FY2007 RESEARCH PROJECT PROPOSAL

Center for Transportation Studies, University of Minnesota

Research Project Title: Use of Fly Ash for Reconstruction of Bituminous Roads

Proposal Type: (check ONLY one)

This proposal addresses:

- ☒ **Problem Statement: PS #** 004
- ☐ **Knowledge-Building Priority: KB #** _____
- ☐ **Other Research Need**

1. Investigator Information

Principal Investigator Information:
Name: Paul R. Bloom
Department: Soil, Water, and Climate
University of Minnesota
Position Title: Professor
Address: 1991 Upper Buford Circle, Rm. 439
St Paul, MN 55108
Phone: (612) 625-4711
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E-Mail: prb@umn.edu

Co-Investigator/Subcontractor Information:
Name: Craig H. Benson & Tuncer B. Edil
Department: Civil & Environmental Engineering
University of Wisconsin-Madison
Position Title: Professor
Address: 1415 Engineering Drive, Madison, WI 53706
Phone: (608) 262-7242, 3225
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2. Key Personnel

None besides those listed in 2.

3. Proposal Abstract

The gravel equivalency, life expectancy, and potential environmental impacts of fly ash stabilized recycled pavement materials will be assessed through large-scale laboratory experiments, small-scale laboratory tests typically used for design and analysis, and continued monitoring of two existing instrumented roads where fly ash stabilization has been conducted and extensively documented. Metals leaching from the stabilized materials will also be evaluated using laboratory column tests and by continuous monitoring of lysimeters at the two road sites. Data obtained from the laboratory tests and the lysimeters will be compared with predictions from the models STUWMPP and WiscLEACH, which were specifically designed to assess potential groundwater impacts from projects where industrial byproducts are used in construction. Results of the study will have a direct impact on the ability to design and evaluate bituminous roads and streets in Minnesota where fly ash is used for in situ base stabilization.

4. Anticipated Duration of Project (in months): 24 months

5. Total Budget (direct costs only): $170,055

6. Budget Details (direct costs only): see below

University of Minnesota Component:

Salaries:

Faculty: $7500 (Bloom)
Graduate Students:
Other $8000 Students , U of M (Civil Service, Scientist, etc.):

Equipment: None
Supplies: Lab analysis $6000
Travel: $600
Subconsultants: see University of Wisconsin budget, below.
Other: None

University of Wisconsin Component:

Faculty: $54,000 (one month each for Benson and Edil per year)
Graduate Students: $37,000 (one 50% graduate student for 24 mos)
Fringe benefits: $25,100

Equipment: None
Supplies: $4000-FWD and distress surveys ($2000/yr)
$3000-Laboratory supplies ($1500/yr)
Travel: $3000 (semi-annual trips to project meetings, visits to field sites)
Other: $9245 (graduate student tuition)
$12,610 (indirect costs : 10% of all)

7. Budget Justification

This is a broad-based project with both geotechnical/pavement and geoenvironmental engineering components that will be conducted collaboratively by research groups at two universities. The breadth of scope requires that the budget be slightly in excess of the typical range of funds (~$83,000 per year). The budget contains salaries for the PIs and a graduate student. The UM PI has been allocated one-half month of salary per year and the UW PIs each have been allocated one month of salary per year, which is commensurate with the time required of each PI to complete the project (any additional effort that is required will be matched by the PIs). The UW graduate student stipend is a 50% research assistantship, which is commensurate with the time that will be required to conduct the laboratory testing and computer analyses. The other amounts budgeted for students are based on the level of effort required to complete the project. All salaries and associated fringe benefits are based on standard UM and UW rates. The budget also includes a small amount that to purchase miscellaneous laboratory and field supplies required for the project (sensors, reagents, chemical analysis, filter paper, tubing, etc.). Travel expenses are based on estimated trips to field sites and meetings in Minnesota from Madison, WI. The budget includes estimated charge-back costs for FWD and distress surveys. Tuition remission is also included per UW requirements as is 10% indirect cost for UW as a subcontractor to UM.

8. Matching Funds

Test sections have already been constructed and instrumented in the roadways that will be used in the study. These roadways will be made available for use in this study at no cost. They constitute significant in-kind support for the study that is being provided by the road owners (City of Waseca and Chisago County).

9. Research Objective

The first objective of the proposed study is to determine the gravel equivalency and life expectancy of fly ash stabilized recycled pavement materials used for reconstructing bituminous roads and streets in Minnesota. The second objective is to conduct an environmental assessment of the use of fly ash stabilization in these applications using laboratory data, field data, and computer models. Both of these contribute to a broader objective of increasing the acceptability and use of fly ash stabilization techniques during roadway construction in a manner this is consistent with Minnesota rule revisions regarding beneficial use of solid wastes.

10. Summary of Previous Work

The research team has taken a leading role in developing the technology for fly ash stabilization of pavement materials for roadway construction and rehabilitation. This work has included the geotechnical/pavement engineering aspects associated with fly ash stabilization and an evaluation of the potential environmental impacts associated with fly ash usage. The proposed study integrates well with the previous work by the investigators, and will be leveraged on the expertise and methods developed in previous studies.

The University of Wisconsin component of the research team (Edil, Benson) has been conducting laboratory and field-scale testing of fly ash stabilization in Minnesota and Wisconsin. This work has focused on identifying improvements in strength and stiffness that can be achieved by incorporating fly

ash into pavement materials, as well as assessing potential groundwater impacts. Six roads have been constructed with this technology and are being studied by the UW research team. Two of these roads are in Minnesota (City of Waseca and Chisago County). All six have been extensively characterized and are instrumented for long-term monitoring, with funding for the Minnesota sites being provided by the LRRB. A leaching model has also been developed (WiscLEACH) for groundwater impact assessments.

The University of Minnesota component of the research team completed an LRRB funded project in 2004 (Bloom et al., 2004) to develop a computer mixing model that uses the total composition in fly ash–soil mixtures and compares total concentrations to Minnesota Pollution Control Agency (MPCA) guidance for residential cleanup using Soil Reference Values (SRV) and Soil Leaching Values (SLV) worksheets. The SRV values provide guidance for protection of human health assuming some stabilized subsoil could, in the distant future, be used in a residential area. The SLV guidance, which is based on leaching of ions and compounds (predicted by the SESOIL transport model), is designed for the protection of groundwater. Earlier Bloom and Gollany (2001) conducted a field investigation of runoff from fly ash stabilized soils and found that the runoff is not high in problematic elements.

11. Literature Search

Turner (1997) conducted a laboratory study to evaluate the effectiveness of using coal fly ashes from Wyoming for stabilization of low-plasticity subgrade soils. Resilient modulus of the fly-ash treated soils ranged between 834 to 6237 MPa, whereas the resilient modulus of the untreated soils was so low as to be unmeasurable with conventional methods. Edil et al. (2002) conducted a field evaluation of Class C fly ash subgrade stabilization. Laboratory and field data showed major strength and stiffness gains due to fly ash treatment and excellent seasonal behavior. An extensive laboratory investigation program was also conducted to evaluate the mechanical properties of various Wisconsin fly ashes alone and as mixtures with a range of fine-grained soft subgrade soils from different parts of Wisconsin (Acosta, Edil and Benson, 2002). Addition of 10% fly ash caused the CBR to increase by a factor of 4, on average, whereas 18% fly ash caused the CBR to increase by a factor of 8. A methodology to incorporate fly ash stabilization of subgrade in flexible pavement design was developed by Bin-Shafique, Edil and Benson (2002). The method was developed using data from two field sites where fly ash was used for subgrade stabilization.

The potential for leaching of metals from fly ash stabilized subgrade soils was evaluated by Bin-Shafique, Benson and Edil (2002). Water leach test (WLT) and column tests were conducted on a wide range of fly ashes and soil-fly ash mixtures. Leachate was also collected using field lysimeters from 3 roadways where fly ash was used to stabilize the subgrade. A user-friendly computer model (WiscLEACH) was developed to predict the maximum concentration of contaminants in groundwater adjacent to roadways using fly ash stabilization (Li, Hatipoglu, Benson, and Edil 2006). Analyses with WiscLEACH showed that in most cases where fly ash is placed above the groundwater table, impacts to groundwater are negligible. However, the level of impact depends on the type and amount of metals in the fly ash.

12. Expected Benefits and Users of this Research:

Minnesota government agencies that construct, manage, and rehabilitate roadways will benefit from this study. Successful application of the technology can result in significant savings relative to conventional total reconstruction costs while also providing a beneficial use for an industrial byproduct. Life cycle costs are also expected to be lower, as stronger and longer lasting roads are obtained. The study will also assess the computer models for assessing groundwater impacts, which can play an important role in the acceptability of fly ash stabilization. The technology should be particularly useful to smaller communities and rural counties without large construction budgets. For example, the City of Waseca and Chisago County have found that fly ash stabilization results in significant cost savings and more rapid roadway construction. Moreover, 68,000 miles of gravel roads exist, and pressure to convert these to paved roads increases annually. Fly ash stabilization should prove to a cost-effective means to upgrade these roads prior to placement of an asphalt surface.

13. Summary of Research Methodology

The first objective of the proposed study is to define the gravel equivalency of recycled pavement materials. This objective will be met by conducting large-scale laboratory experiments, small-scale laboratory tests typically used for pavement design, and performance monitoring of the Waseca and Chisago roads constructed in 2004-05. The second objective is to evaluate the potential for groundwater impacts in the context of rules adopted by the Minnesota Control Agency (MPCA) (www.pca.state.mn.us/waste) by conducting laboratory column tests, monitoring of lysimeters at the Waseca and Chisago sites, and conducting simulations with the STUWMPP and WiscLEACH computer models.

14. Tasks

Task 1 – Selection of Test Materials and Specimen Testing

The main focus of this research is to determine the gravel equivalency of fly ash stabilized recycled pavement materials (RPM) and road-surface gravel (RSG). From the City of Waseca 7th Avenue stabilization project, samples of recycled pavement material were collected along the length of the project at 10 stations. These samples were characterized with respect to their physical attributes (grain size distribution, compaction characteristics, water content, density, asphalt content). Similarly, RSG samples from the CR 53 stabilization project in Chisago Co. were collected along the project route at 10 stations and these materials also are characterized. In both cases, the samples are in a reasonably narrow band of grain size distribution. Based on the range of data a representative RPM sample and a representative RSG sample will be selected for testing purposes. Additionally, Class 5 Gravel will be used as a reference material with a gravel equivalency of 1.00.

The representative materials will be characterized further with respect to their mechanical properties such as stiffness and strength. Resilient modulus (an elastic modulus may be found to be appropriate for such stiff stabilized materials) and CBR tests will be performed on the representative samples and their cured mixtures with the specific fly ashes used in the field (Riverside Units 7 and/or 8) at the field fly ash contents and compaction conditions. Testing will be conducted using standard ASTM and AASHTO procedures. Standard procedures for mixing and preparation of test samples have already been developed by the PIs after a thorough review of the literature. These tests will allow determination of the mechanical properties of the test materials both with and without fly ash stabilization. These tests will be conducted at the University of Wisconsin.

In another series of tests, the freeze-thaw effects on resilient modulus and material loss of the stabilized samples will be assessed. The PIs have developed a protocol for this purpose in which specimens are subjected to a minimum of 5 cycles of freeze-thaw and at each cycle their weight, volume, resilient modulus, and post-resilient modulus unconfined strength are measured. The modulus typically decreases with increasing freeze-thaw cycles but usually stabilizes after 5 cycles. These tests will also be conducted at the University of Wisconsin.

Task 2– Large-Scale Model Experiments

Resilient modulus of each of the materials will also be determined based on loads and deflections measured in the large-scale model experiment (LSME). LSME tests incorporate both the effects of stress magnitude and strain amplitude on modulus (Tanyu et al. 2003) and have been used to determine the equivalency of select stabilization materials both as a working platform over soft subgrades as well as in-service performance as a component of a pavement structure in Wisconsin (Tanyu et al. 2004, Tanyu et al. 2005). Furthermore, moduli obtained from the LSME have been shown to be comparable to moduli operative in full-scale subbases (Tanyu et al 2003). Moduli obtained from the LSME are a more direct measure of equivalency *in lieu* of resilient moduli from conventional laboratory resilient modulus tests because laboratory data would not have accounted for the effect of strain amplitude. As a result, moduli obtained from conventional laboratory resilient modulus tests are lower than moduli observed in the field and the LSME (Tanyu et al 2003). The LSME tests will be conducted at the University of Wisconsin.

The profile to be evaluated in the LSME will consist of (from bottom up) a layer of dense uniform sand, a simulated subgrade, and the layer of RPM or RSG test material. Asphalt concrete is not included

in the LSME, but the stress applied to the surface is adjusted to account for the stress distribution expected to occur in the asphalt layer. The representative samples of RPM and RSG will be placed, compacted to field densities, and tested for a minimum 10,000 cycles under the chosen repetitive load and deflection data will be collected. The loading frequency will follow the resilient modulus loading cycle. Collected deflection data will be analyzed in terms of elastic deflections and accumulated plastic deflections. After testing each material, the fly ash will be mixed in at the field percentage (e.g. 10%) and specified water content, compacted, and cured. The same loading regime will be applied after 7 and 28 days of curing. Finally, a layer of Class 5 gravel compacted to typical specifications will be tested. The thicknesses of these layers will be similar to those used in field applications in each case.

The back-calculated moduli of the five layers described above (RPM, RSG, fly ash stabilized RPM, fly ash stabilized RSG, and Class 5 Gravel) from the LSME will be used to determine gravel equivalency. Ratio of modulus of stabilized RPM and RSG to that of Class 5 gravel will form the basis for gravel equivalency. However, the final gravel equivalency assigned may be tempered based on consideration of freeze-thaw resistance and field FWD data, which will be available covering 3 to 4 winter seasons at the two field sites (i.e., 2004-07 in Waseca and 2005-2007 in Chisago Co. Accumulated plastic deflections and freeze-thaw considerations will be used to determine life expectancy.

Task 3 – Continued Mechanical Monitoring of Field Demonstration Sites

Monitoring of the roads that were constructed will continue during this project. These sites have been instrumented to monitor conditions in the subsurface (temperature, frost depth, and water content). Falling-weight deflectometer (FWD), distress, and rutting surveys will also be conducted each fall to determine in-service pavement conditions. Deflections measured with the FWD will be input to an inversion computer program that determines the moduli of each of the pavement layers. This task will be conducted by the University of Wisconsin, with assistance from Mn/DOT.

Task 4 –Continued Environmental Monitoring at Test Sites

Lysimeters (5 m x 5 m) were installed beneath the fly ash stabilized layer at both the Waseca and Chisago roads to provide continuous monitoring of liquid discharged from the stabilized material that would ordinarily flow to groundwater. Samples have been collected from these lysimeters on a monthly basis since construction, and will continue to be collected from the lysimeters during this project. These samples will be analyzed for all metals considered in the STUWMPP computer model developed for evaluating groundwater impacts in Minnesota. All chemical analyses will be conducted by the University of Minnesota in accordance with methods described in USEPA SW-846.

The STUWMPP and WiscLEACH computer models will be used to predict groundwater impacts at both field sites. Column tests data are required as input to the WiscLEACH code. Thus, column tests will be conducted on stabilized material collected from both sites. These tests will be conducted at the University of Wisconsin, and chemical analysis of the effluent samples will be conducted by the University of Minnesota. Accuracy of the model predictions will be evaluated by comparing the predictions to concentrations of metals in water collected in the lysimeters. Based on this comparison, the efficacy of both codes will be evaluated. Parametric simulations will also be conducted with both computer models to assess the potential for groundwater impacts associated with various fly ash stabilization scenarios. Simulations conducted with STUWMPP will be conducted by the University of Minnesota, whereas the University of Wisconsin will conduct simulations with WiscLEACH.

Task 5– Technology Transfer

A technical report will be prepared at the end of the study that summarizes the findings of the study and contains guidelines on how fly ash stabilization can be used when paving gravel roads and reconstructing city streets. These guidelines will identify gravel equivalencies for fly ash stabilized pavement materials and provide an assessment of their life expectancy. Example problems will also be included to illustrate how designers can incorporate fly ash stabilization in their designs. This report will be prepared by the University of Wisconsin, with input from the University of Minnesota and Mn/DOT.

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Education

B.S. 1970 University of Montana - Secondary Education
M.A.T. 1972 University of Montana - Chemistry
Ph.D. 1978 Cornell University - Soil Chemistry

Employment

1978–1983	Assistant Professor, Department of Soil Science University of Minnesota
1983–1987	Associate Professor, Department of Soil Science University of Minnesota
1986–1987	Visiting Scientist, International Rice Research Institute, Philippines
1988–Present	Professor, Department of Soil Science University of Minnesota

Awards

Elected Fellow of the Soil Science Society of America, 1991

Professional Organizations and Honorary Societies:

- American Society of Agronomy
- American Chemical Society
- Soil Science Society of America
- International Humic Substances Society
  - Vice President/Incoming President 2004 – present
- Sigma Xi

Relevant Publications

Baes, A.U. and P.R. Bloom. 1988. Effect of ionic strength on swelling and alkaline earth ion exchange in a peat. Soil Sci. 146:67–72.

Baes, A.U. and P.R. Bloom. 1988. Exchange of alkaline earth cations in soil organic matter. Soil Sci. 146:6–14.

Cronan, C.S., R. April, R.J. Bartlett, P.R. Bloom, C.T. Driscoll, S.A. Gherini, G.S. Henderson, J.D. Joslin, J.M. Kelly, R.M. Newton, R.A. Parnell, H.H. Patterson, D.J. Raynal, M.Schaedle, C.L. Schofield, E.I. Sucoff, H.B. Tepper, and F.C. Thornton. 1989. Aluminum toxicity in forests exposed to acidic deposition: The ALBIOS results. Water Air Soil Pollution 48:181–189.

Cook, B.D., P.R. Bloom, and T.R. Halbach. 1997. The fate of polyacrylate polymer during composting of simulated municipal solid waste. J. Environ. Qual. 26:618-625.

Meyer, M and P.R.Bloom. 1997. Boric acid and silicic Acid adsorption by a humic acid. Soil Sci.Soc.of Amer. J. 60: 63-69.

Xia, K., F. Wessner, W. Bleam, P. R. Bloom, U. L. Skyllberg, and P. A. Helmke. 1998. XANES studies of oxidation states of S in soil and aquatic humic substances. Soil Sci. Soc. Am. J. 62: 1240-1246.

Xia, K., W. F. Bleam, U. Skyllberg, P. R. Bloom, and E. A. Nater. 1999. XAS study of the binding of mercury (II) to reduced sulfur in soil organic matter. Enviro. Sci. Tech. (33:257-261).

P.R. Bloom 1999. Soil pH and pH buffering. pp. B.333-B.350 M.E. Sumner (ed.) Handbook of Soil Science. CRC Press, Boca Raton.

U.L. Skyllberg*, K Xia, P.R. Bloom, E.A. Nater, and W. F. Bleam 2000. Binding of mercury (II) to reduced sulfur in soil organic matter along upland-peat soil transects. J. Environ. Qual. 29:855-865.

P.R. Bloom, W.F. Bleam and K. Xia, 2001. X-ray Spectroscopy Applications for the Study of Humic Substances *In* C.E. Clapp, M.H.B. Hayes, N. Senesi, P.R. Bloom and P.M. Jardine (eds.). Humic substances and chemical contaminants. Soil Sci. Soc. Amer. Madison WI.

Bloom, Paul R., and Gollany, Hero 2001. Water quality in runoff from fly ash-stabilized pads pp. 2-1 to 2-26 In. Environmental Evaluation for of the use of Ash in Soils Stabilization Applications EPRI, Palo Alto CA, and U.S. Department of Energy, Pittsburg, PA: 2001:1005213.

M.S. Friend P.R. Bloom, T.R. Halbach, K. E. Grosenheider M.R. Johnson. 2004. Screening Tool for Using Waste Materials in Paving Projects (STUWMPP) . Minnesota Local Road Research Board http://www.lrrb.gen.mn.us/more.cfm?code=1962, 32 pp.

Yoon, S-J, L.M. Diener, P.R. Bloom, E.A. Nater, and W.F. Bleam. 2005. X-ray absorption studies of CH_3Hg^+-binding sites in humic substances. Geochimica et Cosmochimica Acta, 69:1111-1121.

P.R. Bloom, U.L. Skyllberg M. E. Sumner 2005. .Soil Acidity pp. 411 - 460 *In* A. Tabatabai and D. Sparks eds. .Chemical processes in soils, SSSA Book Series No. 8. Soil Sci. Soc. Am. Madison.

Khwaja,A.R., P.R. Bloom, and P.L. Brezonik (*in press)* Binding Constants of Divalent Mercury (Hg^{2+}) in Soil Humic Acids and Soil Organic Matter. Environ. Sci. and Tech.

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EDUCATION
B.S.C.E., Lehigh University - 1985
M.S.E., University of Texas at Austin - 1987
Ph.D., University of Texas at Austin - 1989

REGISTRATION
Professional Engineer, State of Wisconsin, License No. 34108-006

HONORS AND AWARDS
Research
UW-Madison Kellet Mid-Career Research Award (2005), ASCE Huber Research Prize (2000), ASCE Croes Medal (1998), ASCE Casagrande Award (1995), ASCE Middlebrooks Award (1995), ASCE Collingwood Prize (1994), U.S. Department of Energy Distinguished Young Faculty Award (1991), National Science Foundation Presidential Young Investigator (1991)

University of Wisconsin Teaching Awards
Polygon Outstanding Instructor Award (1991, 93, 97), ASCE Wisconsin Student Chapter Outstanding Professor Award (1992), Wisconsin Students Association Top 100 Educators Award (1991)

Academics
Univ. of Texas John A. Focht Endowed Presidential Scholarship in Civil Engr. (1988), Univ. of Texas Dawson Endowed Presidential Scholarship in Civil Engr. (1986), Univ. of Texas Engineering Foundation Fellowship (1985), Lehigh University John B. Carson Prize in Civil Engr. (1985), Phi Beta Kappa, Chi Epsilon, and Tau Beta Pi

PUBLICATIONS
Dr. Benson has published 175 works consisting of 78 refereed journal articles and special technical publications, 35 articles in non-refereed conference proceedings, 56 technical reports, and 6 magazine articles. The refereed articles have appeared in a variety of journals including the ASCE *J. of Geotechnical and Geoenvironmental Engineering*, the ASTM *Geotechnical Testing J.*, the *Canadian Geotechnical J.*, the ASCE *J. of Cold Regions Engineering*, the *J. of Geotextiles and Geomembranes*, the *J. of Waste Management and Research*, and *Ground Water Monitoring and Remediation*. Three of the articles in the *J. of Geotechnical and Geoenvironmental Engineering* have received awards (Croes Medal, Middlebrooks Award, and Collingwood Prize).

Some relevant publications are below:

Bin-Shafique, S., Benson, C., Edil, T., and Hwang, K. (2006), Leachate Concentrations from Water Leach and Column Leach Tests on Fly-Ash Stabilized Soil, *Environmental Engineering Science*, in press.

Edil, T., Acosta, H., and Benson, C. (2005), Stabilizing Soft Fine-Grained Soils with Fly Ash, *J. of Materials in Civil Engineering*, ASCE, in press.

Bin-Shafique, S., Edil, T., and Benson, C. (2004), Incorporating a Fly Ash Stabilized Layer into Pavement Design – Case Study, *Geotechnical Engineering*, 157(4), 239-249.

Senol, A., Bin-Shafique, M., Edil, T. and Benson, C. (2002), Use of Class C Fly Ash for Stabilization of Soft Subgrade," *Proc. 5th International Congress on Advances in Civil Engineering*, Vol. 2, Istanbul, Turkey, 963-972.

Edil, T., Benson, C., Bin-Shafique, M., Tanyu, B., Kim, W., and Senol, A. (2002), Field Evaluation of Construction Alternatives for Roadway Over Soft Subgrade, *Trans. Research Record*, 1786, 36-48.

Foose, G., Benson, C., and Edil, T. (2001), Analytical Methods for Predicting Concentration and Mass Flux from Composite Landfill Liners, *Geosynthetics International*, 8(6), 551-575.

Kleven, J., Edil, T., and Benson, C. (2000), Evaluation of Excess Foundry System Sands for Use as Subbase Material, *Transportation Research Record*, No. 1714, 40-48.

Jong, D., Bosscher, P., and Benson, C. (1998), Field Assessment of Changes in Pavement Moduli Caused by Freezing and Thawing, *Transportation Research Record*, No. 1615, Transportation Research Board, 41-50.

Palmer, B., Edil, T. and C. H. Benson (2000), Liners for waste containment constructed with Class F and C fly ashes, *J. of Hazardous Materials*, 18(2-3), 133-161.

SPONSORED RESEARCH

Dr. Benson has conducted research projects with a total budget exceeding $12 million. He conducts research on waste containment systems, groundwater remediation, beneficial use of industrial byproducts, and cold regions geotechnics. Dr. Benson's research is sponsored by federal agencies such as the National Science Foundation, the US Dept. of Energy, the US Environmental Protection Agency, the Federal Highway Administration, State of Wisconsin agencies, municipalities, and industries. Prominent industries supporting Dr. Benson's research include Waste Management, Browning-Ferris Industries, Alliant Power, Kennecott Mining Corporation, and the National Council of the Pulp and Paper Industry for Air and Stream Improvement.

PATENTS

Apparatus and Method for Testing the Hydraulic Conductivity of Geologic Materials, United States Patent No. 6,178,808, with X. Wang.

Pressure Plate Extractor, United States Patent No. 6,718,835, with X. Wang.

GRADUATE STUDENTS SUPERVISED

Dr. Benson has supervised (or is supervising) 90 graduate students alone or cooperatively with other faculty at Wisconsin. He has produced 22 PhD graduates and 58 MS graduates. Dr. Benson is currently supervising 4 PhD candidates and 6 MS candidates (some cooperatively with other Wisconsin faculty).

INVITED LECTURES AND PRESENTATIONS

Dr. Benson has conducted 34 invited lectures and presentations around the world at universities, conferences, and workshops. Recently Dr. Benson has been a keynote speaker for the 1999 African National Geotechnical Conference, the 1999 National Conference of the Italian Geotechnical Society, the KIG2000 Forum in Kyoto, Japan (May 2000, Japanese Geotechnical Society), the GeoEng2000 International Conference on Geotechnical and Geological Engineering (Nov. 2000, Melbourne), and the Second Australian-New Zealand Conference on the Geoenvironment (Nov. 2001, New Castle).

PROFESSIONAL SERVICE

Dr. Benson is a member of seven professional societies and has served in a variety of leadership positions for the ASCE Geo-Institute and ASTM. Dr. Benson is Editor-in-Chief of the ASCE/GI *Journal of Geotechnical and Geoenvironmental Engineering* and is Chairman of ASTM D18.04 on Hydrologic Properties and Hydraulic Barriers.

TUNCER B. EDIL, PH.D., P.E.

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EDUCATION

Ph.D. (Civil Engineering) Northwestern University, June, 1973
M.S. (Civil Engineering) Robert College, January, 1969
B.S. (Civil Engineering) Robert College, June, 1967

REGISTRATION

Professional Engineer, State of Wisconsin, License No. E-14606

ACADEMIC EXPERIENCE

Chair, Geological Engineering Program, University of Wisconsin-Madison, 2002
Professor, Departments of Civil & Environmental Engineering, University of Wisconsin-Madison, 1980 to present (also Professor of Geological Engineering, 1992 to present)
Associate Professor, Departments of Civil & Environmental Engineering and Engineering Mechanics, University of Wisconsin-Madison, 1977-80
Assistant Professor, Departments of Civil & Environmental Engineering and Engineering Mechanics, University of Wisconsin-Madison, 1973-77
Occasional Lecturer, Department of Engineering Professional Development, University of Wisconsin-Madison, 1975 to present
Lecturer, Department of Civil Engineering, Northwestern University, 1973

PERSONAL AWARDS

American Society of Civil Engr., Wisconsin Southwest Branch, Outstanding Civil Engineer Award, 1999
American Society for Testing and Materials, Committee D18 on Soil and Rock:
Standard Development Awards, 1992 and 1996;
Special Service Awards, 1997 and 2001
University of Wisconsin-Madison, Polygon Engineering Council, Outstanding Instructor Award, 1992
Republic of France, Stage Haut Niveau (High Level Exchange) Fellowship Award, 1991
American Society of Civil Engr., Journal of Cold Regions Engineering Award for the Best Paper, 1989
American Society of Civil Engineers, Wisconsin Section, Award of Merit for Individual Achievement as an Engineer in Education, 1988
American Society for Engr. Ed., North-Midwest Section, Dow Outstanding Young Faculty Award, 1980
American Society of Civil Engineers, Wisconsin Section, Young Civil Engineer of the Year Award, 1977
W. P. Murphy Scholarship (Northwestern University), 1969-72
NATO Doctoral Fellowship, 1969-72

PROJECT AND TEAM AWARDS

American Society of Civil Engineers Wisconsin Section, Engineering Achievement Award Honoring the Madison Metropolitan Sewerage District Contaminated Sludge Lagoon Capping (served as Design Engineer and Consultant), 2002
American Society of Civil Engineers Wisconsin Section, Engineering Achievement Award Honoring the Bender Park Waterfront Development (also nominated by the Wisconsin Section for the national Outstanding Civil Engineering Achievement Award) (served as Sub-Consultant for slope modification), 2001
U.S. Army Construction Engineering Research Laboratory, Research Product Development Team Award for Electroosmotic Pulse Technology (served as Academic Team Member), 2000
Civil Engineering Research Foundation, Charles Pankow Innovative Application Award Finalist, Electroosmotic Pulse Technology to control water intrusion in buried concrete structures, (served as Collaborator to the U.S. Army Construction Engineering Research Laboratory, Champaign, IL), 1999

American Society of Civil Engineers, Outstanding Large Section Award for Zone III, (served as President of Wisconsin Section during the award year), 1999

Consulting Engineers Council of Minnesota, Honor Award, Veteran's Memorial Park-Pathways and Amphitheater Project, Richfield, MN, (served as Technical Consultant on this project to Geotechnical Engineering Corporation, Roseville, MN), 1989

EDITORSHIPS

Editor in Chief, *Journal of Geotechnical Engineering*, 1984-89

Co-Editor, *Advances in Understanding and Modelling the Mechanical Behaviour of Peat*, A. A. Balkema Publishers, Rotterdam, Netherlands, 1994.

Co-Editor, *Geotechnics of High Water Content Materials*, American Society of Testing and Materials, ASTM STP 1374, Conshohocken, PA, 2000, 380 p.

DIRECTORSHIP

Co-Director, Consortium for Fly Ash Use in Geotechnical Engineering, with C. Benson

RELEVANT PUBLICATIONS

T. B. Edil and P. M. Berthouex, "Earthen Liners for Waste Containment," *Proceedings* of the International Symposium on Environmental Management for Developing Countries, Envitek A. S., Istanbul, Turkey, Vol. I, 1985, pp. 309-319.

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