.65 (Terzaghi et al., 1996). Thus, compared to most soils, the coal dust is a significantly lighter material as far as the low specific gravity of its solid constituents is considered.

Standard Proctor Compaction Test (AASHTO T99/ASTM D 698)

To establish a relationship between the water content and dry density of coal dust, standard Proctor compaction test was performed at different water contents (AASHTO T99/ASTM D698). Figure 6 shows the laboratory obtained compaction curve of the coal dust samples studied. It indicates that the optimum moisture content for the coal dust is 35%, at which the maximum dry density of 54.2 pcf (0.87 g/cm^3) is achieved with the given compactive effort.

Compared to most fine-grained soils such as clays and silts, the 35% optimum moisture content (OMC) is a very high value corresponding to a quite low maximum dry density of 54.2

pcf (0.87 g/cm^3). As far as the results of the standard Proctor compaction test are considered, the coal dust displays not only higher moisture holding capability but also significantly lower dry density compared to most fine-grained soils.

Triaxial (Unconsolidated-Undrained) Test

In this test, cylindrical coal dust specimens were sheared at their OMC (35%) and maximum dry density (54.2 pcf) determined by the previously conducted standard Proctor compaction test. A servo-pneumatic test frame was used as a UTM setup to conduct triaxial tests on small 2 in. (50.8 mm) in diameter by 4 in. (101.6 mm) high specimens. Shear strength tests were conducted under unconfined and confined conditions with the monotonic loading until failure. Figure 7 shows photos of the triaxial cell and the cylindrical coal dust specimen tested. A vertical actuator applies the axial monotonic load and the confining pressures are applied through the inside the chamber.

Since the drainage valves of the triaxial cell were closed from the beginning, the samples were not allowed to consolidate under the effect of confining pressure after they reached 100% saturation and the shearing stage was achieved under undrained conditions. Since the increase in stress was carried by the pore water (Holtz and Kovacs, 1981), the internal friction angle of the coal dust is found almost equal to zero for the undrained conditions. Figure 8 shows the Mohr circles for the unconsolidated-undrained tests and the resultant Mohr-Columb failure envelope of the coal dust. As the failure envelope levels up, it is concluded that the internal friction angle (Φ) of the coal dust is approximately 1.8 degrees, i.e., almost equal to zero, which is very typical of cohesive clayey soils tested under such undrained conditions.

Figure 9 shows applied deviator stresses graphed with vertical specimen displacements at different confining pressures. Once again, there was no effect of varying confining pressure on the shear strength of the coal dust, which was obtained as the maximum deviator stress at failure of only 3.5 psi (24.1 kPa). This is almost the same as twice the amount of cohesion intercept indicated on the y-axis in Figure 8, which is often called the unconfined compressive strength (Qu) for cohesive (Φ=0) soils.

Direct Shear Test

In this test, coal dust samples at different water contents were sheared horizontally in a 3.94 in. by 3.94 in. (100mm by 100mm) shear box under different normal loads so that the relationships between the normal stress and shear stress were established. A direct shear test equipment Humboldt ShearScan 10 direct/residual apparatus utilizing the pneumatic loading concept was used to apply the vertical load to the sample. In doing so, this self-contained model eliminates the need for loading weights used in dead weight-type systems. The ShearScan 10 is complete with a 2,000-lb. (10-kN) capacity load cell, 1-in. (25.4-mm) stroke horizontal deformation transducer, 0.4-in. (10.2-mm) vertical deformation transducer and a built-in 4-channel analog data acquisition system. Figure 10 shows a picture of the ShearScan 10 direct/residual shear test device used to shear the specimen under a series of applied normal stresses.

Table 1 summarizes the results obtained from the direct shear tests and illustrates the change in the internal friction angle of the coal dust with respect to moisture content. The internal friction angles and cohesion intercepts of the coal dust samples are tabulated with regard to the moisture contents of the test samples. Considering the significant decrease in the friction angle and as a result approximately 47% decrease in shear strength contributed by tan Φ, cohesion intercept stayed almost constant.

CLEAN AND COAL DUST FOULED BALLAST BEHAVIOR

To investigate whether the fouling condition indicated in Figure 2c takes place, i.e., fouling agent's strength dominates over the ballast layer strength properties when heavily fouled, direct shear tests were conducted at the University of Illinois on both clean and coal dust fouled ballast samples. The ballast material tested was a granite aggregate obtained from Gillette, WY and commonly used in the PRB joint line railroad track structures as the ballast layer.

Figure 11 shows the grain size distribution of the granite sample tested in compliance with ASTM C 117 test procedure. Table 2 lists the gradation sieve sizes and the percent passing each sieve properties for the clean granite aggregate. The grain size distribution conforms to the typical AREMA No. 24 ballast gradation having a maximum size (D_{max}) of 2.5 in. (63.5 mm), a minimum size (D_{min}) of 1 in. (25.4 mm), and an average particle size corresponding to 50 percent passing by weight (D_{50}) of approximately 1.77 in. (45 mm). Also listed in Table 2 are the specific gravity, unit weight and corresponding compacted air voids of the clean granite aggregates. ASTM C29 test procedure was used for finding porosity or air voids with known values of the specific gravity and volume and weight of ballast compacted.

Direct shear strength tests were performed on the reconstituted clean and coal dust fouled granite aggregate samples. Figure 12 shows the large shear box equipment used for testing at the University of Illinois. The test device is a square box with side dimensions of 12 in. (305 mm) and a specimen height of 8 in. (203 mm). It has a total 4-in. (102 mm) travel of the bottom 6-in. (152 mm) high component, which is large enough for ballast testing purposes to record peak shear stresses. The vertical (normal direction) and horizontal load cells are capable of applying and recording up to 30-kip and 20-kip load magnitudes, respectively. The device controls and the data collection are managed through an automated data acquisition system controlled by the operator through a build-in display and the test data are saved on to a personal computer.

Direct Shear Test Procedure

1. Obtain 54 lbs. (24.5 kg) of ballast aggregate
2. Compact ballast sample into lower box (14 in. x 12 in. x 6 in. or 356 mm x 305 mm x 152 mm) using two 3 in. (76 mm) lifts. Use vibratory compactor on top of a flat Plexiglas compaction platform and compact until no noticeable movement of particles is observed (see Figure 13).
3. Obtain prescribed weight of fouling material (e,g., coal dust) and water to mix with compacted ballast.
4. Spread fouling material over compacted ballast evenly in two lifts (half of material each lift). Shakedown material using vibratory compactor after each lift. If test is conducted with wet fouling material (for example, at the optimum moisture content or OMC), pour proportional amount of water over ballast after shakedown of each lift (see Figure 14). Place upper ring (3 in. or 76 mm high) on top of lower box. Align ring with sides and back edge of box (opposite of block) and fill with single lift of ballast and compact (see Figure 15).
5. Place box and ring assembly into shearing apparatus. Clamp lower box in place. Place load bearing plate on ballast and inside upper ring. Place air-bladder on bearing-plate. Close normal force load cell over air-bladder. Open air supply and set pressure using an in-line pressure regulator (see Figure 16).

6. Adjust shear force load cell directly against the upper ring.
7. Prepare LabVIEW Data Logger software to record normal and shear force while the test is running.
8. Input shear rate of 0.48 in./min. (12.2 mm/min.) which is approximately 4% strain per minute and run test until shear force output becomes constant or 15% strain has occurred.

Direct Shear Test Results

The ballast samples were sheared horizontally in the shear box under target normal pressures of 25, 35, 45 psi (172, 241 and 310 kPa), typical ballast layer confining pressures, so that the relationships between the normal stress and shear stress could be established. The maximum shear stress at failure under each applied normal pressure was recorded from each test. This maximum shear stress typically occurred when approximately 10% shear strain was reached during testing. The shear strength $\tau_{max} = C + \sigma_n * \tan\Phi$ (where C is the cohesion intercept, σ_n is the applied normal stress, and Φ is the internal friction angle) expression was then developed for each ballast sample tested at a corresponding fouling fines content and moisture state.

Figure 17 shows the maximum shear stresses predicted under the applied normal stresses during shear box testing. As the applied normal stresses increased, the maximum shear stresses at failure or simply shear strength τ_{max} also increased primarily influenced by the ballast fouling percentage and the moisture condition of the coal dust, i.e., dry or wet at OMC = 35%. As expected, the highest shear strength values were obtained from the clean ballast at all applied normal stress levels. When ballast samples were fouled, the shear strengths typically decreased. For all the samples tested, wet coal dust fouling resulted in lower shear strengths when compared to those obtained from dry coal dust fouling. The lowest shear strength values were recorded for the fouling level of 25% by weight of ballast when wet coal dust filled all the voids at 35% moisture content.

Table 3 shows cohesion intercepts (C) and internal friction angles (from slopes of Mohr-Coulomb envelopes in Figure 17) obtained for the clean and fouled ballast samples. The highest friction angle Φ of 45.6 was achieved for the clean granite. For the case of 25% wet coal dust fouling by weight of ballast, the friction angle computed is as low as 34.5 degrees, which is very close to 33.5 degrees at OMC for the coal dust itself. Similarly, a low cohesion intercept of 5.1 psi (35 kPa) value is close to the very low unconfined compressive strength of 3.5 psi (24 kPa) for the coal dust itself. Therefore, the shearing action in the direct shear apparatus was mainly resisted by the wet coal dust governing the behavior. Again, one should note that 35% OMC condition does not represent fully saturated coal dust state. After soaking or 100% saturation, soil suction would be destroyed thus resulting in fairly lower strengths and unstable ballast conditions.

SUMMARY AND CONCLUSIONS

Mechanical properties of representative coal dust samples obtained from the Powder River Basin (PRB) joint line in Wyoming were determined through laboratory testing at the University of Illinois. From the grain size analysis of the coal dust, material finer than 0.00295 in. (0.075 mm) or No. 200 sieve size was found to be 24%. The specific gravity of the coal dust sample was 1.28. While the fines content of the coal dust was lower than that of most silty and clayey soils, the optimum moisture content (OMC) of the coal dust determined from the standard Proctor compaction test was remarkably higher than that of some of the weak cohesive soils, which highlights its ability to hold much greater amounts of moisture. Likewise, the high liquid limit, LL, and plasticity index, PI, of coal dust, i.e., 91% and 41%, respectively, also underscore its high moisture sensitivity. When subjected to precipitation, coal dust can therefore hold excessive amounts of moisture to prevent free draining of the ballast, i.e., can keep ballast wet and saturated, and act as a lubricant between the ballast stones, enabling much greater movement within the ballast layer.

As for the strength characteristics of the coal dust, the unconfined compressive strength of the coal dust tested was a remarkably low Qu = 3.5 psi (24.1 kPa) at the OMC of 35%. The results of direct shear tests indicated a large reduction in the internal friction angle of the coal dust with increasing moisture content. For instance, the internal friction angle of the coal dust was found as 33.5 degrees at 35% OMC whereas the internal friction angle corresponding to 43% moisture was only 19.2 degrees. Therefore, exposure of coal dust to moisture drastically reduces the friction component of the shear strength and can cause significant reduction in bearing capacity and load carrying ability.

Large-sized direct shear (shear box) laboratory tests were next conducted at the University of Illinois on granite ballast samples also obtained from the Powder River Basin (PRB) joint line in Wyoming to measure strength and deformation characteristics of both clean (new) and fouled ballast aggregates with coal dust at various stages of fouling. The grain size distribution of the aggregate conformed to the typical AREMA No. 24 ballast gradation with a maximum size (D_{max}) of 2.5 in. (63.5 mm) and a minimum size (D_{min}) of 1 in. The coal dust, also obtained from the PRB joint line, was used as the fouling agent and mixed with clean aggregates for achieving fouling levels of 5%, 15%, and 25% by weight of ballast under dry and wet (at 35% OMC) conditions.

From the direct shear tests, the highest shear strength values were obtained from the clean ballast at all applied normal stress levels which were representative of the stress states experienced in the ballast layer under train loading. When ballast samples were fouled, the shear strengths always decreased. Wet (35% OMC) coal dust fouling resulted in lower ballast shear strengths when compared to those obtained from dry coal dust fouling. For the case of 25% wet coal dust fouling by weight of ballast, internal friction angle and cohesion obtained were equivalent to those properties of the coal dust itself at 35% OMC. Therefore, the wet coal dust was governing the ballast behavior as the worst fouling agent for its impact on track substructure and roadbed when compared to even the highly plastic type clayey soil fines. Note that even more drastic strength reductions can be realized when dry coal dust, never been saturated or soaked in the field and therefore having a high suction potential, is subjected to inundation and 100% saturation.

ACKNOWLEDGEMENTS

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Table 1. Internal friction angles and cohesion intercepts of coal dust measured by direct shear tests at different moisture contents

Moisture Content (%)	Internal Friction Angle, Φ (Degrees)	tan Φ	Cohesion Intercept, C (psi)
33.00	34.10	0.68	1.11
35.00	33.53	0.66	1.23
37.00	31.83	0.62	1.13
39.00	27.22	0.51	1.07
41.00	21.91	0.40	1.01
43.00	19.23	0.35	0.81

Table 2. Properties of the clean granite aggregate

Granite		
Specific gravity		2.62
Unit weight		93 pcf
Compacted Air Voids		43%
Gradation		
Sieve Size		Percent Passing
in.	mm	%
2.5	63.5	100
2	50.8	82
1.5	38.1	18
1	25.4	0
AREMA		No. 24

Table 3. Summary of ballast internal friction angles and cohesion intercepts

Condition	Fouling % *	Cohesion, c (psi)	ϕ (rad.)	ϕ (deg.)	Max Shear Stress, $\tau_{max} = c + \sigma_N \tan(\phi)$	Regression Coef, R^2
Clean	0	15.24	1.022	45.6	$\tau_{max} = 15.24+\sigma_N\tan(43.9°)$	0.99
Dry	5	13.96	0.991	43.9	$\tau_{max} = 13.96+\sigma_N\tan(43.9°)$	0.99
	15	13.46	0.773	36.2	$\tau_{max} = 13.46+\sigma_N\tan(36.2°)$	0.99
	25	10.90	0.688	36.6	$\tau_{max} = 10.90+\sigma_N\tan(36.6°)$	0.97
Wet (OMC)	5	8.89	0.963	44.7	$\tau_{max} = 8.89+\sigma_N\tan(44.7°)$	0.99
	15	11.12	0.731	37.7	$\tau_{max} = 11.12+\sigma_N\tan(37.7°)$	0.99
	25	5.10	0.744	34.5	$\tau_{max} = 5.102+\sigma_N\tan(34.5°)$	0.97

* percentage by ballast weight

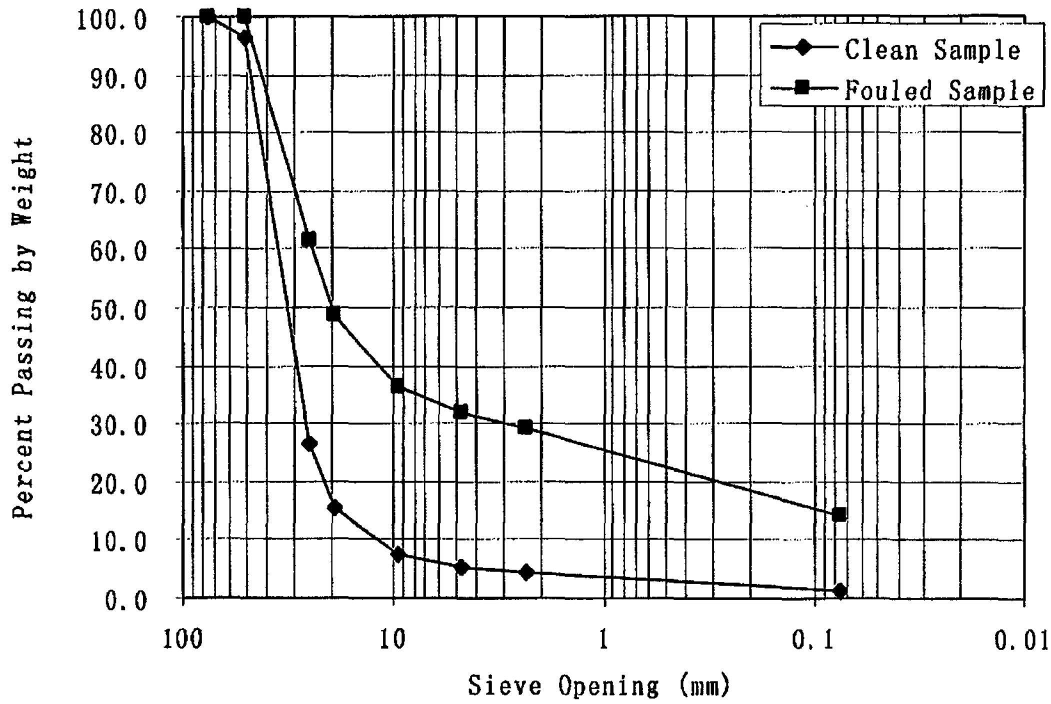
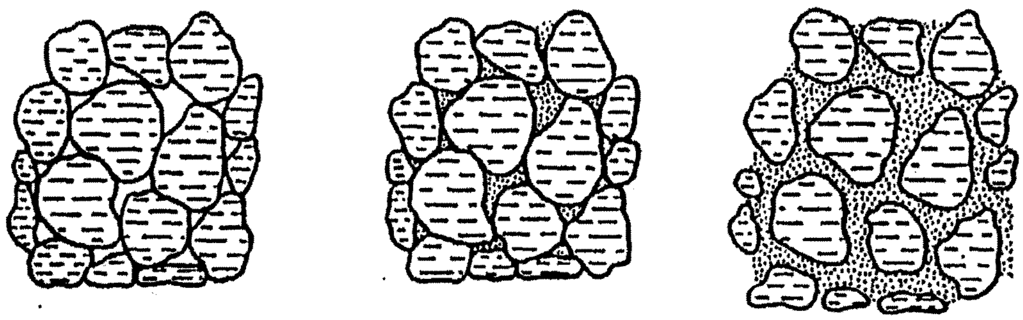


Figure 1. Sample grain size distributions of clean and fouled ballast samples (25.4 mm=1 in.)

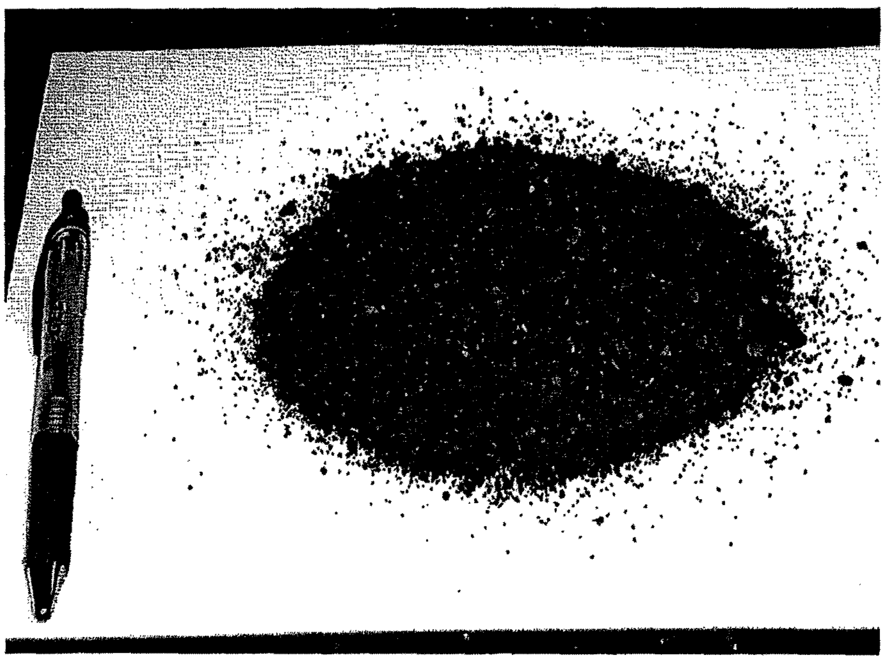


(a) clean ballast

(b) dirty ballast with fine particles filling voids

(c) fouled ballast with aggregate to aggregate contact lost

Figure 2. Critical ballast fouling stages illustrating loss of aggregate to aggregate contact



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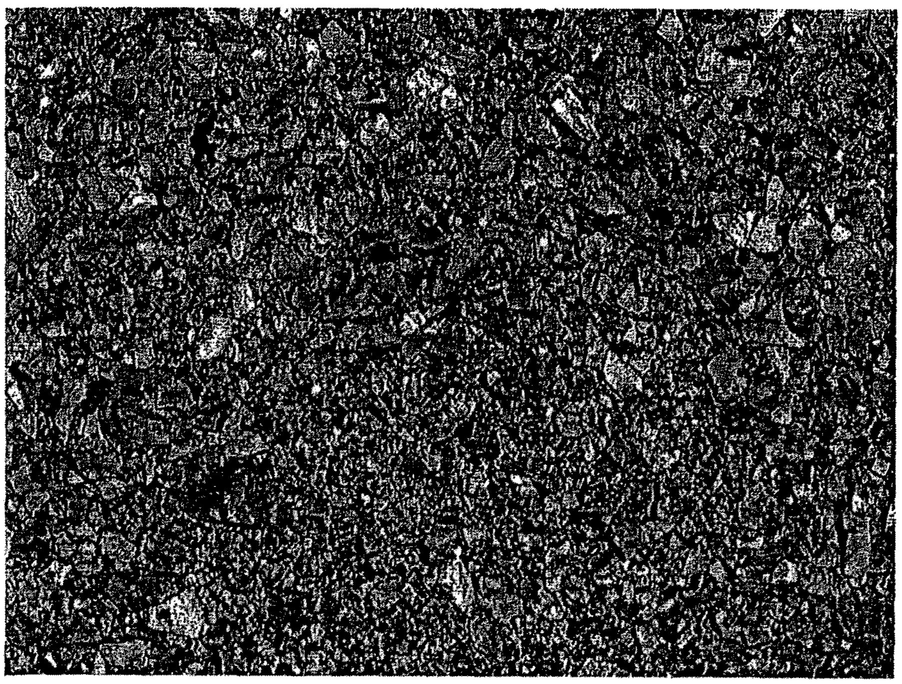

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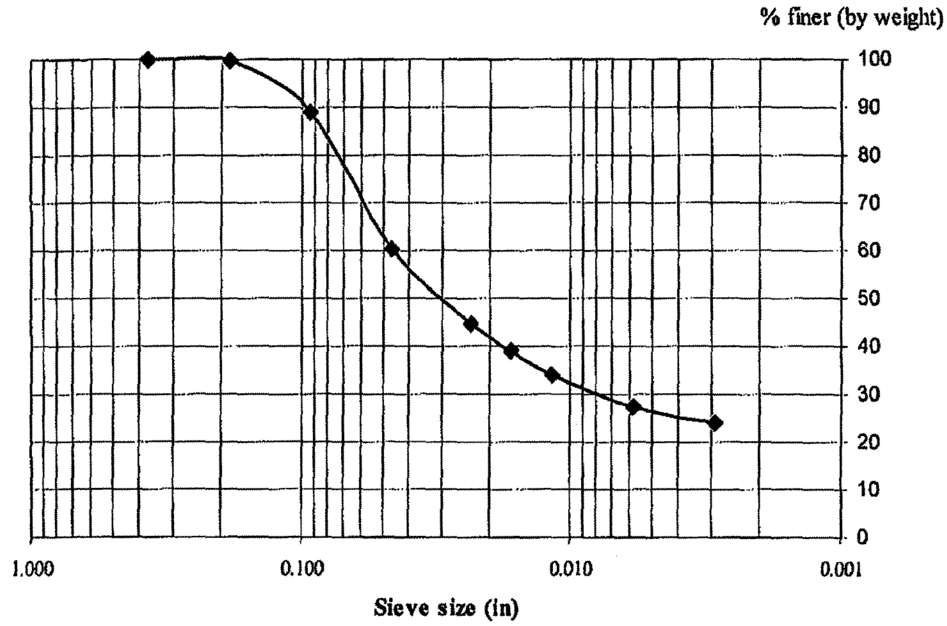

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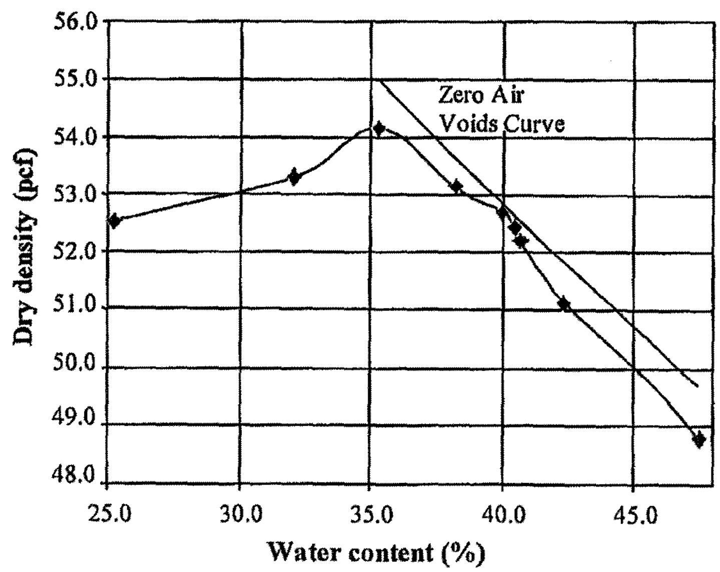

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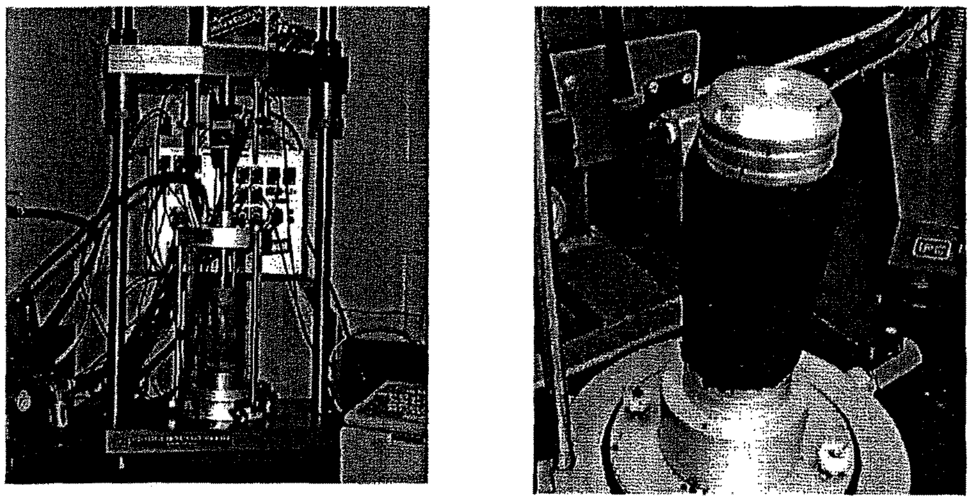

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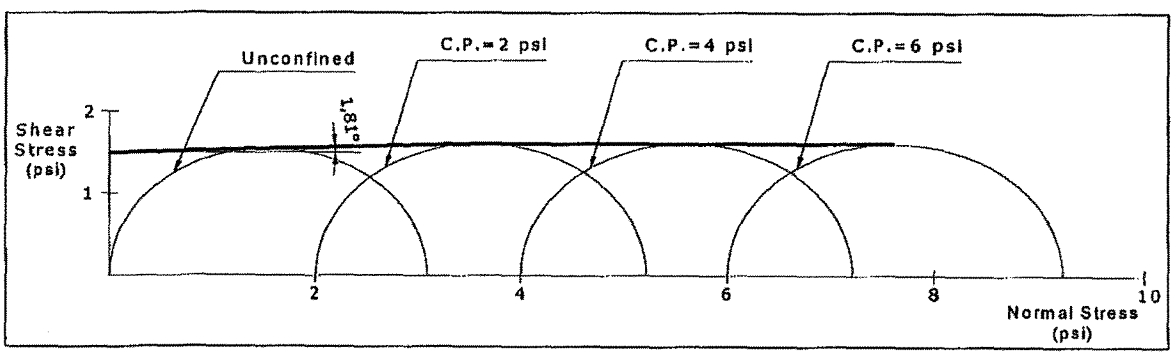

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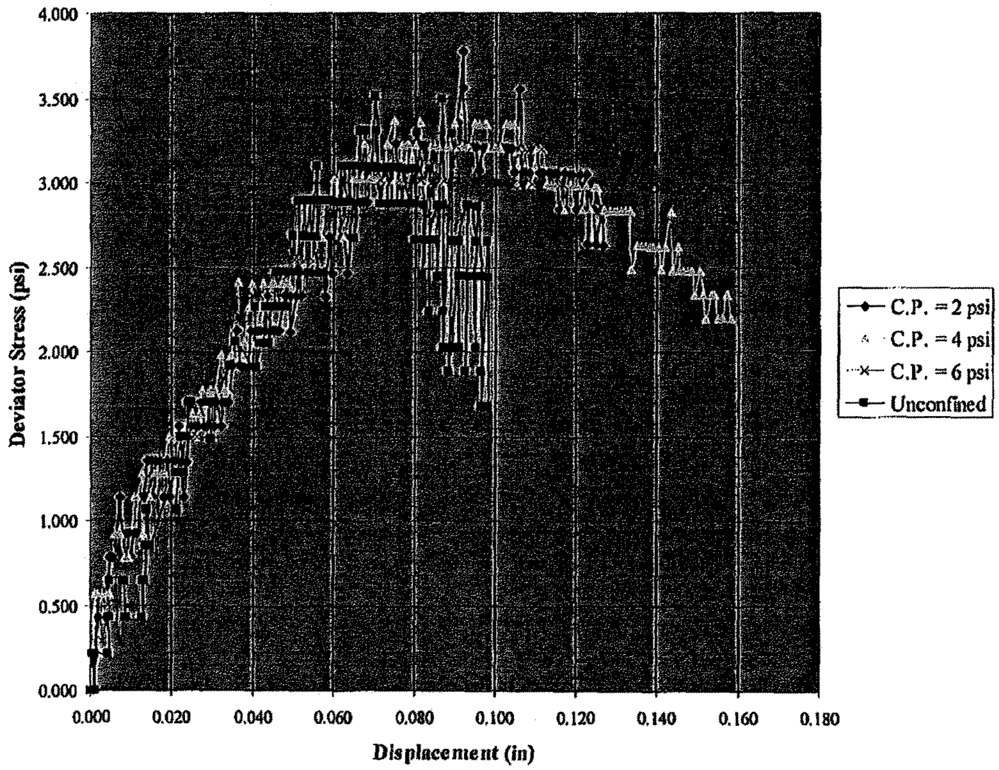

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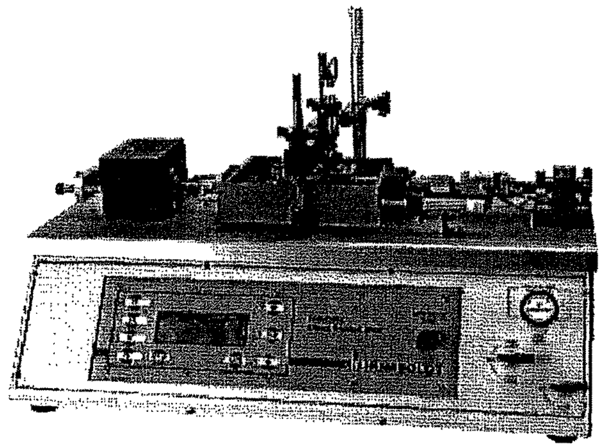
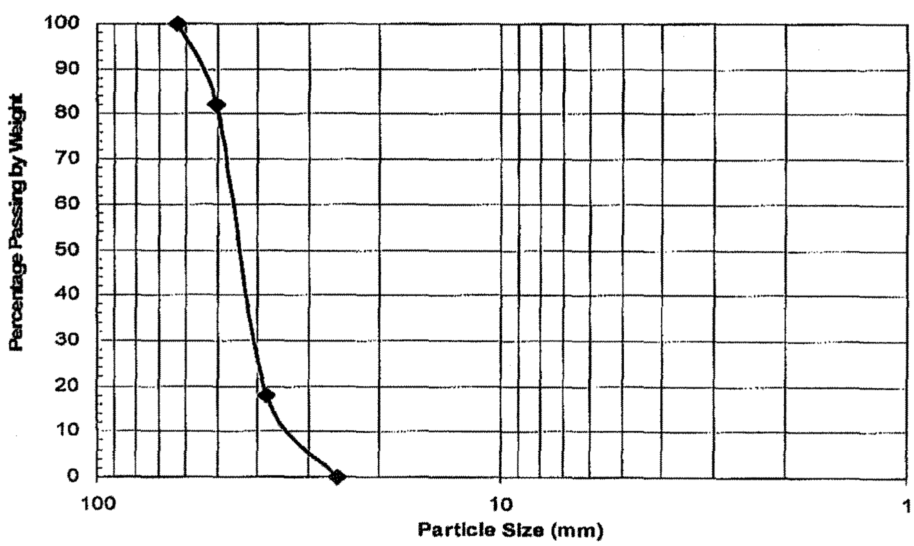


Figure 10. Photograph showing the ShearScan 10 Direct Shear Test equipment



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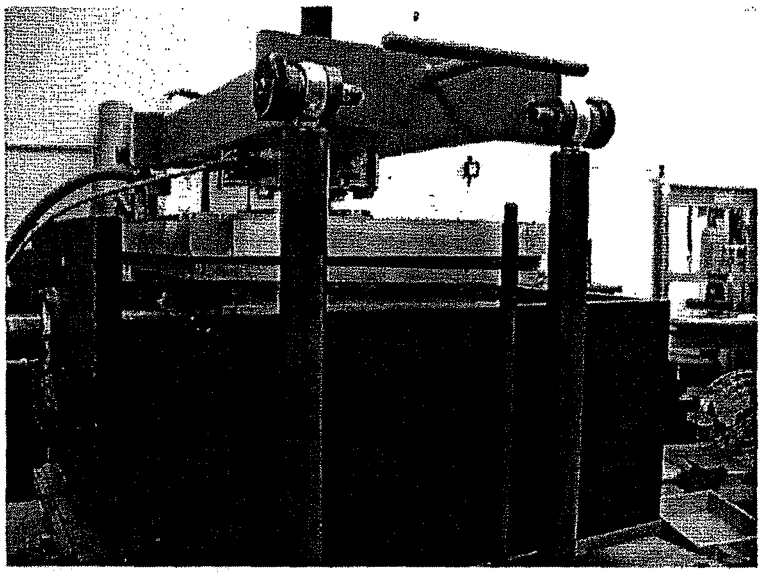

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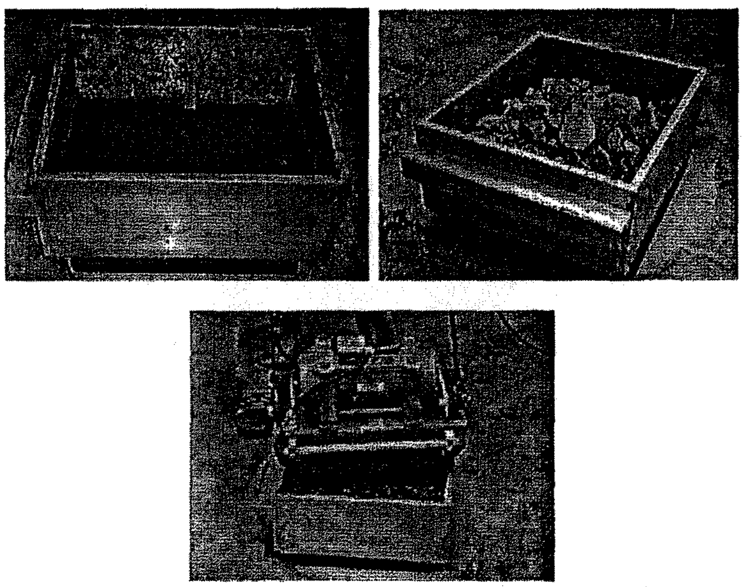

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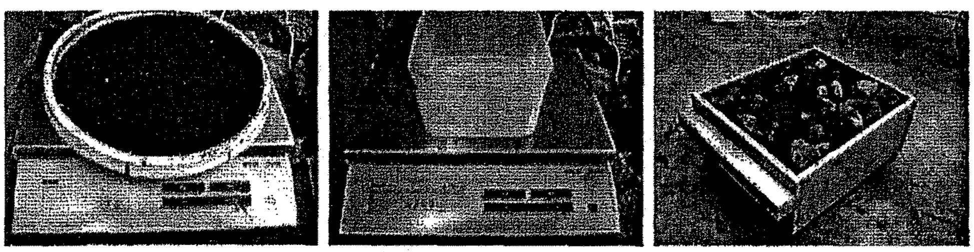

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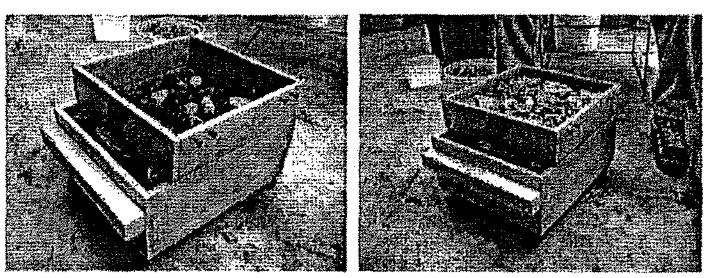

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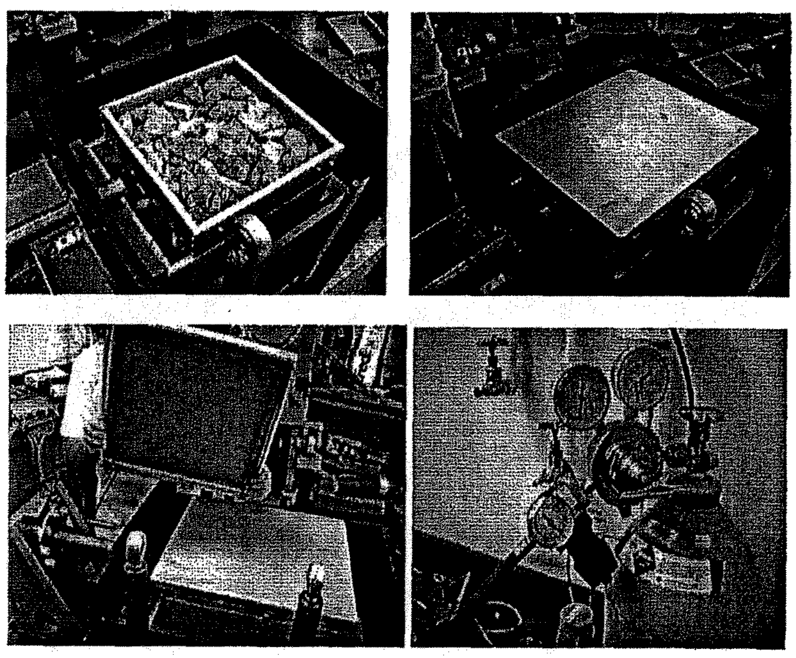

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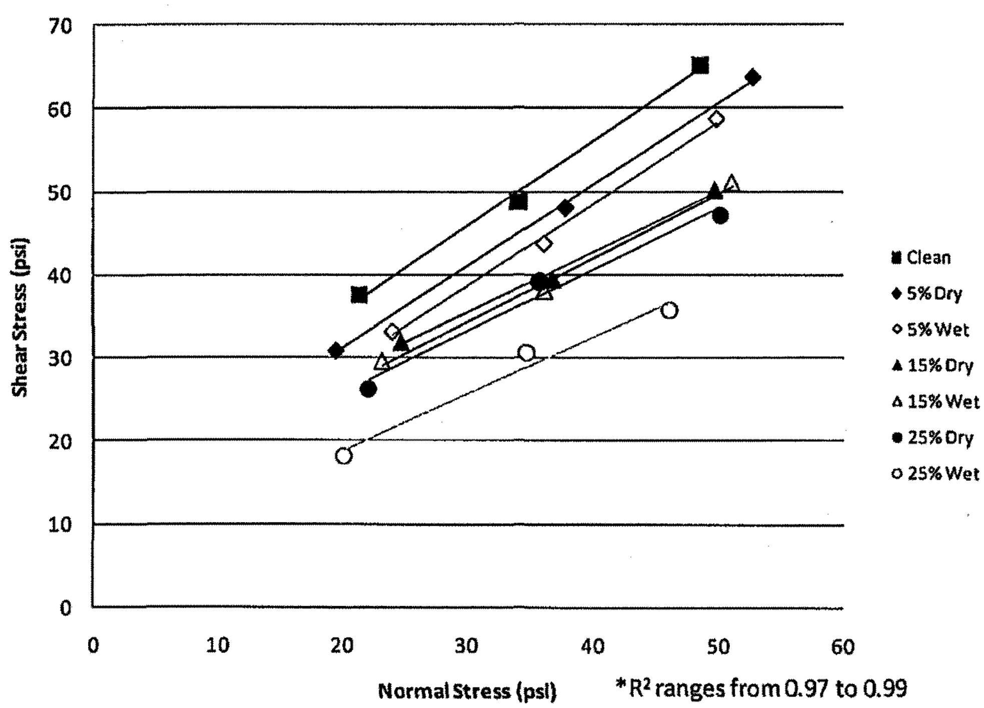

Figure 17. Direct shear box ballast strength test results

EXHIBIT 4

Laboratory Characterization of Fouled Railroad Ballast Behavior

Hai Huang, Erol Tutumluer, and William Dombrow

Fouling refers to the condition of railroad ballast when voids in this unbound aggregate layer are filled with relatively finer materials or fouling agents, which commonly come from breakdown of the ballast aggregate, outside contamination such as coal dust from coal trains, or subgrade soil intrusion. Effects of different fouling agents on ballast aggregate shear strength were studied at the University of Illinois. Through the use of a large direct shear (shear box) device, the strength properties of both clean and fouled ballast samples were determined when three types of fine materials—coal dust, plastic clayey soil, and mineral filler—were added to clean ballast samples at various percentages by weight of ballast under both dry and wet [mostly optimum moisture content (OMC)] conditions. Realistic sample preparation procedures were conducted to closely simulate field-fouling scenarios. Test results showed that when the coal dust fouling percentage increased, the ballast shear strength steadily decreased. Wet fouling was found to exacerbate this trend. Results of ballast samples fouled with clay and mineral filler also showed decreasing trends in strength properties; however, coal dust was by far the worst fouling agent for its impact on track substructure and roadbed. Approximately 15% coal dust fouling by weight of ballast was statistically significant to cause considerable strength reductions. In the case of ballast fully fouled with wet coal dust at 35% OMC, the friction angles obtained were as low as the friction angle of coal dust itself.

Railroad ballast is uniformly graded coarse aggregate placed between and immediately underneath the crossties. The purpose of ballast is to provide drainage and structural support for the loading applied by trains. As ballast ages, it is progressively fouled with materials finer than aggregate particles, filling the void spaces. Methods specifically used to assess track ballast condition deal only with checking visually for evidence of fouling, pumping, and water accumulation (ponding) at ditches and shoulders. Additionally, ballast sampling and testing for fouling through laboratory sieve analyses generally provide some insight into the compositions of the larger aggregate particles and the amount of fines. Nonetheless, for a better evaluation of the serviceability and proper functioning of the existing ballast layer, ballast strength needs to be characterized for different percentages of fine materials, such as plastic soil fines, mineral filler, and more recently coal dust coming from coal trains, which can fill the voids and cause ballast fouling.

Since rail transport, particularly a unit train, provides the most efficient means of transporting bulk commodities such as coal, the role of rail lines in coal transport has always been predominant. In 2005, two derailments occurred in the joint coal line of Burlington Northern Santa Fe (BNSF) and Union Pacific in Powder River Basin (PRB) in Wyoming, the largest source of incremental low-sulfur coal supplies in the United States. The derailments threatened to interrupt the supply of coal to power plants. Both derailments were suspected to be attributed to coal dust fouling, in which coal dust spilled over the ballasts and accumulated moisture, resulting in the loss of strength of the track. The ballast was heavily fouled by coal dust where both of the derailments occurred.

This paper presents findings from a comprehensive laboratory testing program initiated at the University of Illinois to study the effects of different fouling agents—coal dust, plastic clayey soil, and mineral filler—on railroad ballast strength. Using large direct shear (shear box) tests, strength and deformation characteristics of granite type ballast material were investigated for clean ballast and ballast fouled by different agents at various stages under both dry and wet conditions. The shear strength properties, such as cohesion intercept and friction angle, are linked to field ballast fouling levels to better assess the impact of fouling on track instability and ultimately loss of track support, leading to derailments.

BALLAST FOULING AND ITS MECHANISM

Fouling materials in ballast have been traditionally considered not favorable for railroad ballast performance. Early research studies reported that around 70% of the fouling materials were from ballast breakdown (*1–3*). Railroad company internal studies also noted that almost all fouling fines in the railroad track were commonly from aggregate breakdown (*4*). According to Selig and Waters (*5*), ballast breakdown on average accounts for up to 76% of the ballast fouling, followed by 13% infiltration from subballast, 7% infiltration from ballast surface, 3% subgrade intrusion, and 1% due to tie wear.

Selig and Waters (*5*) proposed two indices to describe ballast fouling: (*a*) fouling index is the sum of the percent by weight of ballast sample passing the 4.75 mm (No. 4) sieve plus the percent passing the 0.075 mm (No. 200 sieve) and (*b*) percentage of fouling is the ratio of the dry weight of material passing the 9.5 mm (⅜ in.) sieve to the dry weight of total sample. They also proposed that the particles retained on the 0.075 mm (No. 200 sieve) are treated as "coarse fouling materials" and particles passing the 0.075 mm (No. 200 sieve) are "fine fouling materials" (*5*).

Raymond (*6*) suggested that if fouled ballast had to be used, the liquid limit (LL) of the fines should be less than 25 to maintain the function of drainage. Raymond (*7*) also found that the aggregate breakdown was significantly influenced by the type and especially hardness of the mineral aggregate. Harder aggregates had fewer breakdowns than softer aggregates did. Later, Raymond (*8*) noted

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that the wear of tie was more significant at the worst fouled track locations, possibly due to the abrasive effects of the slurry formed by fouling fines and water.

Chiang (*9*) conducted a series of ballast box repeated loading tests on fouled ballast. Test results indicated that ballast settlement typically increased as the amount of fouling material in ballast increased. Similarly, Han and Selig (*10*) conducted ballast box tests to evaluate the impact of fouling on ballast settlement. They concluded that the degree of ballast fouling indeed had a major impact on the ballast settlement. With an increase in the percentage fouling, both the initial and final ballast settlements increased significantly. Investigations on the strength of fouled ballast and studies on the fouling mechanism, however, have been somewhat limited.

In terms of the stability and load carrying ability of the fouled ballast layer, three volumetric phases can be identified for the different conditions of fine materials filling the void space (Figure 1). Phase I shows a clean or very slightly fouled ballast sample with almost all aggregates establishing contact with each other at the aggregate surface to sufficiently carry the load (Figure 1*a*). As shown in Figure 1*b*, Phase II will have the voids in between aggregates filled with enough fine particles to significantly reduce the strength; however, aggregate-to-aggregate contact is maintained. In a Phase III fouled ballast condition, because of the excessive amount of fine particles, aggregate-to-aggregate contacts are mostly eliminated, and the aggregate particle movements are then constrained only by the fine particles filling the matrix or voids between the particles (Figure 1*c*).

Because ballast in Phase III is no doubt unacceptable and needs immediate remedial action, ballast in Phases I and II is particularly worth studying from the aspect of how different fouling agents at different phases would affect ballast strength and therefore track stability. It is also of great importance to know the dividing line between Phase I and II because it is also the suggested starting point of maintenance activities, such as ballast cleaning. Hypothetically, if ballast aggregate particles are assumed to be spheres, it is possible to define the maximum size of the fouling materials through three-dimensional packing order computations for large and small spheres. Accordingly, Equation 1 defines the radius r of a single fouling particle approximated as a sphere to fit in between three large contacting spherical particles, each having a radius R, without separating them.

$$r = \left(\sqrt{\frac{32}{27}} - 1\right)R \quad (1)$$

Considering that the maximum size of ballast aggregates is often limited to $2R = 76$ mm (3 in.), the largest diameter of a single fouling particle can then be 6.7 mm (0.26 in.), which is smaller than the 9.5 mm (⅜ in.) suggested by Selig and Waters (*5*).

CLEAN AND FOULED BALLAST STRENGTH BEHAVIOR

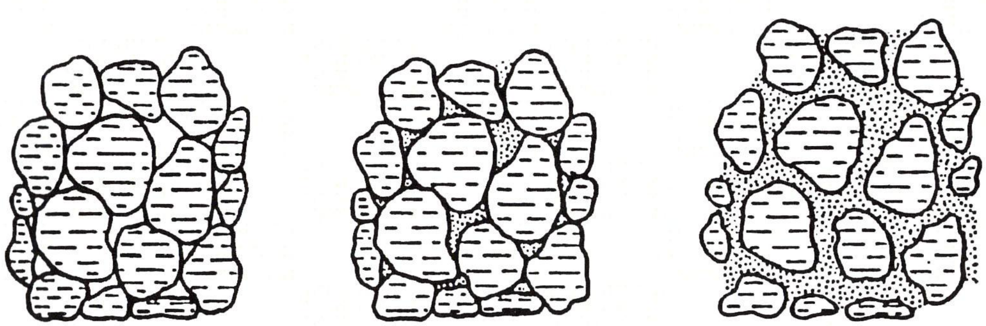
Materials Tested

The ballast material tested was a granite aggregate obtained from Gillette, Wyoming, and commonly used in the PRB joint line railroad track structures as the ballast layer. Figure 2 shows the grain size distribution of the granite sample with a specific gravity of 2.62 tested in compliance with ASTM C117 test procedure. The granite aggregate size distribution conforms to the typical American Railway Engineering and Maintenance-of-Way Association (AREMA) No. 24 ballast gradation having a maximum size (D_{max}) of 63.5 mm (2.5 in.), a minimum size (D_{min}) of 25.4 mm (1 in.), and an average particle size corresponding to 50% passing by weight (D_{50}) of approximately 45 mm (1.77 in.).

From the average size of the clean ballast (45 mm), an average particle fouling size of 4 mm was chosen in this study based on Equation 1. Accordingly, the three types of fouling materials studied with this granite type ballast aggregate were coal dust, refractory clay representing a cohesive fine-grained subgrade soil, and mineral filler obtained from the crushing operations of the same granite aggregate. Figure 2 shows the typical gradations and Table 1 lists the engineering properties of these fouling materials with the moisture density information obtained from the standard Proctor ASTM D 698 test procedure. The coal dust sample tested in this study was also collected from the PRB Orin Line, Milepost 62.4, and was sampled March 10, 2007.

Testing Apparatus

Direct shear strength tests were performed on the reconstituted clean and fouled granite aggregate samples. Figure 3 shows the large shear box equipment used for testing at the University of Illinois. The test device is a square box with side dimensions of 305 mm (12 in.) and a specimen height of 203 mm (8 in.). It has a total 102-mm (4-in.) travel of the bottom 152-mm (6-in.) high component, which is large enough for ballast testing purposes to record peak shear stresses. The vertical (normal direction) and horizontal load cells are capable of



(a) (b) (c)

FIGURE 1 Critical ballast fouling phases: (*a*) clean ballast (Phase I), (*b*) partially fouled ballast (Phase II), and (*c*) heavily fouled ballast (Phase III).

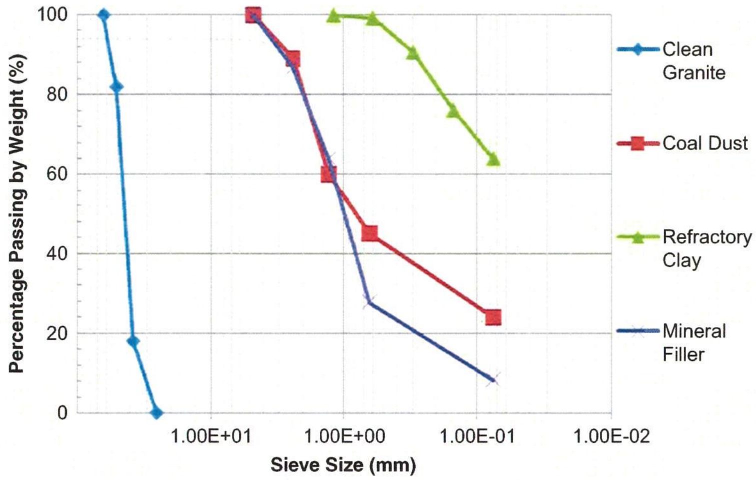


FIGURE 2 Grain size distributions of the clean ballast and fouling materials.

applying and recording up to 50-kN load magnitudes. The device controls and the data collection are managed through an automated data acquisition system controlled by the operator through a built-in display, and the test data are saved on a personal computer.

Sample Preparation

Clean ballast samples were prepared in the lower shear box to the condition similar to the field according to the following steps:

1. Place aggregates in the lower box by lifts (usually two 76-mm lifts).
2. For each lift, use vibratory compactor on top of a flat Plexiglas compaction platform and compact until no noticeable movement of particles is observed (Figure 4).
3. Record the weight of aggregate used.
4. Place upper ring (76 mm high) on top of lower box. Align ring with sides and back edge of box (opposite of block); fill with single lift of ballast and compact (Figure 4).

Granite ballast samples fouled by coal dust were prepared in a manner similar to the clean sample procedure by spreading coal dust on the ballast surface and spraying water, if needed. The individual steps are as follows:

1. Obtain clean aggregates of the same weight as previously recorded.
2. Compact ballast sample into the lower box in two lifts.
3. Obtain prescribed weight of coal dust and water (Figure 5).
4. Spread coal dust over compacted ballast evenly in two lifts (half of material each lift). Shake down material using vibratory compactor after each lift. If test is conducted with wet fouling material [for example, at the optimum moisture content (OMC)], pour proportional amount of water over ballast after shakedown of each lift (Figure 5). Note that this preparation procedure realistically simulated the actual coal dust accumulation in the ballast layer as a result of vibration caused by train loading.
5. Follow Step 4 from the clean sample preparation procedure.

Granite samples fouled with clay were prepared following a different procedure to simulate subgrade intrusion. The individual steps are as follows:

1. Obtain clean aggregates of the same weight as previously recorded.
2. Obtain described weight of clay and water.
3. Place the clay in the bottom of the lower box. If test is conducted with wet clay, thoroughly mix clay with water before placing in the lower box.
4. Place aggregates over the clay and compact in two lifts.
5. Follow Step 4 from the clean sample preparation procedure.

For preparing granite samples fouled with mineral filler, the clean ballast and the mineral filler with designated weights were premixed before placement in the lower box. The goal was to simulate the actual ballast breakdown conditions in the field. Aggregate breakdown could take place with chipped pieces and mineral filler uniformly filling the voids in the ballast layer.

TABLE 1 Engineering Properties of the Selected Fouling Materials

	Specific Gravity	LL (%)	Plastic Limit (%)	OMC[a,b] (%)	Maximum Dry Density[b] (kg/m³)	Passing 0.075-mm or No. 200 Sieve (%)
Coal dust	1.28	91	50	35	874	24
Refractory clay	2.60	37	19	16	1,806	64
Mineral filler	2.62	NP[c]	NP[c]	11	2,193	8

[a]OMC = optimum moisture content.
[b]Obtained from standard Proctor ASTM D698 test procedure.
[c]NP = nonplastic.

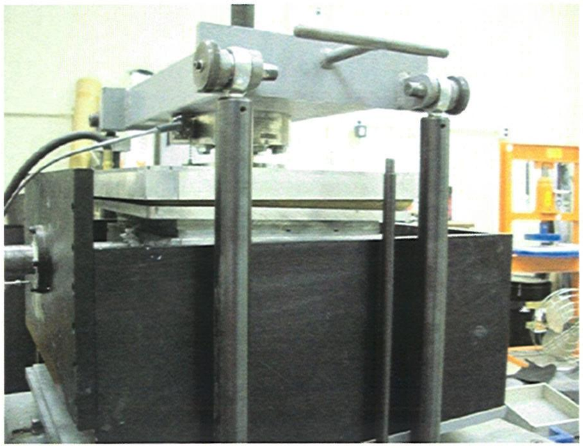


FIGURE 3 Direct shear strength test equipment at the University of Illinois.

Before testing, the box and ring assembly were placed in the shearing apparatus. The lower box was clamped in place, and the load-bearing plate was placed on the ballast but inside the upper ring. The air bladder was placed on the load-bearing plate, the air supply was opened, and normal pressure was set using an in-line pressure regulator (Figure 6). The load cell recording the applied shear force was adjusted directly against the upper ring. The Labview data logger software was initiated to record normal and shear forces during testing. The loading speed was set to an input shear rate of 12.2 mm/min (0.48 in./min), which is approximately 4% strain per minute, and the tests were run until the shear force output peaked or 15% strain occurred.

Sample Volumetrics

After the sample preparation, volumetric properties of the shear box sample were calculated on the basis of the granite aggregate properties. It is worth noting that, for all tests, the same amount of

FIGURE 4 Stages of ballast compaction and upper ring loading.

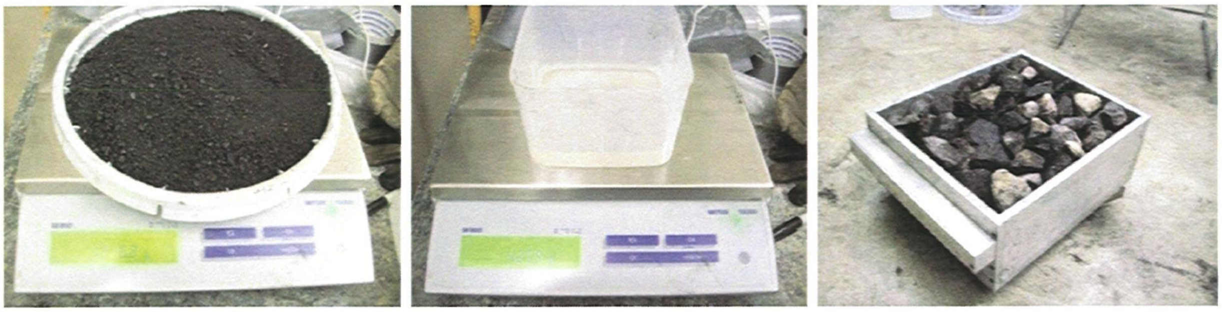


FIGURE 5 Coal dust being mixed as the fouling material.

material was used to prepare approximately the same number of aggregate contacts and a similar aggregate skeleton. That is, the voids available for fouling material to fill in were kept the same in all cases. This void space was found for the clean granite sample to be 43% of the total volume, which corresponds to a void ratio of 0.75 or 75% of the aggregate volume. ASTM C29 test procedure was used for finding porosity or air voids with the known values of the specific gravity and box volume and the weight of ballast compacted.

For the aggregate fouled with coal dust, 25% coal dust by weight of aggregate was found to completely fill in the voids of the clean granite, thus referred to here as "fully coal dust fouled" condition after sample preparation. Similarly, 32% clay by weight of aggregate and 40% mineral filler by weight of aggregate were observed to completely fill in the same void space of the clean granite for the fully fouled conditions for clay and mineral filler, respectively.

Direct Shear Test Results

The ballast samples were sheared horizontally in the shear box under target normal pressures of 172, 241, and 310 kPa (25, 35, and 45 psi), typical ballast layer confining pressures, so that the relationships between normal stress and shear stress could be established. The maximum shear stress at failure under each applied normal pressure

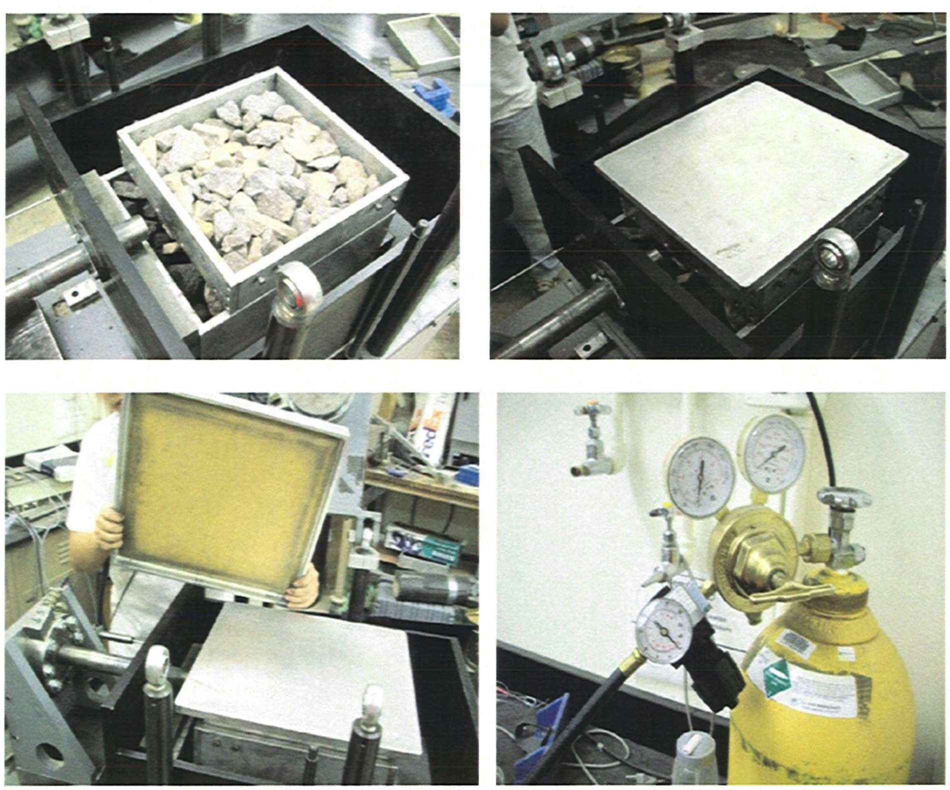


FIGURE 6 Setup of the direct shear box apparatus.

was recorded from each test. This maximum shear stress typically occurred when approximately 10% shear strain was reached during testing. The shear strength expression $\tau_{max} = C + \sigma_n * \tan\Phi$ (where C is the cohesion intercept, σ_n is the applied normal stress, and Φ is the internal friction angle) was then developed for each ballast sample tested at a corresponding fouling fines content and moisture state.

Figure 7 shows the maximum shear stresses predicted under the applied normal stresses during shear box testing for coal dust fouling in comparison with the clean granite test results. As the applied normal stresses increased, the maximum shear stresses at failure or simply shear strength τ_{max} also increased, primarily influenced by the ballast fouling percentage and the moisture condition of the coal dust (i.e., dry or wet at OMC = 35%). As expected, the highest shear strength values were obtained from the clean ballast at all applied normal stress levels. When ballast samples were fouled, the shear strengths typically decreased. For all the samples tested, fouling with wet coal dust resulted in lower shear strengths when compared with those obtained from fouling with dry coal dust. The lowest shear strength values were recorded for the fouling level of 25% by weight (fully fouled) of ballast when wet coal dust was at 35% moisture content.

Figure 8 shows the maximum shear stresses predicted under the applied normal stresses during shear box testing for clay fouling in comparison with the clean granite test results. Limited data were obtained because of the difficulties encountered during sample preparation, especially for wet clay fouling. According to the test results, the clean ballast sample still gave the highest strength. With clay being the fouling agent, the trend of decreasing strength with increasing fouling percentage could not be observed as clearly as in the case of coal dust fouling. In the clay fouling cases, the cohesion intercept (C) in the strength equation increased and the friction angle (Φ) typically decreased with the increasing fouling percentage, which made shear strength of samples less sensitive to varying normal stresses and confining pressures, as expected. This effect was even more significant in the cases fouled with wet clay, because wet clay served as a lubricant, with much lower friction angles (Φ) overall compared with the clean granite sample. It still makes sense, however, since the cohesion increased because the clay paste in the voids supplied some bonding strength, whereas the friction angle decreased because of the lubricating effect of clay paste within the aggregate-to-aggregate contact.

Figure 9 shows the maximum shear stresses predicted under the applied normal stresses during shear box testing for mineral filler fouling in comparison with the clean granite test results. In the dry case, results were similar to results from clay fouling. Once again, the clean ballast sample gave the highest shear strength. In the dry fouling cases, the cohesion intercept (C) in the strength equation increased and the friction angle (Φ) typically decreased with the increasing fouling percentage, similar to the general trend observed for samples fouled with clay. However, for the wet mineral filler tests at only 11% OMC, samples at all fouling levels behaved very closely to dry conditions, with the data points almost falling in the same line, thus indicating that mineral filler as a fouling agent is not as sensitive to moisture as the cohesive clay.

Figure 10 compares, under wet conditions, the maximum shear stresses obtained from the clean granite with those of the coal dust, clay, and mineral filler fouled samples at 5%, 15%, and 25% by weight of ballast. Note that for the 25% clay fouled samples, clay moisture content was at the LL of 37% instead of OMC, which is very close to 35% OMC of the samples fouled by coal dust. Yet, the wet coal dust sample fouled at 25% gave the worst-case scenario with the lowest shear stress values among all the samples tested. Then came the wet mineral filler fouled at 25% by weight of ballast and the wet clay fouled at 15% by weight of ballast, as indicated with the dashed lines in Figure 10. This implies that railroad ballast layers fouled with coal dust are at much higher risk of causing track instability and failures, especially after heavy precipitation, when compared with ballasts fouled because of mineral filler accumulation from aggregate breakdown or even cohesive subgrade soil intrusion.

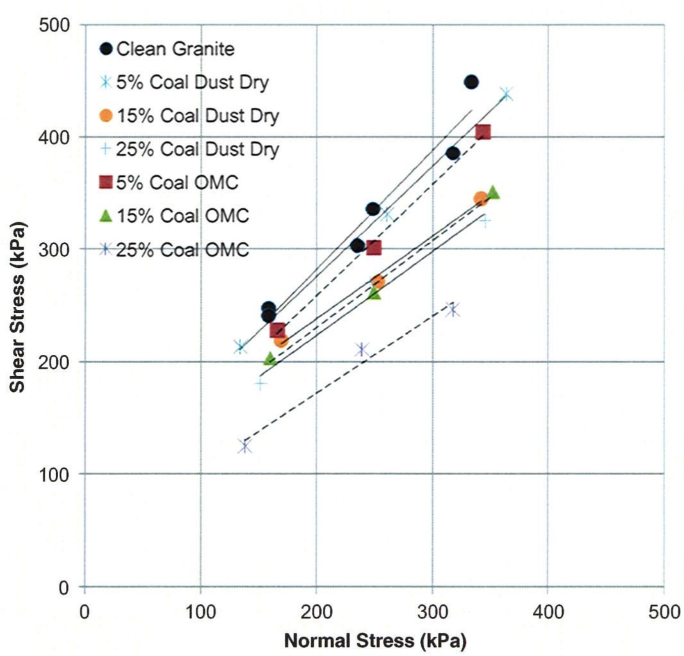


FIGURE 7 Direct shear box test results of ballast samples fouled with coal dust.

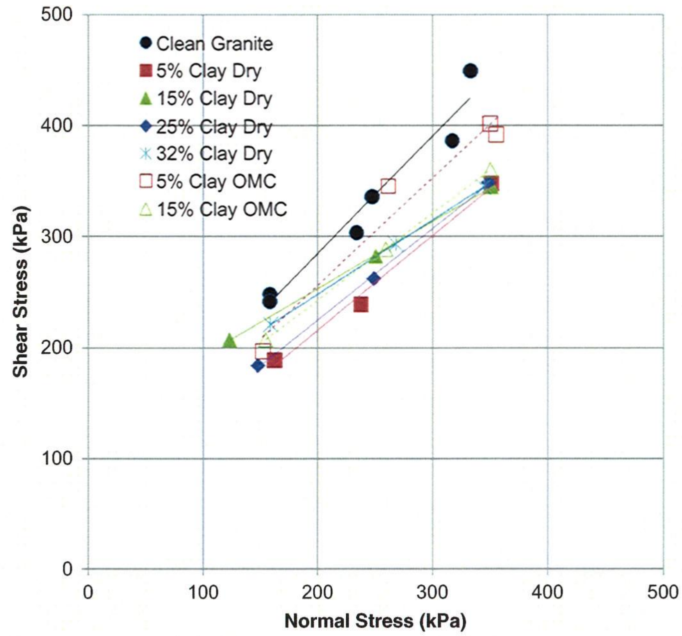


FIGURE 8 Direct shear box test results of ballast samples fouled with clay.

Because the coal dust fouling was found to be the most detrimental case, a statistical analysis was performed for the significance of the different coal dust levels affecting the critical stages of ballast fouling. As described early in this paper, it is important to determine at what fouling level a significant drop in strength would be realized. That is, there is a need to determine the reasonable dividing line between Phase I and II. For this purpose, an F-test statistical approach was used to evaluate the differences between the strength lines graphed in Figure 7. With a value of significance (p-value) of 0.0014 (much less than 0.05), 15% coal dust fouling was found to significantly decrease the strength of ballast. Because all other strength lines in Figure 7 are below the 15% dry coal dust fouling line, 15% coal dust by weight is considered to be the critical stage of coal dust fouling in terms of ballast shear strength.

Table 2 lists cohesion intercepts (C) and friction angles (Φ) obtained from the ballast testing program. High correlation coefficients, R^2

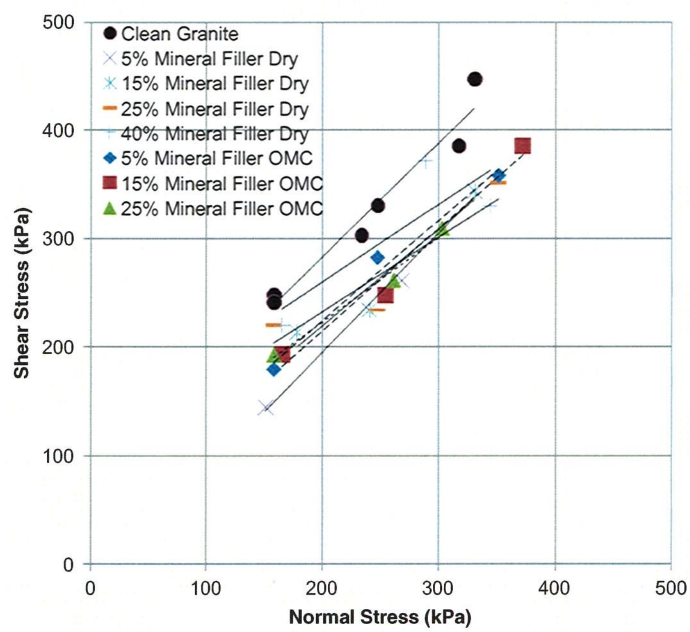


FIGURE 9 Direct shear box test results of ballast samples fouled with mineral filler.

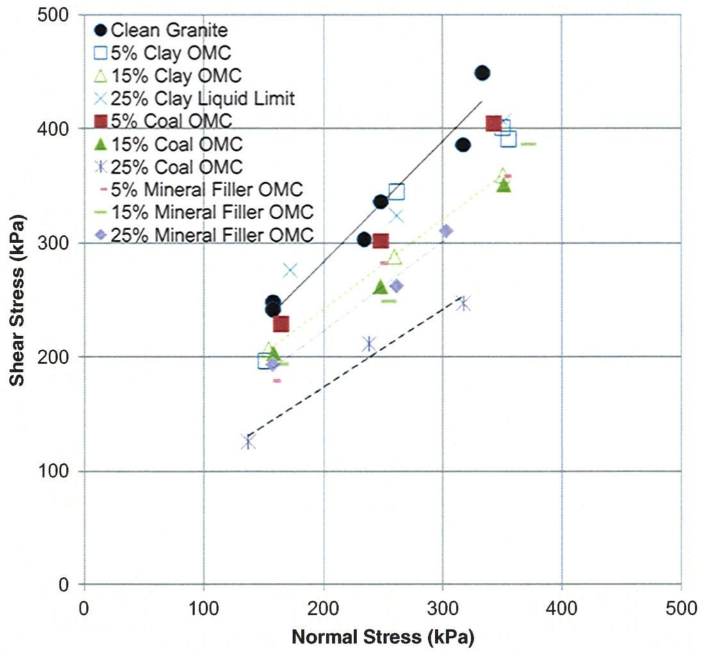


FIGURE 10 Comparisons of three fouling scenarios under wet conditions.

values, were typically obtained for the established shear strength equations except for two mineral filler samples. The clean granite typically had the highest friction angle (Φ) of 46.6°, except for the friction angle of 47.7° obtained for the low 5% dry mineral filler sample. For the case of 25% wet coal dust fouling, the friction angle computed is as low as 34.5°. This value is very close to the friction angle of 33.5°, obtained from a parallel research study (*11*), for the pure coal dust direct shear samples tested at OMC. Similarly, a low cohesion intercept of 35 kPa (5.1 psi) is close to the very low unconfined compressive strength of 24 kPa (3.5 psi) also obtained for the coal dust shear strength properties (*11*). This implies that the shearing action for the 25% coal dust fouled sample was mainly resisted in the direct shear apparatus by the wet coal dust governing the behavior. Again, one should note that 35% OMC condition does not

TABLE 2 Shear Box Direct Shear Strength Test Results

			$\tau_{max} = C + \sigma_n * \tan \Phi$			Shear Strength τ_{max} (kPa)	
Fouling Agent	Percentage by Weight of Clean Ballast	Moisture Condition (see Table 1)	Cohesion *C* (kPa)	Friction Angle (Φ)	Correlation Coefficient, R^2	200-kPa Normal Stress	300-kPa Normal Stress
Clean	0	Dry	72	46.6	.96	283	389
Coal dust	5	Dry	80	44.4	.99	276	374
	15	Dry	93	36.2	.99	239	312
	25	Dry	75	36.6	.98	224	298
	5	OMC	61	44.7	.99	259	359
	15	OMC	77	37.7	.99	231	309
	25	OMC	35	34.5	.97	173	242
Clay	5	Dry	44	40.5	.99	215	300
	15	Dry	131	31.2	.99	252	313
	25	Dry	59	39.5	.99	224	307
	32	Dry	114	33.7	.97	247	314
	5	OMC	61	44.1	.95	255	352
	15	OMC	85	38.0	.99	241	319
	25	LL	144	36.1	.98	290	363
Mineral filler	5	Dry	0	47.7	.99	195	305
	15	Dry	41	41.6	.93	219	308
	25	Dry	94	34.6	.85	232	301
	40	Dry	116	35.7	.71	260	332
	5	OMC	40	42.6	.98	224	316
	15	OMC	26	43.4	.97	215	309
	25	OMC	66	38.0	.98	222	300

represent a fully saturated coal dust state. After soaking or 100% saturation, soil suction would be destroyed, thus resulting in even lower strengths and unstable ballast conditions.

Table 2 also lists for direct comparison purposes the shear strength values computed under normal stress levels of 200 and 300 kPa (29.0 and 43.5 psi), typical field railroad ballast stress conditions. Most of the trends already mentioned and their effects can be clearly seen by comparing the computed shear strength values. In the case of ballast fouled by mineral filler, strength values from both dry and wet tests were very close, which may suggest that the 11% optimum moisture had a minor effect on mineral filler fouling. However, the clay fouled ballast samples at OMC give higher strength values than the dry clay fouled samples, which implies that clayey soils at OMC have higher shear strength properties. Since most geomaterials compacted at OMC usually give the best mechanical properties, future research will need to also investigate fouled ballast behavior when moisture content increases beyond optimum conditions.

SUMMARY AND CONCLUSIONS

A large direct shear (shear box) device was used to conduct laboratory tests at the University of Illinois on granite ballast samples obtained from the PRB joint line in Wyoming. The tests measured strength and deformation characteristics of both clean (new) and fouled ballast aggregates with three different fouling agents—coal dust also obtained from the PRB joint line, plastic clay, and nonplastic mineral filler obtained by crushing the same granite aggregate—at various stages of fouling. The grain size distribution of the aggregate conformed to the typical AREMA No. 24 ballast gradation with a maximum size (D_{max}) of 63.5 mm (2.5 in.) and a minimum size (D_{min}) of 25.4 mm (1 in.). Each fouling material was mixed with clean aggregates for achieving fouling levels of 5%, 15%, 25%, and sometimes up to 40% by weight of ballast under dry and wet, mostly OMC, conditions. The coal dust material was spread on the clean aggregate specimen and vibrated on top to achieve its percolation into the voids in an effort to realistically simulate coal dust falling off trains into the ballast layer in the field. The plastic refractory clay and the mineral filler were mixed with granite aggregates by means of different sample preparation techniques, again to simulate realistic field-fouling scenarios of subgrade intrusion and aggregate breakdown, respectively.

From the direct shear tests, the highest shear strength values were obtained from the clean ballast samples at all applied normal stress levels, which were representative of typical stress states experienced in the ballast layer under train loading. When ballast samples were fouled, the shear strengths always decreased. This result was mostly apparent with lower friction angles and cohesion intercepts. Wet fouling generally resulted in lower ballast shear strengths when compared with those obtained from fouling with dry coal dust. Primarily because of increasing cohesive nature (i.e., cohesion intercepts) with increasing fouling percentages, plastic refractory clay fouled samples exhibited slight increases in shear strength under both dry and wet conditions. However, samples fouled with mineral filler at 5%, 15%, and 25% were somewhat insensitive to the low 11% moisture content increase from the dry condition and resulted in similar shear strength values.

Coal dust was by far the worst fouling agent for its impact on track substructure and roadbed, and it caused the most drastic decreases in shear strength, especially at high fouling levels. Through statistical evaluation, 15% dry coal dust fouling by weight of ballast was shown to be sufficiently significant to cause critical fouling and decrease considerably the ballast strength. For the case of 25% wet coal dust fouling by weight of ballast, the lowest shear strength properties, internal friction angle and cohesion, obtained were equivalent to those properties of the coal dust itself at 35% OMC. Note that even more drastic strength reductions can occur when dry coal dust, which has never been saturated or soaked in the field and therefore has a high suction potential, is subjected to inundation and 100% saturation.

It is still difficult to make unique conclusions on ballast fouling because of the differences between laboratory and field conditions and difficulties in sample preparation process. This study is a first step of trying to better understand fouling and its effect on ballast strength and stability. Further studies and different methods of investigation are needed to fully understand ballast fouling.

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