CONTAMINANT LEACHABILITY FROM UTILIZED WASTES IN GEOSYSTEMS

An Invited Thematic Lecture
by

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ABSTRACT

Urbanization rates of population range from about 1% in the developed countries to about 4% in developing countries. For a global population that may reach 10 billion within the next 40 years, pressure has arisen for an increase in the large-scale use of wastes and byproducts in construction. Ironically, most of the wastes that need to be recycled are generated in large cities where the need for constructed facilities to serve large population is high. Waste and recycled materials (WRM) that are used in construction are required to satisfy material strength, durability and contaminant leachability requirements. These materials exhibit a wide variety of characteristics owing to the diversity of industrial processes through which they are produced. Several laboratory-based investigations have been conducted to assess the pollution potential and load bearing capacity of materials such as petroleum-contaminated soils, coal combustion ash, flue-gas desulphurization gypsum and foundry sand. For full-scale systems, although environmental pollution potential and structural integrity of constructed facilities that incorporate WRM are interrelated, comprehensive schemes have not been developed for integrated assessment of the relevant field-scale performance factors. In this presentation, a framework for such an assessment is proposed and presented in the form of a flowchart. The proposed scheme enables economic, environmental, worker safety and engineering factors to be addressed in a number of sequential steps. Quantitative methods and test protocols that have been developed can be incorporated into the proposed scheme for assessing the feasibility of using WRM as partial or full substitutes for earthen highway materials in the field.

A BRIEF PROFILE OF THE SPEAKER

Prof. Inyang is the Duke Energy Distinguished Professor of Environmental Engineering and Science, Professor of Earth Science and Director of the Global Institute for Energy and Environmental Systems at the University of North Carolina-Charlotte. Prior to his current position, he was University (titled) Professor, Dupont Young Professor and Director of the Center for Environmental Engineering, Science and Technology (CEEST) at the University of Massachusetts, Lowell. Previously he taught at George Washington University, Washington, DC; Purdue University, West Lafayette, Indiana; and University of Wisconsin, Platteville. Professor Inyang also served at the U.S. Environmental Protection Agency (1991-1993) as a Senior Geoenvironmental Engineer and subsequently as the President of Geoenvironmental Design and Research (GDR) Inc., a small research firm that he founded in 1993. From 1997 to 2001, he was the Chair of the Environmental Engineering Committee of the USEPA Science Advisory Board, and also served on the Effluent Guidelines Committee of the National Council for Environmental Policy and Technology, both of which dealt with key issues that presently fall within the scope of environmental security. He has authored/co-authored more than 170 research articles, book chapters, federal design manuals and the textbook, Geoenvironmental Engineering: principles and applications, published by Marcel Dekker (ISBN: 0-8247-0045-7). His expertise includes environmental security issues such as radiation control engineering, monitoring and containment technologies for released contaminants and inhibition of dusts that may spread contaminants and pathogens through the air. Professor Inyang has contributed on a continual basis and in a leadership role, to several scholarly publications. He is an associate editor/editorial board member of 17 refereed international journals and contributing editor of three books, including the United Nations Encyclopedia of Life Support Systems (Environmental Monitoring Section). He led the expert group on performance monitoring technologies to support the containment system expert group convened by the US Department of Energy, DuPont Corporation and the USEPA to develop and publish the 1995 state-of-the-art waste containment systems book for use in practice. Professor Inyang has given more than 100 invited speeches and presentations on a variety of technical and policy issues at many institutions and agencies in several countries. Among these presentations are the ALCOA Endowed Lecture at Carnegie-Mellon University (2002); the Earth Day Celebrations Lecture at Spellman College, Atlanta; the AMOCO Foundation Lecture at Iowa State University (1996); and the Goldberg and Zoino Lecture at Massachusetts Institute of Technology (1994). Professor Inyang holds a Ph.D. with a double major in Geotechnical Engineering and Materials and a minor in Mineral Resources from Iowa State University, Ames, Iowa; an M.S. and B.S. in Civil Engineering from North Dakota State University, Fargo, North Dakota; and a B.Sc. (Honors) in Geology from the University of Calabar, Nigeria. His research has been sponsored by NOAA, FHWA, USDOE, USDOD, USNRC, DuPont Corporation, Sandia National Laboratory, Duke Energy Corporation and the National Science Foundation. For his research contributions to advances in geoenvironmental science and engineering, professional practice in many countries, and public policies on energy and environmental issues, he has received several professional honors, including selection as a Fellow of the Geological Society of London, the 1999 Chancellor's Medal for Distinguished Public Service of the University of Massachusetts, Lowell; 2001 Swiss Forum Fellow selection by the American Association for the Advancement of Science ; the 1996 National Research Council Young Investigator Selection; 1992 Eisenhower-Jennings Randolph Award of the International Public Works Federation/World Affairs Institute that was instituted to honor the international achievements of former U.S. President Dwight D. Eisenhower, and the 1991 American Association for the Advancement of Science/USEPA Environmental Science and Engineering Fellowship.

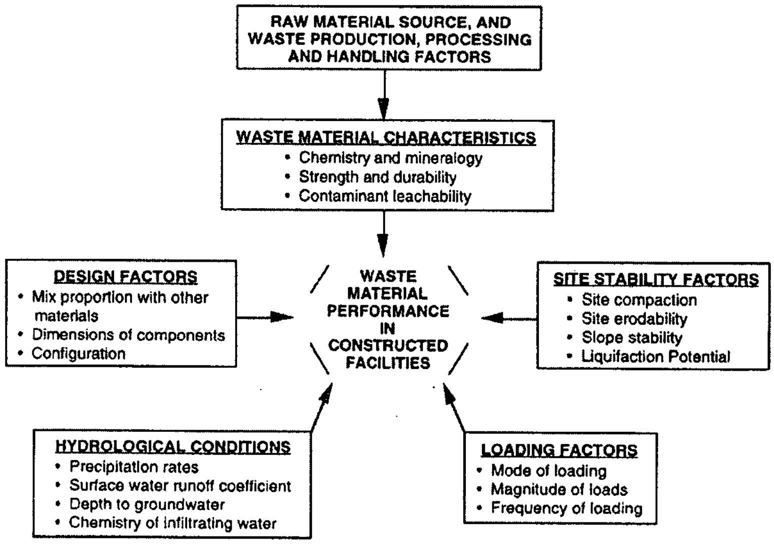
SOME INFRASTRUCTURE DRIVING FACTORS

- Need for construction materials for transportation facilities over large land masses.
  - **Australia:** A road length per capita of 450 m compared to 280 m for US and 90 m for Japan.
  - **United States:** Within 20 years, Vehicular and Truck traffic are expected to increase by 45% and 90% respectively.

SOME INFRASTRUCTURE DRIVING FACTORS

- **Limited storage space due to high population density**
  - **Hong Kong**:
    - Possible exhaustion of landfill space by 2015 (Chen et al., 2002a)
    - Annual generation rate of waste glass is 58,060 metric tonnes of which 45,360 metric tonnes is recoverable
  - **Singapore:** At a population density of more than 4600 persons/km^3 disposed abouth 2.8 million tonnes of solid waste (Bai and Sutanto, 2002)
  - **Taiwan:** In 1998, waste generation was at the level of 500 metric tonnes per km^2 (Wei and Huang, 2002)
  - **Japan:** Current Annual areal generation of waste is about 650 metric tonnes/km^2 (Wei and Huang, 2002)
  - **United States:** 210.4 million metric tonnes of municipal waste alone was generated in 2000, out of which only 58.4 million tonnes was recycled

FACTORS THAT CONTROL THE ENVIRONMENTAL AND STRUCTURAL PERFORMANCE OF WASTE AND RECYCLED MATERIALS (WRM) IN CONSTRUCTED FACILITIES



RAW MATERIAL SOURCE, AND WASTE PRODUCTION, PROCESSING AND HANDLING FACTORS

WASTE MATERIAL CHARACTERISTICS
- Chemistry and mineralogy
- Strength and durability
- Contaminant leachability

DESIGN FACTORS
- Mix proportion with other materials
- Dimensions of components
- Configuration

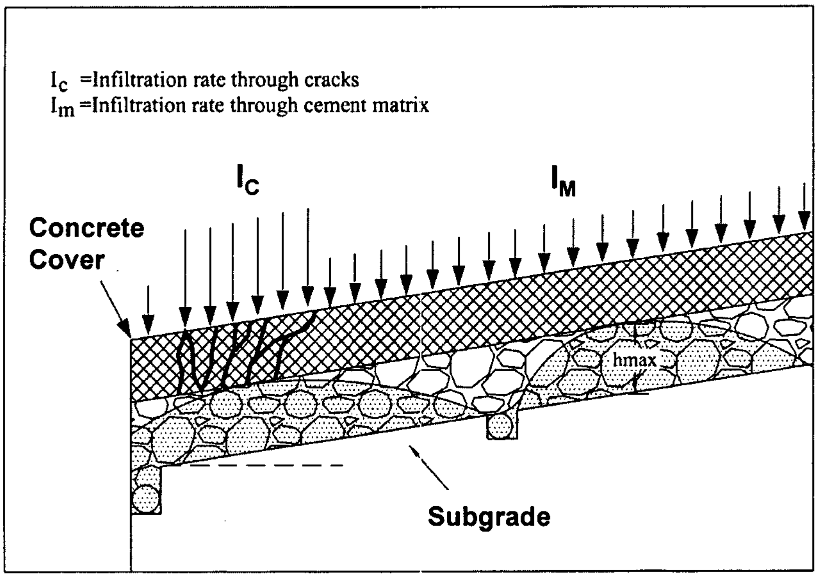
WASTE MATERIAL PERFORMANCE IN CONSTRUCTED FACILITIES

SITE STABILITY FACTORS
- Site compaction
- Site erodability
- Slope stability
- Liquifaction Potential

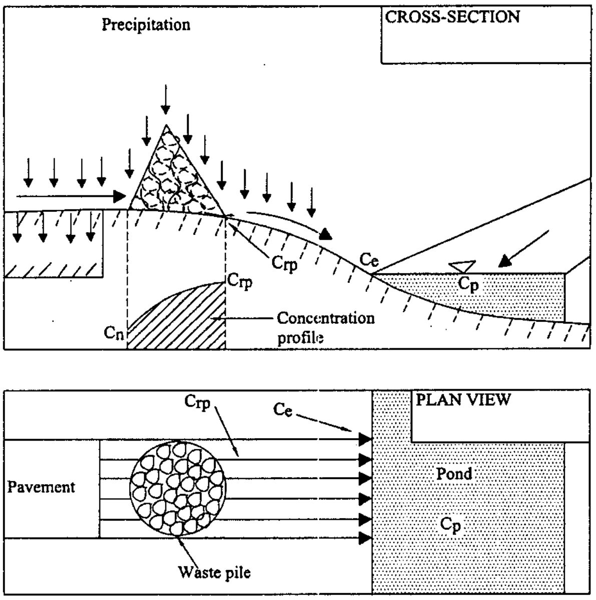
HYDROLOGICAL CONDITIONS
- Precipitation rates
- Surface water runoff coefficient
- Depth to groundwater
- Chemistry of infiltrating water

LOADING FACTORS
- Mode of loading
- Magnitude of loads
- Frequency of loading

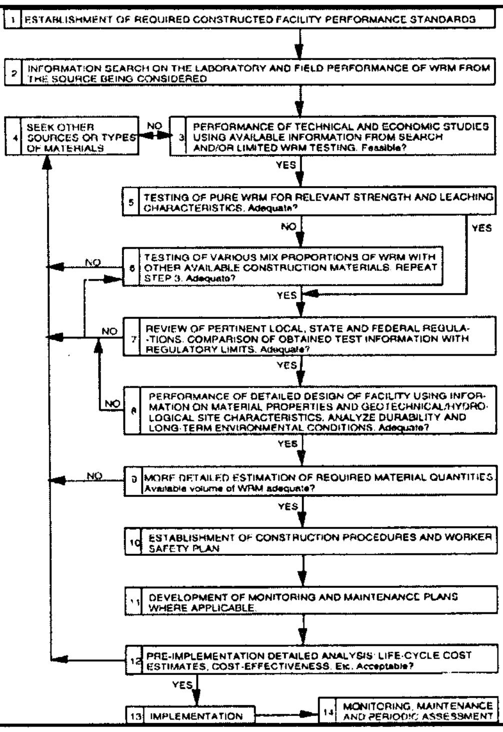
STRUCTURAL DETERIORATION AND ITS IMPACTS ON THE INFILTRATION OF PAVEMENTS AND COVERS



SCHEMATIC ILLUSTRATION OF CONTAMINANT WASHOUT FROM WASTE PILES AT CONSTRUCTION SITES



ANALYTICAL STEPS OF THE FEASIBILITY ASSESSMENT AND PROJECT IMPLEMENTATION METHODOLOGY FOR USE OF WASTE AND RECYCLED MATERIALS (WRM) IN CONSTRUCTION



1 ESTABLISHMENT OF REQUIRED CONSTRUCTED FACILITY PERFORMANCE STANDARDS

2 INFORMATION SEARCH ON THE LABORATORY AND FIELD PERFORMANCE OF WRM FROM THE SOURCE BEING CONSIDERED

3 PERFORMANCE OF TECHNICAL AND ECONOMIC STUDIES USING AVAILABLE INFORMATION FROM SEARCH AND/OR LIMITED WRM TESTING. Feasible?

4 SEEK OTHER SOURCES OR TYPES OF MATERIALS

5 TESTING OF PURE WRM FOR RELEVANT STRENGTH AND LEACHING CHARACTERISTICS. Adequate?

6 TESTING OF VARIOUS MIX PROPORTIONS OF WRM WITH OTHER AVAILABLE CONSTRUCTION MATERIALS. REPEAT STEP 3. Adequate?

7 REVIEW OF PERTINENT LOCAL, STATE AND FEDERAL REGULATIONS. COMPARISON OF OBTAINED TEST INFORMATION WITH REGULATORY LIMITS. Adequate?

8 PERFORMANCE OF DETAILED DESIGN OF FACILITY USING INFORMATION ON MATERIAL PROPERTIES AND GEOTECHNICAL/HYDROLOGICAL SITE CHARACTERISTICS. ANALYZE DURABILITY AND LONG-TERM ENVIRONMENTAL CONDITIONS. Adequate?

9 MORE DETAILED ESTIMATION OF REQUIRED MATERIAL QUANTITIES. Available volume of WRM adequate?

10 ESTABLISHMENT OF CONSTRUCTION PROCEDURES AND WORKER SAFETY PLAN

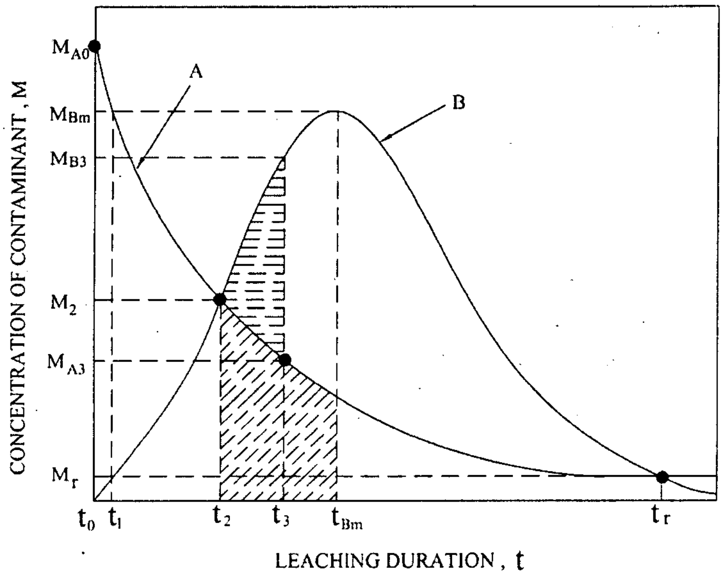
11 DEVELOPMENT OF MONITORING AND MAINTENANCE PLANS WHERE APPLICABLE.

12 PRE-IMPLEMENTATION DETAILED ANALYSIS: LIFE-CYCLE COST ESTIMATES, COST-EFFECTIVENESS, Etc. Acceptable?

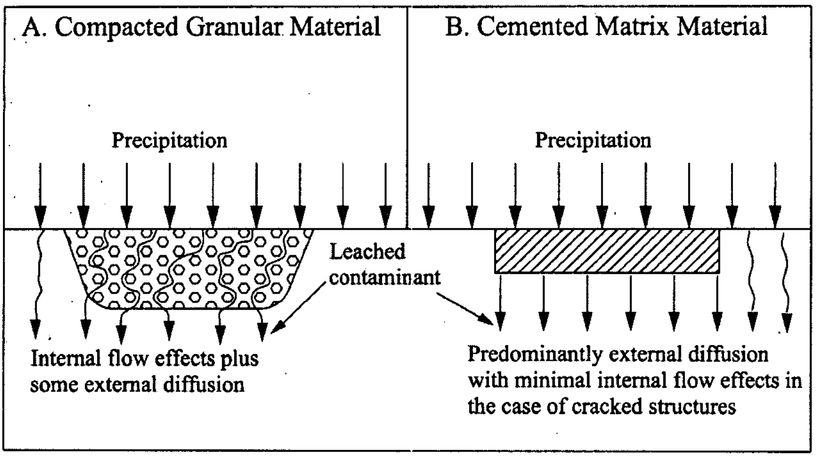
13 IMPLEMENTATION

14 MONITORING, MAINTENANCE AND PERIODIC ASSESSMENT

IDEALIZED PATTERNS OF CONTAMINANT LEACHING FROM SUBSTANCES IN CONTINUOUS LEACHING TESTS



CATEGORIZATION OF CONTAMINANT EMISSION MODELS FOR STRUCTURAL SYSTEMS IN THE FIELD



A. Compacted Granular Material

B. Cemented Matrix Material

Precipitation

Precipitation

Leached contaminant

Internal flow effects plus some external diffusion

Predominantly external diffusion with minimal internal flow effects in the case of cracked structures

CONTAMINANT LEACHABILITY QUANTIFICATION

- The release of contaminants into an adjacent medium from locations at distances x, from the source medium can be described using the following form of the one-dimensional advection-dispersion expression.

$$D_e\left(\frac{\partial^2 C_d}{\partial X^2}\right)-V_v\left(\frac{\partial C_d}{\partial X}\right)-\left[1+\left(\frac{1-f}{f}\right)\rho_t K_d\right]\left(\frac{\partial C_d}{X}\right)=0 \qquad (1)$$

- D_e is the diffusion coefficient (L^2/T),
- C_d is the concentration of the contaminant in the pcs concrete (M/L^3),
- x is the distance from the concrete surface into the concrete (L),
- V_v is the advective flow velocity of the contaminant from the concrete to the surrounding medium (L/T),
- f is the porosity of the concrete (dimensionless fraction),
- ρ_t is the density of the concrete (M/L^3),
- K_d is the distribution coefficient of the contaminant for the concrete matrix solid-pore fluid combination (L^3/M),
- t is time (T).

CONTAMINANT LEACHABILITY QUANTIFICATION (CONT'D)

- Asphalt concrete typically has very low values of effective porosity, which often results in hydraulic conductivity of the order of 10^{-11}-10^{-8} cm/sec.
- For low hydraulic conductivity media of this type, diffusion is the dominant mechanism of leaching.
- Then, Fick's law, which is expressed as equation (2) applies.

$$\frac{\partial C}{\partial t} = D_e \left(\frac{\partial^2 C_d}{\partial X^2} \right) \qquad (2)$$

Crank (1975) applied the simplifying assumption that De will remain constant during leaching and solved equation (2) resulting in the following expression which has been customized to the problem of focus in this analysis.

$$M_t = 2(C_0 - C_i)\left(\frac{D_e t}{\pi} \right)^{0.5} \qquad (3)$$

- M_t is the quantity of contaminant leached per unit surface area of the pcs concrete after a given time interval (M/L^2)
- C_o is the initial concentration of the contaminant in the pore solution of the pcs concrete (M/L^3)
- C_i is the concentration of the contaminant at the concrete/soil interface (M/L^3). The concentration of C_i can be considered to be zero if the surrounding material is clean of the target contaminant.

CONTAMINANT LEACHABILITY QUANTIFICATION (CONT'D)

- It should be noted that C_o is pore solution concentration, warranting the use of a partition coefficient or mass transfer coefficient as follows.

$$C_0 = K_p C_d = K_p \left(\frac{m_d}{v_d} \right) \qquad (4)$$

- K_p is the mass transfer coefficient of the target contaminant from solid matter in the concrete to its internal pore (dimensionless fraction)

- C_d is the mix design concentration of the contaminant per bulk volume of the pcs concrete (M/L3)

- m_d is the mass of the contaminant in the pcs concrete (M),

- V_d is the design volume of the pcs concrete containing md (L3)

CONTAMINANT LEACHABILITY QUANTIFICATION (CONT'D)

- With the introduction of equation (4), equation (3) can be re-written as:

$$M_t = 2K_p\left(\frac{m_d}{v_d}\right)\left(\frac{D_e t}{\pi}\right)^{0.5} \qquad (5)$$

Considering that the units of M_t are in mass per unit surface area, equation (5) needs to be multiplied by the total external surface area of the pcs concrete, S, in order to estimate the total mass, of the target contaminant that will be leached from the emplaced pcs concrete of known dimensions.

$$M_{tt} = 2SK_p\left(\frac{m_d}{v_d}\right)\left(\frac{D_e t}{\pi}\right)^{0.5} \qquad (6)$$

- M_{tt} is the total mass of the target contaminant released from the pcs concrete (M).

- If the total leachant volume and the rate of washing is known from infiltration analysis, then it can be applied as follows to estimate the concentration of the target contaminant in pore solution, C_{bt}, at the base of the concrete.

$$C_{bt} = \frac{M_{tt}}{V_t} = \frac{2SK_p}{V_t}\left(\frac{m_d}{v_d}\right)\left(\frac{D_e t}{\pi}\right)^{0.5} \qquad (7)$$

COUPLING OF LEACHABILITY WITH GROUNDWATER WELL STANDARDS

- For a particular contaminant, a regulatory concentration limit can be specified based on the results of the four sequential steps of health risk assessment:
  - hazard identification
  - dose-response assessment
  - exposure assessment
  - risk characterization

- Essentially, the magnitude of M_{tt} should not exceed a specified value M_{ttp} that is consistent with the attainment of the health-based (with possible additional considerations) concentration of the target contaminant in the well water.

- This is analogous to stating that there is a limiting value of C_{bt}, which is herein denoted by C_{btp}.

COUPLING OF LEACHABILITY WITH GROUNDWATER WELL STANDARDS (CONT'D)

- Contaminant attenuation and dilution will result in reduction of the concentration of the target contaminant as it travels through distances h and B. Thus,

$$C_{btp} = \frac{M_{ttp}}{V_t} = \frac{C_w}{F_d}\left[\sum_{i=1}^{n} A_i\right]^{-1} \qquad (8)$$

- M_{ttp} is the maximum mass of the target contaminant to be released from the pcs concrete during time t, without exceedance of the maximum concentration,
- C_w of the contaminant in groundwater that permeates into the underground well.
- A_i is the contaminant attenuation factor for travel pathway i (dimensionless fraction) which represents a reduction in contaminant concentration.

COMBINATION AND REARRANGEMENT OF EQUATIONS (7) AND (8)

Purpose: to arrive at a relationship for determining the maximum concentration of the target contaminant in the pcs concrete that will meet the groundwater quality standard (C_w) at the water well.

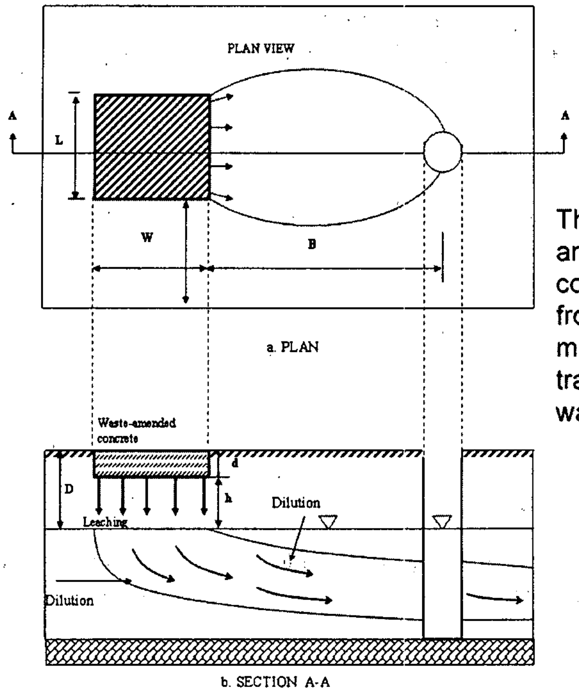
$$\frac{M_{tt}}{V_t} = \frac{2SK_p}{V_t}\left[\frac{m_d}{v_d}\right]\left[\frac{D_e t}{\pi}\right]^{0.5} \le \frac{M_{ttp}}{V_t} = \frac{C_w}{F_d}\left[\sum_{i=1}^{n} A_i\right]^{-1} \qquad (9)$$

$$\frac{m_d}{v_d} \le \frac{C_w V_t (\pi)^{0.5}}{2F_d S K_p}\left[\frac{1}{(D_e t)^{0.5}}\right]\left[\sum_{i=1}^{n} A_i\right]^{-1} \qquad (10)$$

Recalling equation (4)

$$C_d \le 0.9 C_w V_t \left[\left[F_d S K_p (D_e t)^{0.5}\right]\left[\sum_{i=1}^{n} A_i\right]\right]^{-1} \qquad (11)$$

$$C_d = \frac{m_d}{V_d} \qquad (12)$$



The scenario (plan and section views) of contaminant leaching from a partially buried monolithic mass and transport to a ground water well

DATA COLLECTION METHODS AND JUSTIFICATION FOR PARAMETER RANGES

- Tests conducted by Ezeldin et al. (1996) show that D_e values are of the order of 10^{-11} – 10^{-8} cm2/s in this analysis 10^{-10} cm^2/s is used.
- For sample computations, a realistic F_d value of 0.8 is used. This implies that due to dilution, the contaminant concentration is assumed to decrease to 80% of what it would be without dilution.
- A buried pavement segment with dimensions (length, width and depth) of 20 m x 8 m x 0.25 m with the opportunity to leach contaminants only from the side and bottom surfaces is considered. This provides a value of s of 170 m^2.

DATA COLLECTION METHODS AND JUSTIFICATION FOR PARAMETER RANGES (CONT'D)

- It is estimated from measurements at equilibrium that about 20% of the concentration of the target contaminant is unbound and available for transport from the pore fluid. Therefore, Kp = 0.20.

- The timeframe, t for this analysis is 10 years.

- For the transport pathways, it is assumed that the soils with which the contaminant establishes contact during transport reduces its concentration through sorption to 60% of its original release point value.

BACKCALCULATION OF MAXIMUM ALLOWABLE CONCENTRATION OF PCS IN CONCRETE

- Typically, values of C_w are generally based on drinking water standards or the Maximum Concentration Levels (MCLs) specified by regulatory agencies.

- The maximum allowable concentration of a target contaminant that could be contributed to a well from sources such as pcs concrete used in this study can be estimated from equation 13.

$$C_{w(cps)} = \mathrm{MCLs} - C_{ini} \qquad (13)$$

- $C_{w(pcs)}$ is the Maximum allowable concentration of a target contaminant from PCS concrete in the MCLs
- C_{ini} is the background concentration of the target contaminant in the well water, which is assumed to be zero, therefore $C_{w(pcs)}$ is equal to MCLs (same as C_w).

COMPUTATIONS FOR CHROMIUM

•Using tabulated data for the variables in equation 11, the maximum allowable contaminant concentration, C_d, at the base of the concrete is computed to be 0.21 mg/L.

•For a pcs concrete of design volume V_d of 1m3, the total mass of the target contaminant (in this case chromium) in the pcs mix ratio is computed using equation 12 to be 210 mg.

•This implies that for the scenario and data presented in this study, the maximum allowable pcs in a concrete of design volume of 1 m^3 must not contain more than 210 mg of chromium if water quality in the well is to remain within the NPDWS level without requiring any treatment process.

SOME OBSERVATIONS

- For various values of C_w, the values of C_d decrease as D_e increases.
- Since D_e is a measure of the ability of the contaminant to diffuse from the concrete matrix, the lower the diffusion coefficient D_e, the lower the quantity of the contaminant that will be leached, therefore the more the quantity of pcs that could be added to the concrete.
- The effect of dilution factor F_d which is similar to that of the attenuation factor A_i is assessed in Figure C.
- In the Figure, F_d of 1 indicates no dilution of the contaminant between the source and the sink, as dilution factor decreases, the value of C_d increases.
- Since the dilution ratio is inversely proportional to the dilution factor in this study, increase in the recharge volume into the release quantity of the target contaminant as it travel to the sink can significantly increase the quantity of pcs in the concrete design volume.

Parameter	General Units	Typical Data Collection Methods	Value Used For Backcalculation	Value Used For Figure A	Value Used For Figure B	Value Used For Figure C
C_w	M/L^3	Specified by regulatory agency as drinking water standard or other standards.	Chromium 0.10 (mg/L)	2-10 mg/L	2-10 mg/L	8 mg/L
F_d	Dimension-less fraction	Computed through hydrogeological analysis of the quantity of water introduced into the contaminant transport pathway.	0.8	0.8	0.8	0.5-1.0
S	L^2	Computed as the external surface area of the partially or fully buried concrete through which leaching occurs.	170 m^2	170m^2	170m^2	170 m^2
K_p	Dimension-less fraction	Computed from the distribution coefficient of the contaminant for the solid and aqueous phases.	0.20	0.20	0.20	0.20
D_e	L^2/T	Estimated from dynamic and pseudo-dynamic leaching tests in the laboratory.	10^{-6} cm^2/s	$10^{-10}cm^2/s$	$10^{-12}–10^{-2}$ cm^2/s	10^{-4} cm^2/s
T	T	Scaled as time of existence of the buried concrete as a contaminant source.	20 years	2-20 years	20 years	5-25years
A_i	Dimension-less fraction	Computed for the transport path of the target contaminant as the percentage of the original release concentration that remains after attenuation during contaminant transport to the well.	0.6	0.6	0.6	0.6
V_t	L^3	Computed through infiltration analysis for a given duration.	100 L	100 L	100 L	200L
C_d	L^3	Maximum concentration in pcs concrete	0.21 mg/L Computed in section 6.2	Computed using equation 11	Computed using equation 11	Computed using equation 11

FIGURE A - PLOT OF C_d VERSUS C_w RANGING FROM 2 TO 10 mg/l (2 TO 20 YEARS TIME SCALE)

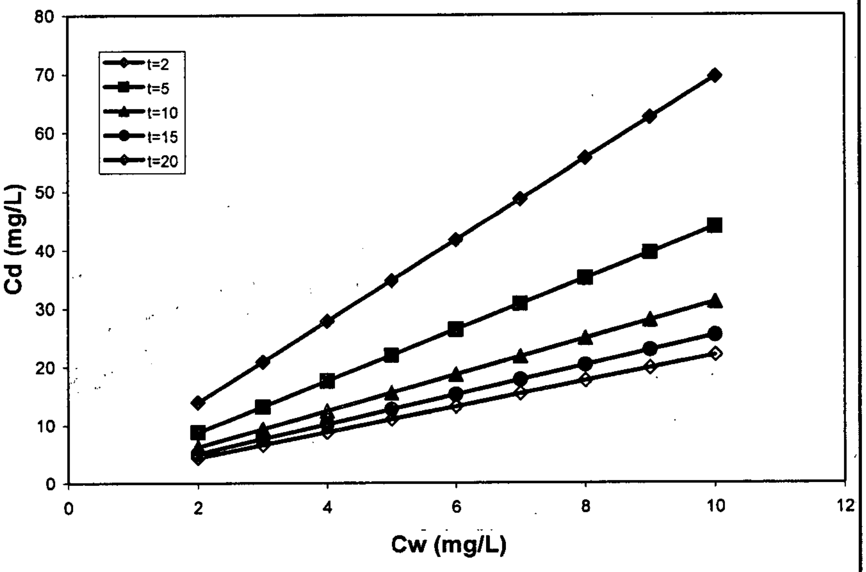


FIGURE B - PLOT OF C_d VERSUS D_e RANGING FROM 10^{-12} TO 10^{-2} cm^2/s (20 YEARS TIME SCALE)

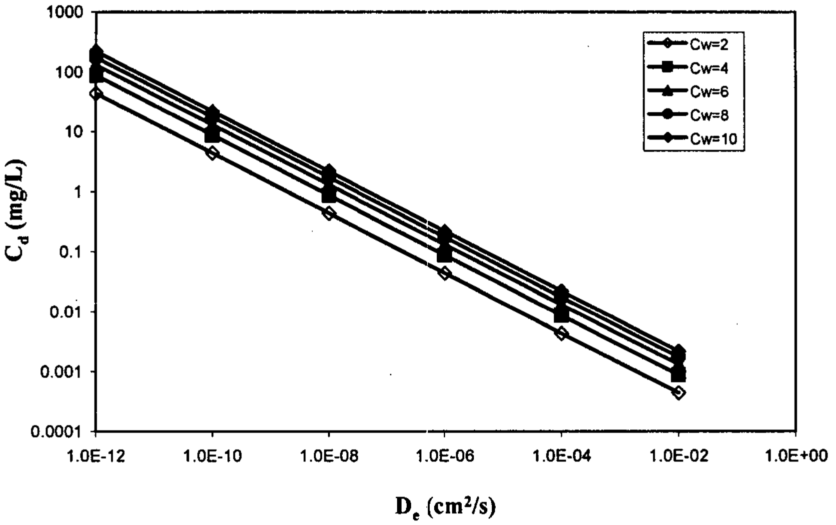
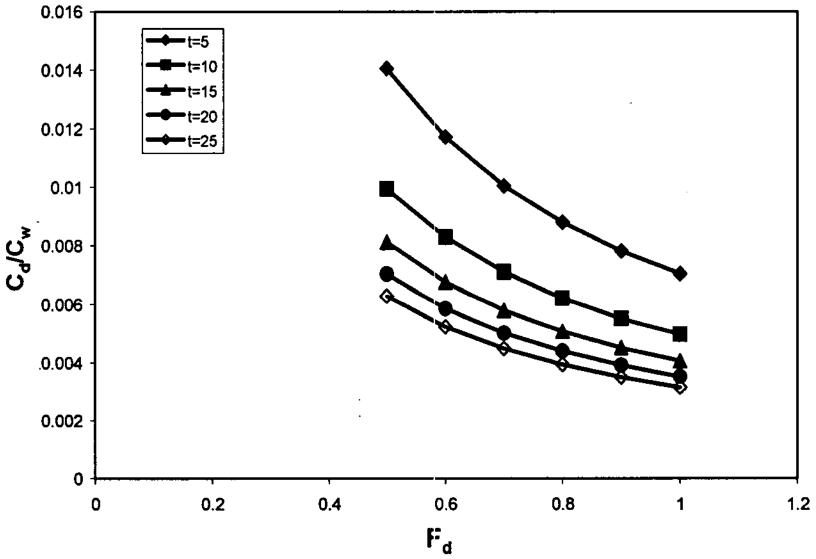


FIGURE C - PLOT OF C_d/C_w VERSUS F_d RANGING FROM 0.2 TO 1 (5 TO 25 YEARS TIME SCALE)



MATERIALS WITH REUSE POTENTIAL

A . Fabricated Products

- **Polymeric**
  - Geosynthetics
  - Synthetic Fibers
  - Nanomaterials
- **Non-Polymeric**
  - Natural Fibers

B . Natural Materials

- **Clean**
  - Soil
  - Rock
- **Contaminated**
  - Dredge Sediments
  - Mining Waste
- **Biomass**

MATERIALS WITH REUSE POTENTIAL

C . Wastes

- **Solid and Construction Wastes**
- **Hazardous Waste**
- **Radioactive Waste**
- **Liquid Waste**
- **Agricultural Waste**

D . Byproducts

- **Industrial Sludges**
- **Ashes**
- **Slags**
- **Tires**
- **Biosolids**
- **Foundry Sand**
- **Composts**

IMPORTANT CHARACTERISTICS

- Physical (specific gravity, particle size distribution, pore size distribution, plasticity indices, particle shape, organic content, moisture content, microtexture, microcharacteristics)
- Mechanical (compaction, flowability, hydraulic conductivity, strength, and volume change characteristics)
- Chemical and Mineralogical (pH, elemental analysis, leachability, leachate analysis, solubility, sorption, volatility, toxicity, reactivity, corrosivity, flammability, BOD, COD)
- Durability (environmental and chemical exposure tests, creep, particle soundness, corrosion, radiation damage tests, UV radiation tests, microbe resistance tests)
- Compatibility (material)

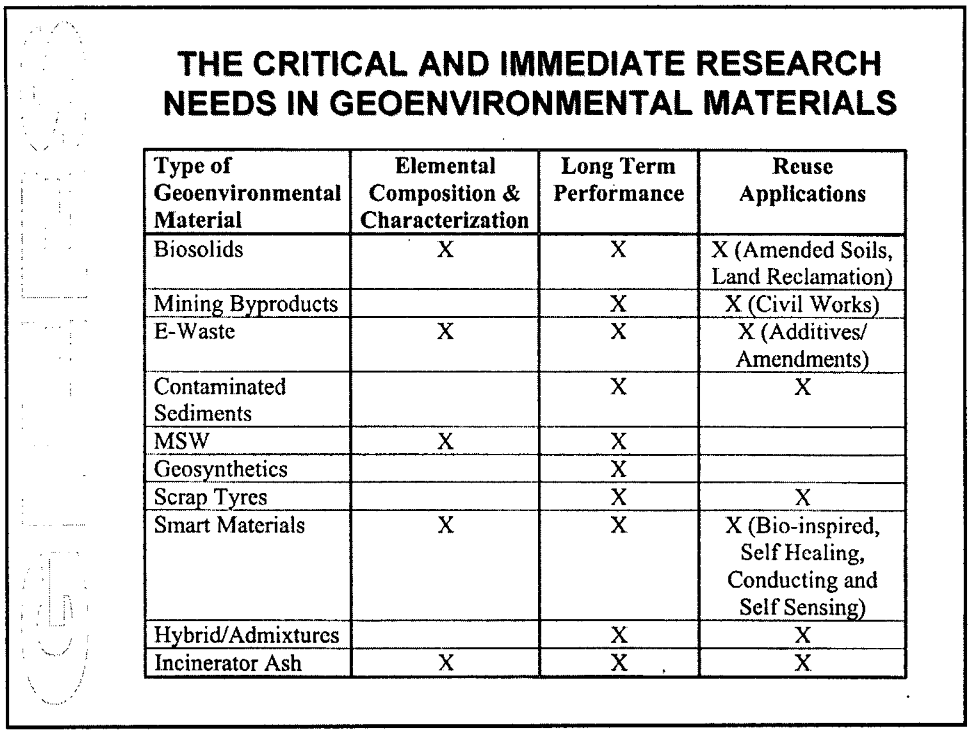
ADVANTAGES AND DRAWBACKS OF THE USE OF WASTES AS CONSTRUCTION MATERIALS AS A WASTE VOLUME CONTROL MEASURE

Advantages:

- **Conservations of Natural Resources**
- **Economics**
- **Good Public Relations**
- **Good Environmental Stewardship**
- **Enhances Recycling Efforts**
- **Less Landfilling**

Drawbacks:

- **Liability**
- **Time, Space and Equipment Constraints**
- **Unpredictability of Performance**
- **Lack of Adequate Specifications and QA/QC Methods**



THE CRITICAL AND IMMEDIATE RESEARCH NEEDS IN GEOENVIRONMENTAL MATERIALS

Type of Geoenvironmental Material	Elemental Composition & Characterization	Long Term Performance	Reuse Applications
Biosolids	X	X	X (Amended Soils, Land Reclamation)
Mining Byproducts		X	X (Civil Works)
E-Waste	X	X	X (Additives/ Amendments)
Contaminated Sediments		X	X
MSW	X	X	
Geosynthetics		X	
Scrap Tyres		X	X
Smart Materials	X	X	X (Bio-inspired, Self Healing, Conducting and Self Sensing)
Hybrid/Admixtures		X	X
Incinerator Ash	X	X	X