การจัดทำฐานข้อมูลด้านวิศวกรรมโยธาบนเครือข่ายอินเตอร์เน็ต

(Development of Civil Engineering Resources on the Internet)

ภาคผนวก 1

Construction & Management

Geotechnical

นาย พีรพงษ์ ทีฆภัทรดิลก

ปริญญานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิศวกรรมศาสตร์บัณฑิต

สาขาวิชาวิศวกรรมโยธา ภาควิชาวิศวกรรมโยธา

คณะวิศวกรรมศาสตร์ มหาวิทยาลัยนเรศวร

ปีการศึกษา 2540

คำนำ

จากความเจริญก้าวหน้าทางด้านเทคโนโลยีสารสนเทศ (Information Technology) ทำให้โลกไร้พรมแดน การติดต่อสื่อสารเป็นไปอย่างง่ายดาย และรวดเร็ว ทำให้ทุกคนต้องตกอยู่ในฐานะที่ต้องแข่งขันกันตลอดเวลา ในฐานะของนิสิตที่จะเป็นวิศวกรในอนาคตจำเป็นอย่างยิ่งที่จะต้องเรียนรู้ และรับเอาความรู้และเทคโนโลยีใหม่ๆ มาประยุกต์ใช้ในงานทางด้านวิศวกรรม เครือข่าย Internet นับเป็นเครื่องมือหนึ่งที่จะนำเอาความรู้ต่างๆ มายังเครื่อง Computer ที่วางอยู่ต่อหน้าได้ แต่ปริมาณของข้อมูลที่มีอยู่อย่างมากในเครือข่าย Internet เป็นอุปสรรคในการนำมาใช้ให้เกิดประโยชน์สูงสุดเพราะไม่เสมอที่ทุกครั้งที่เข้าไปยัง Web Site ใด Web Site หนึ่งแล้วเราจะได้รับความรู้อย่างที่ตั้งใจไว้

ฉะนั้นจะเป็นการดีอย่างยิ่งถ้ามีรวบรวมเอา Web Site ที่มีข้อมูลที่เป็นความรู้ทางด้านวิชาการและตรงกับสายงานวิศวกรรมโยธาไว้อย่างเป็นหมวดหมู่ และแสดงรายละเอียดของ Web Site นั้นออกมา โดยสังเขปเพื่อให้เกิดความรวดเร็วและง่ายต่อการค้นคว้า

โครงงานนี้เป็นการจัดทำฐานข้อมูลทางด้านวิศวกรรมโยธาบนเครือข่ายอินเตอร์เน็ต (Civil Engineering Resources) เพื่อให้การศึกษาหาความรู้ทางด้านวิศวกรรมโยธาที่มีอยู่บนเครือข่ายอินเตอร์เน็ตง่าย สะดวก และรวดเร็วขึ้น โดยข้อมูลที่จัดเก็บจะเน้นเฉพาะข้อมูลทางวิชาการ งานวิจัย กรณีศึกษา การทดลอง ตลอดจนเทคโนโลยีใหม่ๆ ซึ่งได้สืบค้นจาก Search Engine : http://www.yahoo.com เป็นส่วนใหญ่ โดยข้อมูลทั้งหมดจะถูกจัดแบ่งออกเป็น 5 สาขาคือ

- Construction & Management
- Geotechnical
- Hydrology
- Land Surveying
- Structure

การแสดงผลข้อมูลที่ได้จะอยู่ในรูปของดัชนี (Index) ที่แสดงบทคัดย่อของแต่ละ Web Site ออกมาในรูปของ Web Page : Civil Engineering Resources ที่อยู่บนเครือข่าย Internet สามารถเข้าไปศึกษาได้ที่ Web Site ของคณะวิศวกรรมศาสตร์ มหาวิทยาลัยนเรศวรที่ URL : http://www.eng.nu.ac.th/ ในส่วนของภาควิชาวิศวกรรมโยธา (Department of Civil Engineering) แล้วเข้าไปสู่ Link ของ Civil Engineering Resources

ภาคผนวกนี้ได้จัดทำขึ้นเพื่อใช้เป็นข้อมูลอ้างอิงถึง Web Site ที่ได้ทำการสืบค้นจากดัชนี (Index) ของ Search Engine : http://www.yahoo.com/ และจาก Search Engine ที่มีอยู่ใน Web Site ที่ช่วยในการค้นหา โดยได้เรียงลำดับ Web Site ตามสาขาที่กล่าวข้างต้น แบ่งออกเป็น 2 เล่ม คือ

➢ เล่มที่ 1 : ประกอบด้วยเนื้อหาของ 2 สาขาคือ

1) **Construction & Management**

2) **Geotechnical**

➢ เล่มที่ 2 : ประกอบด้วยเนื้อหาของ 3 สาขาคือ

1) **Hydrology**

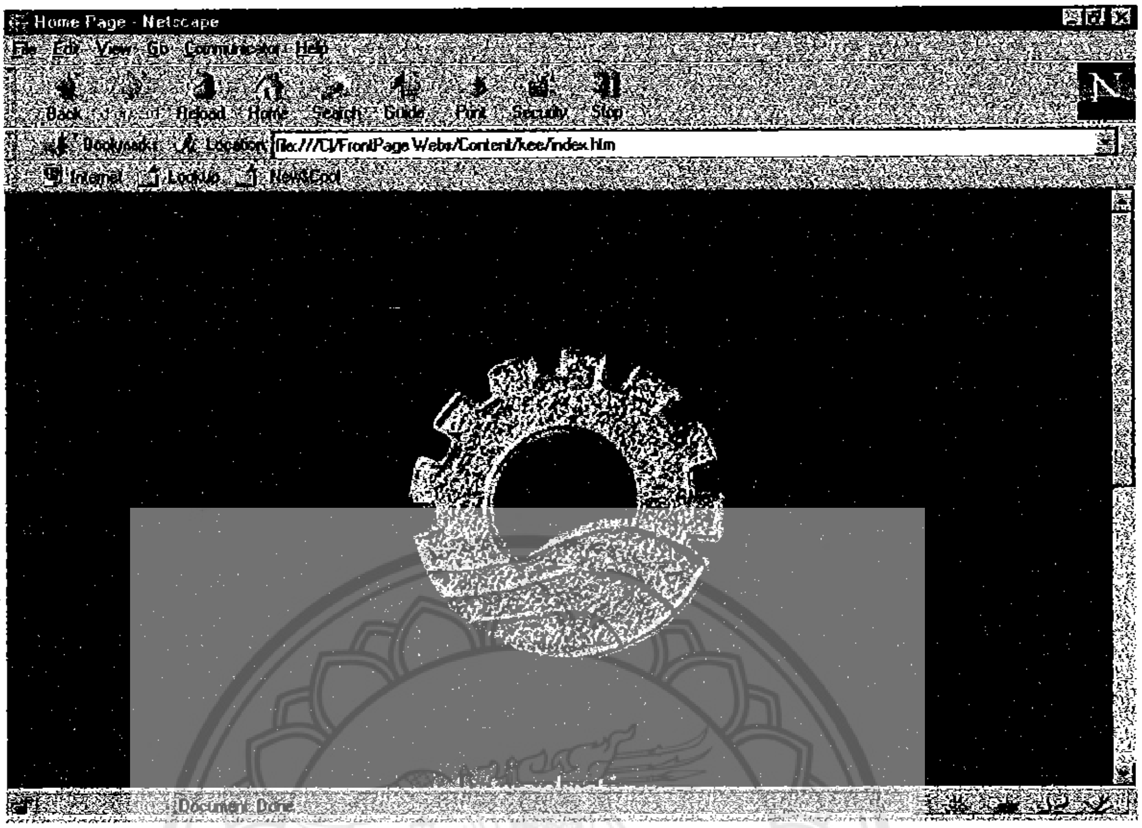
2) **Land Surveying**

3) **Structure**

และได้แสดง Web Page ในแต่ละสาขาประกอบ เพื่อใช้เป็นสารบัญลำดับ Web Site ที่ได้สืบค้น

ผู้ดำเนินงานวิจัย

นายพีรพงษ์ ทีฆภัทรดิลก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Back Reload Home Search Guide Print Security Stop
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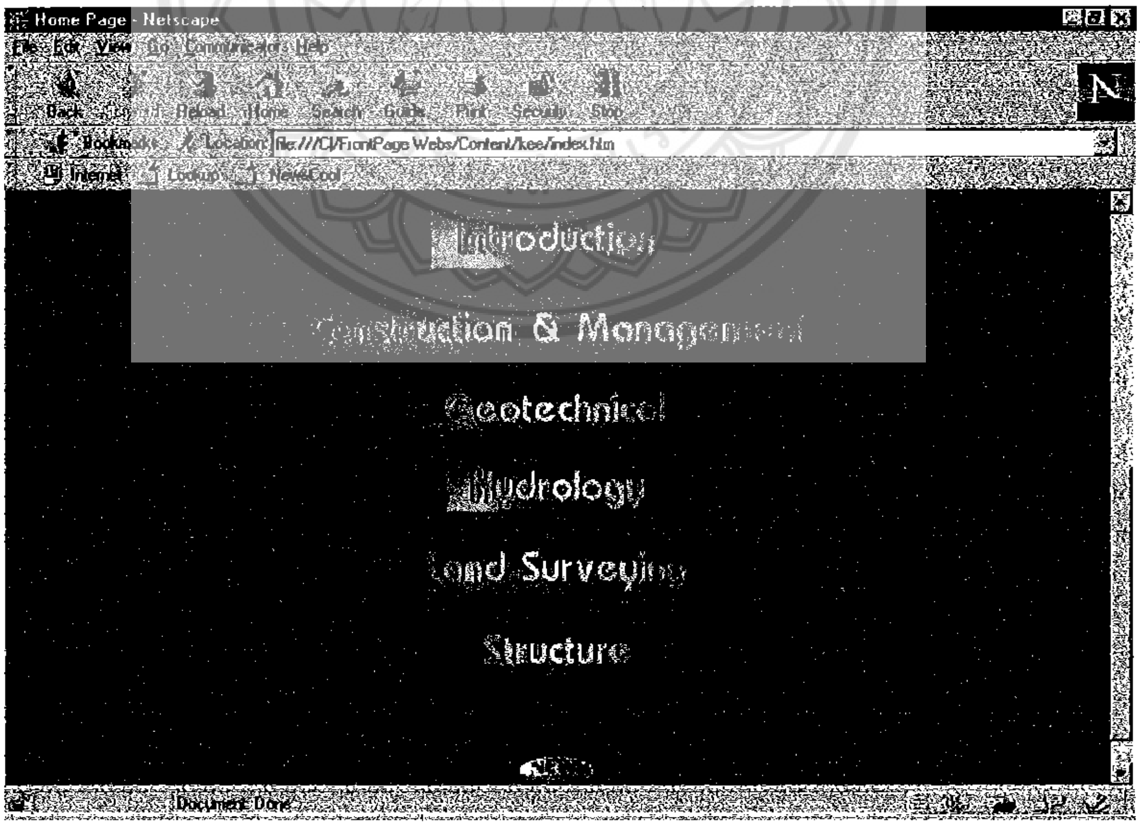
Document: Done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Introduction

The Civil Engineering Resource is a web site which present information about Civil Engineering. This web site has combined a lot of useful knowledge's which involves to Civil Engineering. Education that can be devoid into 5 section :

- Construction & Management
- Geotechnical
- Hydrology
- Land Surveying
- Structure

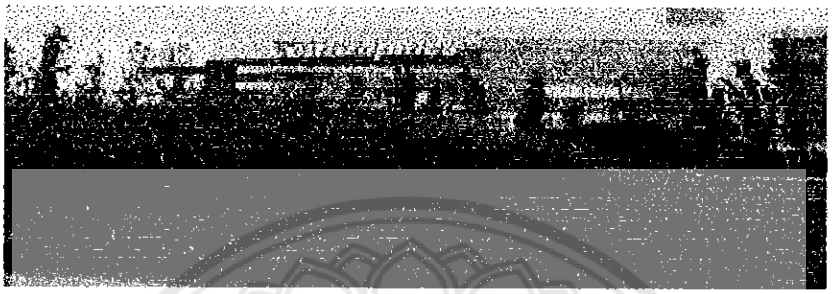
Our purposes want to use the Civil Engineering Resource as a Search Engine for searching the information and to emphasize learning from experiments in laboratory , research , case study as well the fundamental knowledge in many parts of Civil Engineering.

We wish this Civil Engineering Resource would be useful to every visitors who want to know about Civil Engineering. If you have encountered anything which incorrect an error in this web site , don't hesitate to inform me.

Faculty of Engineering Naresuan University

sombat@hotmail.com

Construction & Management



- *Internet Center for the Construction Industry : Building Web*

  http://www.buildingweb.com/

  - **Construction Products**
  - **Professional Service**
  - **Association-Council-Institute**
  - **Civil & Structural Engineering**

- *Engineering & Construction Division : U.S. Army Corps of Engineering's*

  http://www.hq.usace.army.mil/cemp/mainmp.htm

  - **Construction and Design Branch**
  - **Cost Engineering & Program Formulation Branch**
  - **Medical Facilities Office**
  - **Architect and Master Planning Team**

Value Engineering Branch

Guide to NIST :

http://www.nist.gov/public_affairs/guide/

Materials Science and Engineering Laboratory

Building and Fire Research

Information Technology Laboratory

The Construction Specifications Institute:

http://www.csinet.org/

Construction Specifier Index :

http://www.csinet.org/specify/csindex/csindex.htm

This Index encompasses the entire listing of features , department , and columns published in the Construction & Management

Concrete Block Insulating System : CBIS

http://www.cbisinc.com/

Property , Type , Design of Concrete Block Insulating System for Energy Efficiency and

Modern Masonry

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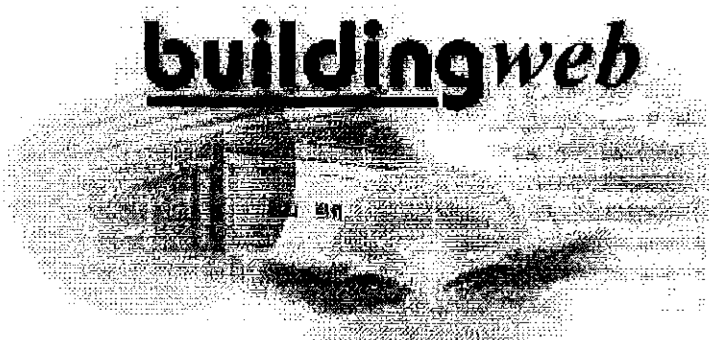
ICON Insert

HI-R Wall System



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06: Wood & Plastic
07: Thermal & Moisture Protection
08: Doors & Windows
09: Finishes
10: Specialties
11: Equipment
12: Furnishings
13: Special Constructio
14: Conveying Systems
15: Mechanical
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17: Environmental

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General Construction Categories

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Construction Products

01: General

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- Office Equipment and Supplies
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- Construction Facilities
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- Miscellaneous

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03: Concrete

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04: Masonry

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08: Doors and Windows

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- Wood & Plastic Doors
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09: Finishes

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- Metal Toilet Compartments
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- Fluid and Waste Disposal Equipment
- **Food Service Equipn**
- Industrial and Process
- Laboratory Equipment
- Medical Equipment
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- **Auditorium & Theater**
- Interior Plants / Planters

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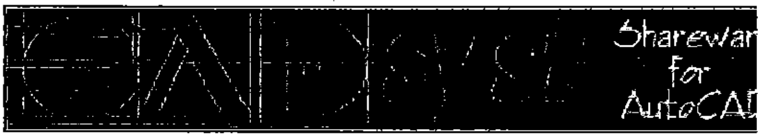

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13: Special Construction

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- Water Conditioner
- Centrifugal Water (
- Cooling Towers
- Condensers
- Heat Exchangers
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- Dehumidifiers
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- Ductwork Access
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Welcome to the U. S. Army Corps of Engineers Headquarters Directorate of Military Programs

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CREATE WEB PAGES

Welcome ! William A. Brown Sr., P.E., became Deputy Director of Military Pr Headquarters U.S. Army Corps of Engineers 1997. Mr. Brown's previous assignment was Program Management Division, Directorat Construction. [Brief background li

NEW LINKS to WEB PAGES

ACASS

Managing Military Design & Construct Programs

Formerly Utilized Sites Remedial Acti Program (FUSRAP)

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Programs Management

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[List of Divisions within Military Programs:
Engineering&Construction; Management Support Center;
Environmental; Programs Management; Installation_Support
Liaison Office: CPW]

The POC for this page:

Lisele Okojie, HQUSACE (CEMP-EE),
lisele.okojie@inet.hq.usace.army.mil

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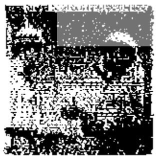
The Military Programs Divisions and associated topic list



ENGINEERING & CONSTRUCTION DIVISION - **[CEMP-E]**

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- *Organization of CEMP-E*
- *Staff Notes*

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Deputy Chief, James R. Jones, P.E.

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●Installation and Management Support Team;
●Construction and Design Evaluation Team

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- Partnering
- Construction Policy
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- **Cost Engineering & Program Formulation Branch [CEMP-EE]**

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- *MILCON Programming and Economic Analysis*
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- **Medical Facilities Office [CEMP-EM]**

●Architecture and Project Direction Team;
●Engineering and Technical Management Team

- *Functions*
- *Example Projects*
- *ARMS*

- **Technical Engineering Branch [CEMP-ET]**

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- **Civil and Structural Engineering Team;**
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- **Mechanical Engineering Team**

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- **Value Engineering Branch [CEMP-EV]**

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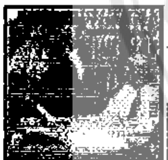

MANAGEMENT SUPPORT OFFICE - **[CEMP-ZM]**

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- *Contracting Opportunities*
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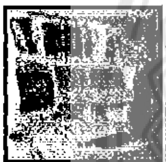
- Hazardous, Toxic, Radioactive, Waste Center of Expertise (HTRW-CX)
- Environmental Initiatives
- Installation Restoration Branch [CEMP-RI]



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  - Construction Appropriations Control and Execution System - CAPCES
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- DEFENSE AGENCIES/SUPPORT FOR OTHERS BRANCH,
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- AIR FORCE BRANCH, AND
- POLICY BRANCH

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Directorate of Military Programs
Construction and Design Branch

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Telephone Number: 202-761-4804

E-mail james.lovo@usace.army.mil

***Construction and Design Branch** is responsible for establishing and directing construction management activities for all military programs and for performing related services for other federal construction programs assigned to USACE worldwide. Establish policies for execution of the military, civil works and support for others construction management process. Execute the worldwide construction quality assurance program. Manage military program resource and manpower requirements. Manage the USACE Installation Support program. Manages the USACE Architect-Engineer Contracting Progam.*

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Construction News
December 1997

A-E Contracting Bulletin 98-02, Subject: Six Percent

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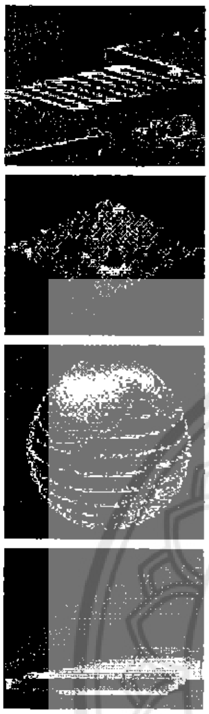
RMS - Resident Management System

Construction Recognition Programs

Links to Industry

Guide to NIST



- Welcome!
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- Manufacturing Extension Partnership
- National Quality Program
- Laboratory Programs
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- Research Facilities
- Office of the Director
- Office of the Chief Financial Officer

- Search the *Guide to NIST*

You are viewing the electronic version of the *Guide to NIST*, a catalog of NIST programs, projects, and services. Based on the September 1996 printed Guide, the information contained here is updated periodically to reflect major program changes and changes in contacts. Send questions or comments to Sharon Shaffer.

National Institute of Standards and Technology

NIST HomePage

Measurement and Standards Laboratories

Higher quality products, more reliable and more flexible processes, fewer rejected parts, speedier product development, more efficient market transactions, higher levels of interoperability among machines, factories, and companies. These are some of the practical advantages that U.S. companies realize from the NIST laboratories' research, services, and standards-related activities. The ultimate U.S. reference point for measurements with counterpart organizations throughout the world, the laboratories provide companies, entire industries, and the whole science and technology community with the equivalent of a common language needed in nearly every stage of technical activity. In furthering the technical aims and capabilities of U.S. industry, the NIST laboratory program serves as an impartial source of expertise, developing highly leveraged measurement capabilities and other infrastructural technologies.

Several hundred laboratory projects are under way at NIST during a single year. Some relate to the evolving needs of mature industries such as steel, machine tools, automobiles, and chemical processing. Others concentrate on the technical challenges confronting emerging industries such as those sprouting from advances in nanotechnology or the ones facing established high-technology sectors undergoing rapid technology change such as microwave communications. NIST has stepped up efforts to address the infrastructural needs of the biotechnology and information technology industries as well as others pursuing commercial prospects in young, rapidly developing areas of technology.

Contact: HomePage

Examples of NIST Lab Projects

The examples of recent accomplishments described below are a small sampling of laboratory activities. They illustrate the ways in which NIST is carrying out its mission to provide infrastructural support to U.S. industry.

- NIST measurements are vital to the functioning of the entire economy, helping to ensure fairness and efficiency in the sale of more than $2 trillion worth of goods and services. Accurate and uniform measurements of weight, size, volume, and other quantities maximize efficiency and promote customer confidence in the sale of goods ranging from lunch meat at the deli counter to natural gas flowing through transnational pipelines to ultrapure gases purchased by semiconductor manufacturers.

- NIST tools and services are the ultimate references for the hundreds of millions of measurements made daily by U.S. companies, small and large. More than 350 different NIST-developed measurement tools and services are embedded into the quality control systems of the automotive industry--from small suppliers of metal parts to large refiners of gas and oil. Virtually all U.S. semiconductor manufacturers depend on NIST-developed test methods to evaluate their raw materials, processes, and products. The entire U.S. steel industry relies on more than 125 NIST Standard Reference Materials in assessing the quality of raw materials and finished products.

- Women getting mammography exams at licensed U.S. facilities will have greater assurance of receiving proper X-ray exposures thanks to a new NIST radiation standard and instrument calibration facility. The new facility will allow the operators and inspectors of more than 10,000 U.S. mammography centers to trace the accuracy of their X-ray exposure measurements to the primary X-ray standards at NIST. The calibration facility was established to help the U.S. Food and Drug Administration implement the Mammography Quality Standards Act of 1992.

- A NIST computer model that compensates for a common source of error in coordinate measuring machines (CMMs) promises to increase greatly manufacturers' ability to check accurately the shape and dimensions of products. The new "SuperFit" software corrects "probe-lobbing" errors, a chronic and relatively large source of measurement uncertainty in 98 percent of the 30,000 CMMs in U.S. factories and laboratories.

- NIST researchers have produced quantitative images of dopant densities in semiconductor circuits with 20 to 30 nanometer (billionths of a meter) resolution. The achievement brings the industry closer to meeting a key requirement of the National Technology Roadmap for Semiconductors for producing next-generation microcircuits by the year 2000. Dopants are chemical elements such as boron or phosphorus that are introduced into silicon and other semiconducting materials to selectively change their electrical characteristics.

- NIST scientists completed work on a fingerprint classification system for the Federal Bureau of Investigation (FBI) that helps to automate the last step in fingerprint analysis done completely by hand. For the last 30 years, NIST researchers have worked with the FBI to speed up the process by which fingerprint evidence is matched against the FBI's files--currently some 30 million sets of fingerprints.

- A new NIST quality assurance standard will help forensic and medical laboratories ensure that DNA profiles made with the polymerase chain reaction, or PCR, method are accurate. PCR is a relatively new method of DNA analysis that produces results in hours rather than the weeks required for earlier methods and requires only tiny amounts of DNA, such as the few cells carried in saliva left on a cigarette butt or a postage stamp.

- Working in collaboration with engineers at Howmet Corp., Whitehall, Mich., NIST researchers have developed an X-ray sensor that could take some of the guess work out of turbine blade technology. Manufacturers of jet turbine blades often can't tell if a blade has been "cooked" right until they remove the mold and take a look. The NIST system should allow manufacturers to optimize their processes so that they consistently grow single-crystal blades in the shortest amount of time.

- In collaboration with voluntary standards organizations, NIST has developed a standard, called BACnet, to allow interoperability of heating, ventilating, and air conditioning control systems in buildings. NIST worked with a consortium of 17 companies to test their prototype products implementing the standard. Use of the standard should lead to competitive, open procurement; integration of separate systems; and increased energy efficiency.

Technology Services and Products

NIST provides many different technology services and products to help U.S. industry improve the quality, reduce the cost, and increase the competitiveness of its products. Examples include Standard Reference Materials,Standard Reference Data, calibration and laboratory accreditation services, and evaluations of energy-related inventions.

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The Construction Specifications Institute

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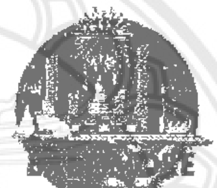

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▶ Spring Seminars Are

Volunteers Nee To Support NST Hotline

The National Scienc is seeking a few good engineers to staff its " Scientist or Engineer" part of its National S Technology Week (I activities, April 26 to year's theme is "Pola Connections," focusi and engineering resea and Antarctic regions knowledge of these re affects everyday livin
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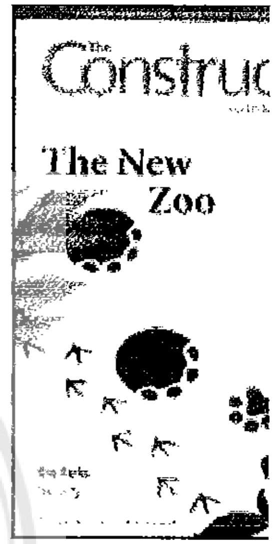

▸ The New Zoo in March's Onli

This special online ve *Construction Specifi* the "The Evolution Computer-Aided Fa Management" and " Techniques for a Co Design Schedule. Ch
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Manual of Practice and its component modules are a comprehensive reference containing theories, techniques, and formats to aid you in every aspect of construction documentation.
Check here for descriptions of CSI's Format Documents including UniFormat™, MasterFormat™, SectionFormat™ and PageFormat™.
CSI's Supplemental Documents include Abbreviations, Sources of Contruction Information, Standard Reference Symbols and others.

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▶ Catch Up With E-Week

E-Week is over, but you can still experience the multitude of events. Consult our E-Week Schedule at a Glance.

How can future office buildings be made healthier places to work? How is office automation and

▶ Here's an Op[p] To Sharpen You[r]

CSI members are invited to participate with members of **APPA: The Association of Higher Education F[a] Officers** in a special s[...] will help them improv[e] productivity. **"Indivi[dual] Effectiveness Skills,** of APPA's Profession[al] Center, will take plac[e] 29-April 3, 1998, at S[tanford] University in Stanfor[d]

The seminar curricul[um] customized for faciliti[es] professionals by the Franklin-Covey Lea[dership] Center, which bases i[ts] on the best-selling "T[he 7] Habits of Highly Effe[ctive] and "Principle-Center[ed] Leadership," authored [by Stephen] R. Covey.

CSI members' eligibili[ty] APPA seminar stems [from a] five-year alliance betw[een] organizations to provi[de] members access to enh[anced] services and advance t[he] technology and qualit[y] construction and man[...] North America. For m[ore] information and to re[gister] APPA's web site. Or [call] Cotrena Aytch at APP[A] 684-1446 ext. 235.
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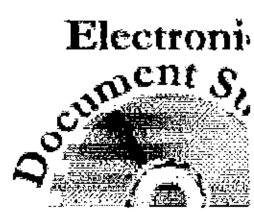

furniture design improving people's productivity? What changes can we expect in **mechanical, electrical and structural systems?** A panel of **eminent engineers** recently addressed these and other questions in an online discussion. Read a **transcript** of the online chat session, co-sponsored by CSI and ***Engineering News-Record***.

Read Messages from the 1998 Chairs of E-Week: **W. W. Allen, P.E.**, Chairman and CEO, Phillips Petroleum Company, and **Robert B. Molseed, FCSI, CCS**, 1998 President, Construction Specifications Institute.

The National Building Museum in Washington, D.C., will highlight "The Creative Engineer" in an exhibition celebrating the Year of the Engineer.

As co-sponsor of National Engineers Week 1998, CSI is planning a variety of events. Read more about it and visit the E-Week web site.

What does cake-baking have to do with E-Week anyway? Sift this!
3/2/98

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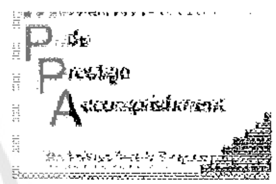

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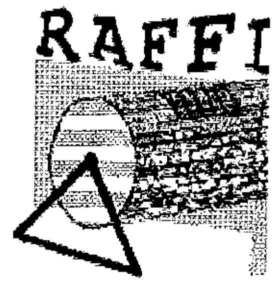

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The Construction Specifications Institute (CSI) is a nation
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continuing education, professional conferences, and product s
enhance communication among all the nonresidential buildin
construction industry's disciplines and meet the industry's ne
common system of organizing and presenting construction d

CSI's more than 17,000 members include architects, engineer
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The Construction Specifier

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check similar categories for related articles.

Note: Some early issues were published quarterly. Readers may find the abbrevia
"WI," referring to the spring, summer, fall, or winter quarter in which the article

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http://www.cbisinc.com
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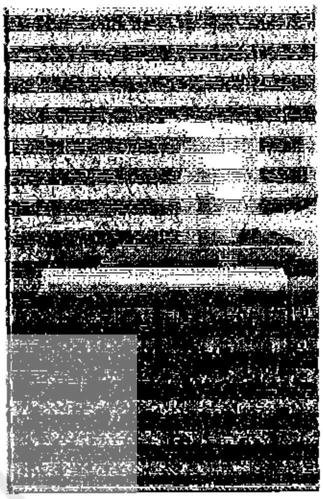

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Building Environmental Science and Technology and Center for Renewable Energy and Su

V1.3 25 June, 1997

Concrete Block Insulating Systems:
Thermal Protection for Today's Buildings

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Advantages

Korfil Inserts

ICON Inserts

HI-R Wall System

Thermal Design Data

Specifications

Energy Codes and Standards

GRACE Construction Products

Using modern preinsulated masonry units, the Garrison Middle School (R) was able to achieve high levels of energy efficiency at modest cost.

Note the use of architectural units and color which can appear on the exterior face of the building since the thermal protection is built in to walls.

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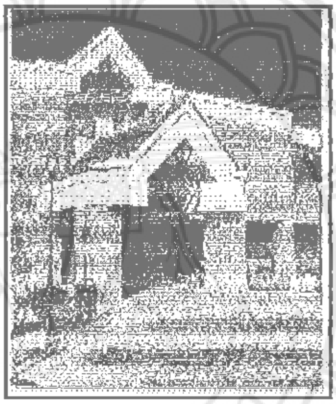
view.
Garrison Middle !



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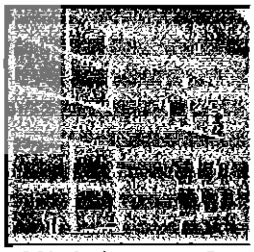
Lake City High - Entrance

Similarly, the Lake
School (L) was des
be both energy eff
and to take advant
environmentally fi
locally produced b
materials -- such a
pre-insulated HI-I

The attractive and comfortable interior is well suited for daylighting due to good thermal protection and high "thermal mass" that tempers the swings in temperature during sunny days, and provides passive solar re-heating of spaces at night to lower utility costs.

Research by the US Department of Energy has clearly shown the benefits of thermal mass, and daylighting buildings. "Mass"



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Lake City High - I

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is now included in model codes and standards.

Photographs: Tom Young, Courtesy NW Concrete Masonry A

Rev. 1.3 / 25 June, 1997

KORFIL U-Shaped Insulation Inserts

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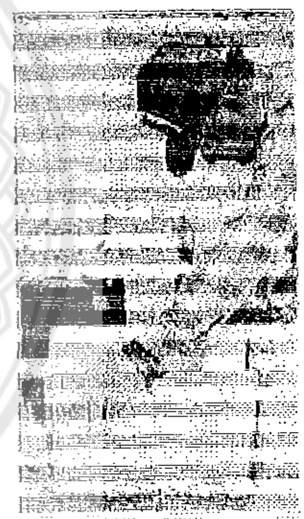
This original version of KORFIL is composed of Block Plant Installed individually molded inserts of expandable polystyrene (EPS) designed to fit tightly against both inside faces of two-core concrete blocks of 6, 8, 10 and 12 inch thickness.

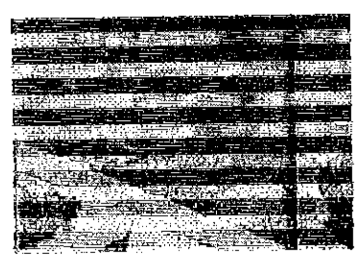
Block plant labor instal
so mason labor can be m

The type of Korfil best suited is dependent on the type of block selected and the energy code requirements for the particular location and building use. KORFIL inserts are designed to insulate that portion of the block known as the Core Area. By improving the heat flow balance between the three primary heat paths, Core Area, Web Area and Mortar Joint Area, the wall surface temperature variations are significantly reduced.



Here a mason contractor e
insulated wall containing

All KORFIL Products have been tested to determine their thermal capabilities and advantages. KORFIL's thermal capabilities are qualified by testing procedures approved by the American Society of Testing



Materials (ASTM), using the ASTM(C236-80) "Guarded Hot Box" Test. The tests were performed by the ***University of Rhode Island***'s Chemical Engineering Department and ***Dynatech Research Corporation*** of Cambridge, Mass.

Tests have been conducted on reinforced and grouted concrete masonry walls to demonstrate that the presence of KORFIL inserts does not significantly affect the structural characteristics of this type of construction.

The physical tests were conducted in the ***National Concrete Masonry Association*** (NCMA) Research and Development Lab in Herndon, VA, USA.

Reinforced concrete ma designed with pre-insulate without removing *KORFIL pre-insulated co units were approved as an . of construction in A (ICBO Research Repo*

Test results were sub to the Research Comn the International Con of Building Officials (I part of an application : Research Approval.

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ICON *Universal Insulation Inserts*

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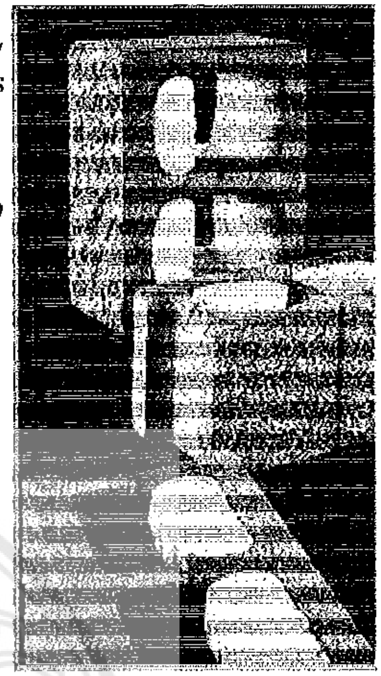
Like the original KORFIL U-shaped inserts, ICON is designed to be Block Plant Installed in the CMUs prior to delivery to the job site.



Block plant labor installs the
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productive.

ICON's unique patented design allows one size insert to fit all sizes of block cores -- whether 6, 8, 10 or 12 inches wide units.

ICON and KORFIL U-shaped inserts have been shown to have similar thermal characteristics.

ICON inserts are designed to insulate that portion of the block known as the Core Area. By improving the heat flow balance between the three primary heat paths, Core Area, Web Area and Mortar Joint Area, the wall surface temperature variations are significantly reduced.

Applicable Standards

ASTM C578-90 replacing Fed. Spec. HH-I-524C; 1, specification for Preformed Cellular Polystyrene Thermal Insulation.

ASTM C90-90 Specification for Hollow Load Beari Concrete Masonry Units.

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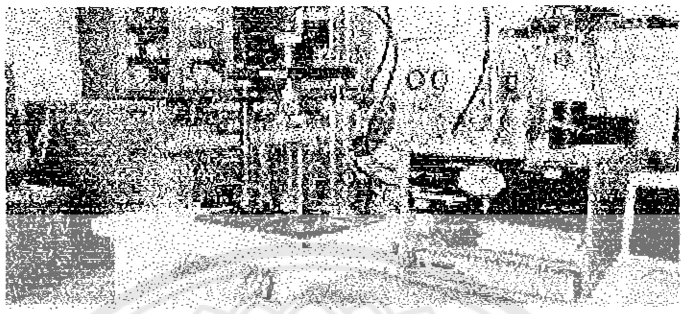
Geotechnical



- *Selected Research Project for Geotechnical:Northern University*

  http://www.civil.nwu.edu/geotech/research.htm

  - **Blast Vibration Analysis**
  - **Predicting Field Behavior of a Braced Cut in Clay**
  - **Fracture Propagation**
  - **Plane Strain Compression Device**
  - **Blast Densifacation of Sand**
  - **Physical Chemistry of Waste in Soil**
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- **Nondestructive Elevation of Deep Foundation**
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- **Penetration of Clay Soil by Chlorinated Solvents**
- **Time Domain Reflectrometry**

- *Geotechnical Laboratory : Delft University of Technology*

  http://dutcgeo.ct.tudelft.nl/home_e.htm

  The Geotechnical Laboratory is a section of the Faculty of Engineering and Technical Geosciences and is organized around the chairs of Geomechanics , Ground Water Mechanics and Foundation Engineering

- *The Bechtel Geotechnical Laboratory : Purdur University*

  http://ce.www.ecn.purdue.edu/~geowww/LAB/

  - **Consolidation Frame**
  - **Permeability Testing**
  - **Cyclic Triaxial Testing System**
  - **MTS Triaxial Testing Machine**
  - **Resonant Column Device**
  - **Direct Shear Apparatus**

- **For Information on Lab Facilities at Purdue University**

- *Soil Mechanics and Geotechnical Engineering Research : Oxford University*

  http://www-civils.eng.ox.ac.uk/soils.html

  - **Offshore Foundation**
  - **Institute Testing**
  - **Trenches Technology**
  - **Reinforced Soil**
  - **Soft Clays**
  - **Unsaturated Soils**
  - **Theoretical Modeling of Soils**
  - **Settlement Damages**

- *Slope Design Home Page:*

  http://www.dur.ac.uk/~des0www4/cal/slopes/index.html

  About Slope Stability Analysis , Remedial and Corrective Measures for Failing Slopes , Slope in Real World , and Sample Slope Stability Problems.

- *Vibration and Waves Animations :*

  http://apollo.gmi.edu/~drussell/Demos.html

  The Links below contain animations which visualize certain concepts concerning Vibration and Waves . The choice of

[illegible] with topics covered in the course [illegible]

Fundationtals of Acoustic...

- **Vibration**
- **Mechanical Waves (Acoustics)**
- **Electromagnetic Waves (Optics)**

- *Soil Dynamics and Geotechnical Earthquake Engineering : Princeton University*

  http://www.ceor.princeton.edu/~radu/recpub.html

  Recent publication relate to research in Soil Dynamics and Geotechnical Earthquake Engineering ;Spatial Variability of Soil Properties , Constitutive Relations for Soil Materials , Centrifuge Validation of a Numerical Model for Dynamic Soil Liquefaction ,etc.

- *The Shilstone Companies :*

  http://www.shilstone.com/public/CIVLIST.HTM

  The list of civil engineering resources is brought to you by The Shilstone Companies. We also have online a list of concrete-related design and construction association.

  - **BBSs**
  - **Mailing lists**
  - **University web pages**
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- **Telnet sites**
- **FTP site**
- **gopher sites**
- **Usenet newsgroups**

Selected Research Projects

- Blast Vibration Analysis
- Predicting Field Behavior of a Braced Cut in Clay
- Fracture Propagation
- Plane Strain Compression Device
- Blast Densification of Sand
- Physical Chemistry of Wastes in Soil
- Thickened Slurry Disposal
- Pile Load Testing Without a Load Frame
- Modeling and Analysis of Mining-Induced Subsidence
- National Geotechnical Experimentation Site
- Nondestructive Evaluation of Deep Foundations
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Blast Vibration Analysis

Evaluation of the effects of blasting vibrations on structures involves three steps: 1) estimation of ground motions produced by the blast, 2) evaluation of a structure's response to that motion, and 3) establishment of structural response limits to prevent cracking. Research in structural dynamics has shown that structures respond differently when excited by vibration, equal in all respects but differing by principal excitation frequency. Research is being conducted in all three areas a Northwestern. Topics include ground motion from unusual situations, such as blasts in soil; comparison of Fourier and single degree of freedom response spectra; before and after blast crack inspection to isolate natural cracking from blast induced cracking; and development of computerized instrumentation for remote monitoring of both excitation and structural response.

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Predicting Field Behavior of a Braced Cut in Clay

Field measurements of performance of earth and earth-supported structures are the ultimate measure against which design methodologies and analytical techniques are substantiated. While developments in constitutive modeling have proliferated in the past decade, documentation of field performance of soil behavior has been left behind. The purposes of this research were to measure complete foundation soil response during and after constru- ction of a deep, braced excavation in clay, and to evaluate effects of common assumptions made to predict these responses. Northwestern installed field instrumentation, performed in situ tests, collected field performance data for both the embankment and deep excavation, conducted an extensive laboratory testing program, and performed finite element simulations of the braced cut construction. Amisotropic effective stress models based on the laboratory test results were coupled with fluid flow equations to allow computation of pore pressures through time.

Last revision date: 2/27/97

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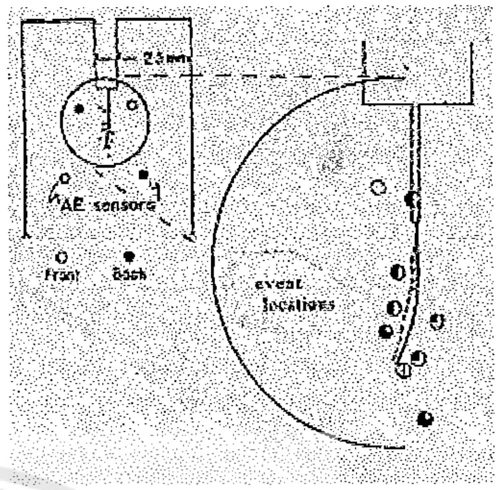
Fracture Propagation

Many theoretical models explain fracture propagation in materials such as concrete and rock, but there is little experimental data for comparison. The experimental difficulty always has been to measure, from the outside of a specimen, the fracture process occurring inside. New techniques using source characterization, wave propagation, and digital signal processing allow for interpretation of micro seismic motions for Acoustic Emissions (AE) time histories to map fracture propagation within a body. The new technique enables the distinction of various modes of deformation, as well as event location along an internal fracture front. This research aims for basic understanding of fracture propagation at the microscopic level.



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Plane Strain Compression Device

An internally instrumented plane strain compression device is used to study failure processes in soils. The bottom platen fits in a sled that is free to slide on linear bearings which allows kinematically unconstrained formation of shear bands. Four load cells permit the measurement of axial force, eccentricity of the applied load, and friction along the side walls. Four load cells are embedded in an aluminum sidewall to measure out-of-plane loads, allowing a full evaluation of the boundary forces during consolidation and shear. Seven displacement transducers measure axial and lateral displacements of the specimen and horizontal movement of the sled. Pore water pressure at the top and bottom of a specimen, as well as the cell pressure, is continuously monitored by pressure transducers. Special pore pressure transducers can be mounted on the side of the specimen when testing cohesive soils. Output signals of these transducers are linked to a PC which controls all operations. Software has been developed to apply any stress path in plane strain conditions. The use of a plexiglass side wall allows photographs of the deforming specimen to be taken. These photos can be analyzed using stereophotogrammetry to develop internal displacement fields and thus internal strains.

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Blast Densification of Sand

Blast densification has been employed as a viable and efficient method for improving loose, saturated, cohesionless soil since the 1930's. Unfortunately, the vibration disturbance of adjacent facilities is not an insignificant disadvantage. Laboratory studies at Northwestern have shown that dividing the blast into a number of small charges of explosives that are delayed from each other by as little as 25 one thousandths of a second can reduce vibration while still densifying the soil as efficiently as larger charges. Cone penetration resistance (a measure of sand density), continued to increase over time indicating penetration tests conducted within a few days of blasting are not indicative of the soil's ultimate density. These experiments are being repeated in the field to investigate the influence of boundaries and experiment size on the laboratory based conclusions.

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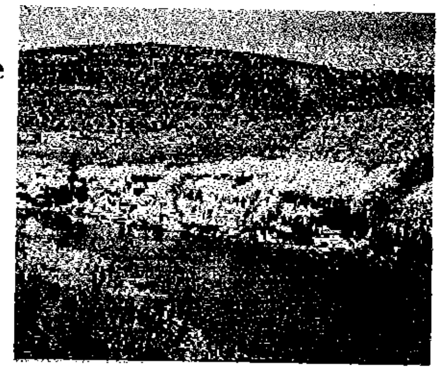
Physical Chemistry of Wastes in Soil



Tailings from the acid-leach processing of uranium ore pose a low level radioactive waste disposal problem, due to the extremely acid nature of the waste and its content of radium and radon. Of primary geotechnical interest is the transport and fate of radium in seepage from the tailing's impoundments; ideally, one hopes for a hydrogeochemical model amenable for use as a predictive tool, not only for long-term transport of this element from impoundment sites, but also for disposal site selection in the case of any wastes containing radium. Obstacles to the successful development and application of such models include ignorance of the precipitation-dissolution and absorption-desorption behavior of radium in waste and in subsurface geomaterials as functions of the chemical and physical milieu. These physico-chemical aspects of uranium mill tailings, and of ore producing wastes such as phosphogypsum and bauxite muds, are under study at Northwestern. One offshoot of these studies is the development of a relatively new breed of geotechnical engineer, i.e. individuals with the background and expertise to apply chemical and physico-chemical concepts to the general problem of chemical waste disposal in the earth.

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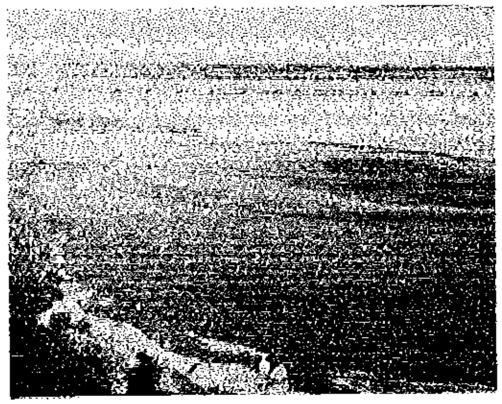
Thickened Slurry Disposal



This research consists of optimizing a waste disposal process wherein a thickened slurry is pumped into a diked contaminant area and allowed to desiccate before an overlying layer is placed. The interaction among the various aspects of this problem is very complex, and considerable experimental and analytical effort is being directed toward developing a descriptive mathematical model. The rheological properties of the thickened slurry must be such that a relatively thin layer with broad areal dimensions will be formed as the material is pumped. The deposition process is complicated by the fact that the underlying layer is dewatering the newly placed layer due to a

difference in soil-water potential. Once the new layer is deposited, desiccation begins due to atmospheric conditions, and the succeeding layer should not be placed until an appropriate gain in strength and dry density has been achieved. This project has involved extensive laboratory and field work, and it had led to the development of an equilibrium mathematical model for the deposition process and several empirical correlations for the mechanical properties.

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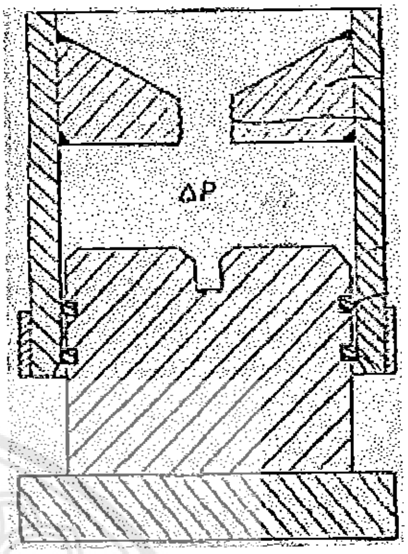
Pile Load Testing Without a Load Frame



Jorj O. Osterberg has developed a new device for field testing the bearing capacity of driven piles that eliminates the need for a several hundred ton dead weight load frame. Instead, a flat jack, which is attached to the bottom of a pile before driving, uses the friction between the pile and the ground as a reaction for applying load. The device is capable of measuring separately skin friction and end bearing. It has many advantages over the conventional load testing method. It enables test performance in a fraction of the time required for a conventional test. The frictional and end bearing resistances can be determined separately. Because of its low cost and ease and speed of testing, the device can be used as a "proof tester" during production pile driving by quickly testing one out of 50 or 100 piles. Field research is being conducted to compare load test results from this device and conventional methods.

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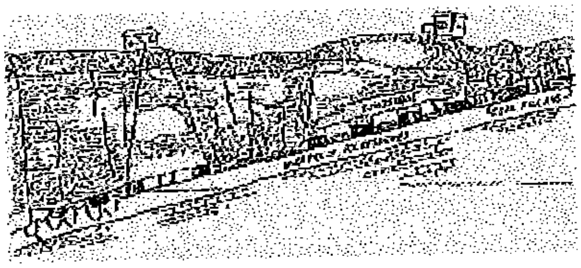
Modeling and Analysis of Mining-Induced Subsidence



Removing coal with longwall mining techniques causes overlying rock to cave and deform, which leads to a settlement trough on the surface. To characterize the deformation and stress redistribution within the rock mass, federal agencies have implemented a number of comprehensive field instrumentation programs. The Northwestern University Rigid Block Model (NURBM) and a CAD work station are employed to analyze this data by numerically simulating coal mine subsidence and thereby gain insight into the rock mass properties responsible for the behavior. Development of a model will allow prediction of ground movement to assist mine planning and aid assessment of surface effects.

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National Geotechnical Experimentation Site

The lakefill on the campus is the setting for a National Geotechnical Experimentation Site (NGES), one of five such sites in the US supported by the National Science Foundation and the Federal Highway Administration. One of the major drawbacks of conducting full scale geotechnical engineering research is the expenses associated with site characterization. The NGES site at NU has been subjected to intensive site characterization, including both in situ and laboratory tests. Three full scale experiments have been conducted on the site. Axial load tests have been conducted on 50-ft long driven piles and drilled shafts over a period of 43 weeks. These experiments formed the basis of a pile prediction symposium held in conjunction with the 1989 Foundation Engineering Congress held at NU. Three groups of drilled shafts, with lengths as much as 90 ft and diameters as large as 3 ft, with pile caps form the basis of a test section for non-destructive evaluation of existing deep foundations. A micropile test section has been constructed wherein 7 micropiles where installed, load tested in axial compression, and then extracted to quantify the as-built geometry of the piles.

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Nondestructive Evaluation of Deep Foundations

Concern of the aging of the nation's infrastructure has sparked interest in procedures to evaluate the conditions of existing structures. This project focuses on techniques which can quantify the condition of drilled shafts and driven concrete piles as they exist in the ground. Techniques such as the impulse response, the sonic echo, parallel seismic and cross hole sonic logging are applied to the groups of drilled shafts located at the NGES at NU. The most promising approach in terms of simplicity in experimental procedures and quantifiable information is the impulse response method. This method can provide information concerning concrete quality and pile length and continuity. It has been extended such that the effects of intervening structure between the shaft and the test location can be considered. Several in-service bridge piers have been successfully analyzed. Field and theoretical work is ongoing to further extend the method by using multiple transducers to receive signals and by considering the dispersive nature of the interface waves which propagate along the soil-shaft interface.

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Failure Processes in Soils

Characterizing the behavior of soil near and beyond peak stress levels has proven to be quite challenging due to the occurrence of localized strains. When a shear band intersects a specimen, deformation is concentrated within the localized zone, and is essentially arrested elsewhere. Consequently to gain insight into the post-peak softening and critical state behavior, focus must shift towards the continued deformation within the shear band. A non-invasive analysis technique based on stereophotogrammetry has been develop to quantify the deformation within a shear band. This quantification of local stress and strain behavior within a shear band provides unique insight into the nature of load softening and the existence of a critical state. Work to date on sands indicates that the post-peak softening response, although coincident with shear band formation, can be attributed in part to decreasing dilatancy within a persistent shear band. Furthermore, there is not a unique critical state void ratio for a given mean normal effective stress. Work to date on clays indicates that excess pore pressures develop near the band as it forms, which are not discernible with typical pore pressure measurements. More experimental work is needed to sufficiently quantify these responses for a variety of materials. Theoretical work is ongoing which will incorporate these observed responses into the framework of a constitutive model.

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Fault Gouge Constitutive Responses

An appropriate constitutive model for fault zones is a critical element in understanding the earthquake process, properly interpreting field observations, and using models to anticipate future behavior and to design observational strategies. The purpose of this work is to help understand earthquake processes by providing physical property data and conceptual insight into viable earthquake models. Specifically, the work provides direct experimental evidence of the relation between critical sliding distance and shear band thickness of granular fault gouge material and to quantify the dependence of volumetric strain in a shear band on the rate of shearing. The onset of shear banding in gouge material will also be directly quantified in experiments in a heavily instrumented, plane strain compression device which permits the deformation process to be recorded photographically. By conducting tests under both drained and undrained conditions, the relative effects of alteration of pore pressure by dilatancy can be compared to those of intrinsic rate and state effects.

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Air Sparging/Soil Vapor Extraction for Contaminated Site Remediation

A pilot-scale air sparging/soil vapor extraction system was designed and built at a contaminated site in Columbia, South Carolina. The soils at the site are sandy clays and clayey sands that have low intrinsic permeabilities and exhibit heterogeneity. The pilot system was implemented to investigate the feasibility of air sparging/soil vapor extraction to address contamination by gasoline hydrocarbons in this low permeability environment. The pilot system was able to remove a substantial amount of hydrocarbons from the source area at the site. Well losses and heterogeneities were found to be important to site evaluation, system design, and operation.

Related Publications

Aelion, C.M., J.N. Shaw, R.P. Ray, M.A. Widdowson, and H.W. Reeves, "Simplified Methods for Monitoring Petroleum-Contaminated Ground Water and Soil Vapor," *Journal of Soil Contamination*, 4,3, 225-241, 1996.

Widdowson, M.A., R.P Ray, H.W. Reeves, and C.M. Aelion, "Integrated Site Characterization for SVE Design," *Geoenvironment 2000, Volume 2*, Edited by Acar, Y.B. and Daniel, D.E., ASCE Geotechnical Special Publication No. 46, pgs. 1291-1305, 1995.

Widdowson, M.W., O.R. Haney, H.W. Reeves, C.M. Aelion, and R.P. Ray, "A Multi-Level Soil Vapor Extraction Test for Heterogeneous Soils," *ASCE Journal of Environmental Engineering*, accepted for publiction, 1996.

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Last revision date: 7/18/96

Penetration of Clay Soils by Chlorinated Solvents

Fine-grained sediments are typically thought to prevent the migration of non-aqueous phase liquids. However, high concentrations of trichloroethylene and tetrachloroethylene were found in a clay unit below an unlined settling basin at the Savannah River Site near Aiken, South Carolina. To help understand these observations, experiments with clay cores collected at the site were performed to assess the potential for solvent liquid penetration into the clay. Cores collected from a clay outcrop at the site were subjected to tetrachloroethylene, and the migration into saturated cores and cores at field conditions was assessed after three, five, and eight weeks of exposure. Results indicate that an organic solvent can migrate into the clay under field conditions. Heterogeneities within the clay unit seem to govern this migration.

Related Publications

Reeves, H.W., Lough, K.A., and Goni, M.A., "An Experimental Investigation of Organic Solvent Infiltration into a Natural Clay," *Proceedings of the Fourth Great Lakes Geotechnical and Geoenvironmental Conference: In-Situ Remediation of Contaminated Sites,* Edited by K.R. Reddy, The University of Illinois at Chicago, 1996.

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Last revision date: 6/18/96

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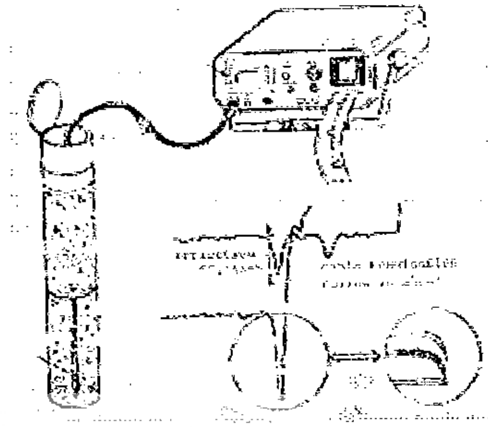
Time Domain Reflectory (TDR) Instrumentation



TDR systems provide an inexpensive means of monitoring in situ rock mass deformation and soil slope instability normally undertaken with extensometers and slope indicators. The system shown in the illustration consists of a voltage pulse generator, recording tester, and a cable grouted in the rock or soil mass. Rock or soil deformation that shears the cable produces electrical discontinuities in the cable, which in turn produces voltage reflections when the cable is pulsed by the tester. Recent developments at Northwestern now allow the reflected voltage pulses to be numerically and quantitatively linked to the type and magnitude of deformation. Future work includes development of new, compliant cables for soft soils, demonstration of the usefulness of telemetry of data, application of TDR technology for the measurement of water and contaminants

Visit the TDR Clearing House for detailed TDR articles. Uses of TDR technology for bridge monitoring may be found at the Infrastructure Technology Institute homepage.

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- TU Delft
- Faculty of Civil Engineering

Welcome at the Geotechnical Laboratory of Delft University o Technology.

The Geotechnical Laboratory is a section of the Faculty of Civi Engineering and Technical Geosciences and is organized arour the chairs of Geomechanics, Ground Water Mechanics and Foundation Engineering.

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- The people who work here
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- See what Geotechnical software is available
- Short description of the courses and other student info
- Some descriptions of current Graduation Projects
- Links to other geotechnical institutes

- Deze pagina is ook in het Nederlands beschikbaar

General questions and remarks can be addressed to Info.Geo@ct.tudelft.nl

 Last edited: Wednesday, March 18, 1998

Geotechnical Laboratory

0 Picture 0

Under Construction
The main hall of the Geotechnical Laboratory is dedicated to tl oedometers and triaxial apparatus used for the students soil mechanics practicum. The aquarium in the center of the hall houses the student assistents. The rooms for the staff are locate around the hall. The major research facilities are located in the basement.

Soil Mechanics Practicum

Student facilities, soil mechanics practicum, oedometer test, triaxial tests, sieve curves.

Research Facilities

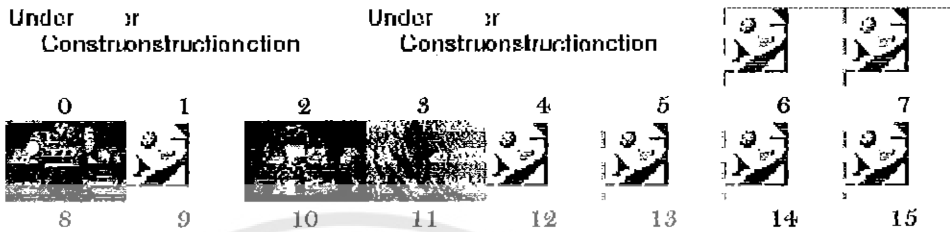
Main research apparatus are in the cellar.

Biaxial devices dr.ir. H.G.B. Allersma drs. A. Bizarri

Optical stress measurements dr.ir. H.G.B. Allersma

Horizontal Cone Penetration, Calibration Chamber ir. W. Broe

Centrifuge dr.ir. H.G.B. Allersma



General questions and remarks can be addressed to Info.Geo@ct.tudelft.nl

Research

The following list gives the various subjects which are cı under research, or have been recently finished, at the Geotechnical Laboratory. Most link to the descriptions o researchers pages. A rough division has been made into Geomechanics, Ground Water Mechanics and Foundatic Engineering.

Geomechanics

- Centrifuge Modelling
- Discrete Element Analysis of Granular Materials
- Optical Stress Strain Analysis

Ground Water Mechanics

- Modelling non-stationary dispersive groundwater flow non-homogeneous fluid conditions
- Research on Storage Capacity of Gassy Sludge
- Stochastic Characterization of Geological Heterogeneit Impacts on Groundwater Contaminant Transport

Foundation Engineering

- Call for predictions for a field test on a steel sheet pile
- Development of Unified European Design Rules for St Sheet Piles and the Introduction into Eurocode 3, part
- Horizontal Cone Penetration Testing
- Investigation of tunnel face stability during slurry shie tunnelling in soft soil
- Optimalisation of the Tunnel Boring Proces in Soft So
- Rotation Capacity in Steel Sheet Piles
- Road Reconstruction A15 Motorway
- Numerical Analysis of Soft Soil Tunnelling
- Rotation Requirement in Steel Sheet Piling

General questions and remarks can be addressed to Info.Geo@ct.tudelft.nl

Sheet pile wall field test

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- Graduation Projects
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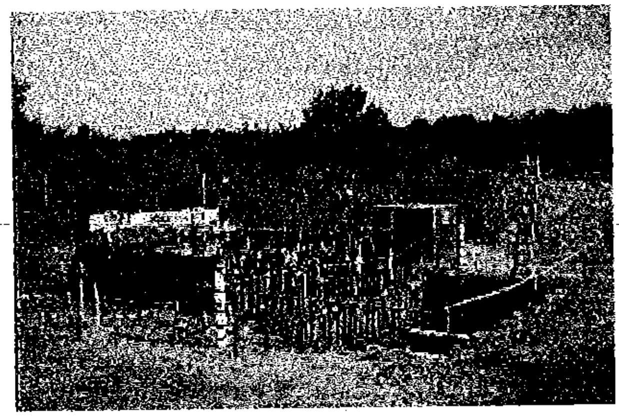
- TU Delft
- Faculty of Civil Engineering



This sheet pile wall field test was carried out near K
A follow-up will be carried out near Rotterdam in Sept

Call for predictions

Bezoek de Nederlandstalige aankondiging.
Visitez l'annonce française.
Besuchen Sie die Ankündigung in deutscher Sprache.

This page is still under construction. More in

1 April 1998

Researchers
Prof. A.F. van Tol, Delft University of Technology, Geo
D.A. Kort, Delft University of Technology, Geotechnical
A. Jonker, Centre for Civil Engineering Research and Co

General questions and remarks can be addressed to Info.

 Last edited: Wednesday, March 11, 1998

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Research

Numerical Analysis of Soft Soil Tunnelling

In recent years for very soft, heterogeneous soil conditio shield-supported tunnel construction methods are consid suitable alternative for cut-and-cover methods and imme tunnel construction. However, accurate and accessible to predict the influence of the tunnel boring process on its environment, which would be quite useful already durin design stage of a tunnel project, are still lacking.

The aim of this research project is to develop a user-frier memory-efficient numerical model applicable to the analy soft soil shield tunnelling.

The geometry of shield tunnelling problems is usually qu repetitive along the tunnel axis. This may be exploited ir structuring of the new model and for the input of data. Ii agreement with geotechnical practice, where two-dimens numerical models are often used, input data may consist data at a number of specified cross-sections, and data on shield and the tunnel lining. In this way, the complicated data usually associated with general three-dimensional n models, which are capable of processing arbitrary geome may be circumvented. Moreover, these modest input requirements will enable the use of this model already in design stage of a project. To facilitate this use even more should run on ordinary personal computers, therefore th memory requirements should be as limited as possible.

For a numerical analysis of the shield tunnelling process required to include volume elements to model the soil, sl elements to model the relatively thin tunnel lining and tl and interface elements to model the interaction between and the structural elements. The advancement of the shi be modelled in a discontinuous manner: for a segmental t lining for instance, in each subsequent calculation step th may be put one ring of elements farther. As with soft soi tunnelling usually soil plasticity occurs, the constitutive implemented for the soil should not be limited to linear e material behaviour only, but it should account for plastic behaviour as well. Finally, it would be desirable if calami as pressure losses at the excavation face, can also be simu the model. With the model it should be possible to predic stresses, tunnel lining forces and deformations of the soil tunnel within reasonable limits.

Publications

Consolidation associated with shield tunnelling, Masters Delft University of Technology, Faculty of Civil Enginee Geotechnical Laboratory, Geotechnical Report no. 376, I 1994

General questions and remarks can be addressed to Info.Geo@ct.tudelft.nl

 Last edited: Friday 13 March 1998

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Research subject

Optimalisation of the tunnel boring process

Modelling of the soil movements around tunnel boring machines and methods of soil investigation and monitoring during boring

The boring of tunnels in very soft and layered soils is a technique which widely been used. The influence of the boring process on the soil and vice substantial. Soil conditions which differ from the expectations can lead to instabilities, settlements and/or stagnation of the tunnel boring process. during an undisturbed excavation process settlements and stress changes This can lead for instance to the partial loss of bearing capacity of deep fo To prevent such disturbances during the boring process a number of prec taken and wide safety margins are applied. These measures increase the b of bored tunnels. If more precise and detailed information about the soil could be obtained, and accurate models could be used, the amount of and precaution measures could be reduced.

Therefore this research program is focused on the influence of the excava on the surrounding soil and on methods to influence this process. Special will be paid to the following subjects:

- Stability of the tunnel face in a slurry shield
- Deformations of the soil due to stress differences at the tunnel face
- Influence of soil properties and layers on deformation
- Conditioning methods for sand and sandy soils excavated by an ea pressure balance shield
- Liquefaction of sand at the tunnel face

Besides modelling of the soil behaviour around the tunnel boring machin is also important to measure the exact soil properties in front of the TBM Horizontal soil investigations, executed from the TBM, are a likely meth this information.

Horizontal Cone Penetration Testing

One of the possible testing methods which can be carried out from the wo chamber of a TBM is a horizontal cone penetration test. The horizontal c penetration tests would supplement the information gained from the vert penetration tests (CPT) and soil sampling which have been performed be tunnel works start. Although the technique of horizontal cone penetratio (HCPT) does not differ fundamentally from vertical cone pentration testi interpretation of the measurements poses a problem. So far there are no r between measurements from horizontal CPT and soil parameters, so a te has been developed at the Geotechnical Laboratory of Delft University of Technology, to measure the differences between horizontal and vertical C Objective of this research is to present relations between measurements f and soil properties, as well as relations between HCPT and traditional ve so that traditional relations can be used for the interpretation. The test re validated by use of theoretical model of horizontal cone penetration base cavity expansion theory, in which model the anisotropy of stresses has be into account.

Professors involved:

prof.ir. A.F. van Tol
prof.ir. F. Horvat
prof.ir. W.J. Vlasblom

Publications

W. Broere: Risico's en storingen bij geboorde tunnels; Delft University o Technology, Geotechnical Laboratory, Geotechnical Report No. 378, Del

W. Broere, B. Polen: Risico's en storingen bij geboorde tunnels; Delft Un Technology, Underground Space Technology / Centrum Ondergronds B Report No.02, Gouda 1996 (Abstract in Dutch)

W. Broere, A.F. van Tol: Horizontal Cone Penetration Testing; First Int Conference on Site Characterization, Atlanta 1998 (publication April '98,

W. Broere: Face Stability Calculation for a Slurry Shield in Heterogeneo Tunnels and Metropolises, Sao Paolo April 1998 (publication April '98, a

The Bechtel Geotechnical Laboratory

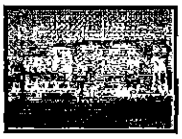
The Steven Bechtel Jr. Geotechnical Laboratory at Purdue is one of the top geotechnical research facilities in the world. Four different laboratories provide a framework for both undergraduate and graduate teaching, and advanced research. A wide range of state-of-the-art laboratory and field testing and monitoring equipment are available for research and teaching. Additionally, geotechnical graduate students have designated computer facilities including Sun work stations, and IBM compatible and Macintosh personal computers

Some pictures of the equipment:

- Consolidation Frame (133K GIF)
- Permeability Testing Equipment (153K GIF)
- Cyclic Triaxial Testing System (144K GIF)
- MTS Triaxial Testing Machine (79K GIF)
- Resonant Column Device (123K GIF)
- Direct Shear Apparatus (97K GIF)
- For More Information on Lab Facilities at Purdue University

In addition, there are MANY other pieces of specialized equipment. Purdue University maintains a machine shop which is capable of producing full scale testing equipment for any specialized purpose!

Last updated March 9, 1995
Please send comments to (ashmawy@ecn.purdue.edu)

 Civil Engineering Home Page

 Geotechnical Engineering Home Page

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Geotechnical Engineering Undergraduate Facilities

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Research | News & Events | Facilities | Professional Activities | People

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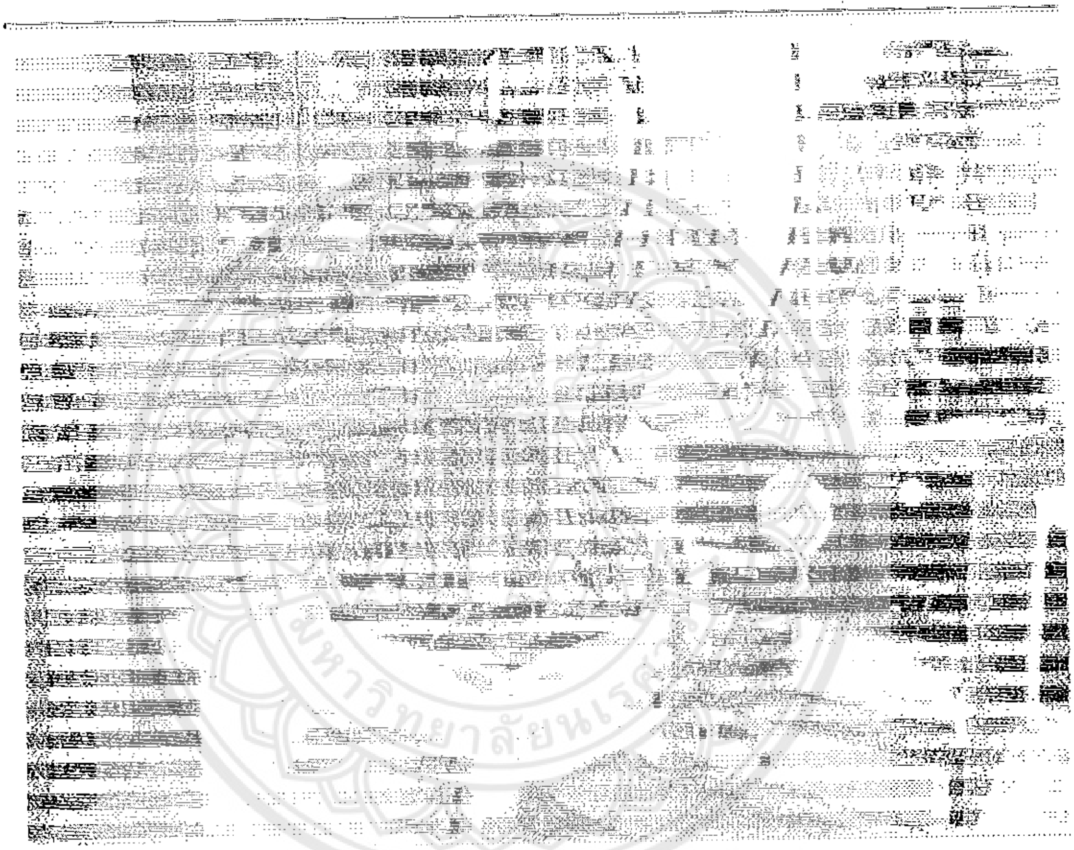
Geotechnical Engineering Undergraduate Facilities



webmaster-ce@ecn.purdue.edu

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Soil Mechanics and Geotechnical Engineering Research at Oxford University

Soil mechanics research at Oxford covers a wide range of different studies, involving both experimental and analytical work. The areas of activity are:

- Offshore foundations ✓
- In situ testing
- Trenchless technology
- Reinforced soil ✓
- Soft clays
- Unsaturated soils
- Theoretical modelling of soils
- Settlement damage

How to contact Civil Engineers at Oxford

Research in Civil Engineering

The following is an extract (Chapter 6) from the latest Research Summary published by the Department of Engineering Science. It contains the following subsections:

- In situ testing
- Soft soils, sedimentation processes and environmental applications
- Unsaturated and gassy soils
- Offshore foundations
- Reinforced soil
- Trenchless construction
- Piling engineering
- Dynamics of civil engineering structures
- Settlement damage
- Theoretical modelling of soils

6.0 CIVIL ENGINEERING

Research at Oxford in Civil Engineering involves a diverse group of topics. While the work in soil mechanics and structures is listed here, many research projects with applications to civil engineering are also found in other chapters of this report. Much of the work of the Wind Engineering research group has civil engineering applications. Research in geophysics has applications in mining engineering. Several of the topics listed under Coastal and Offshore Engineering are also of direct concern to civil engineers.

The work of the soil mechanics group involves both fundamental studies of soil properties and behaviour, and also applied work on geotechnical engineering problems. Research techniques involve theoretical studies, both analytical and numerical, laboratory testing and field testing. The group has particular strengths in scale model testing and in applications of finite element analysis. Research in the dynamics of civil engineering structures combines the measured behaviour of actual structures, both at full and model scale with the predictions of analytical models. It is intended to expand the current work in this area. Existing facilities are to be extended by the addition of a first-floor laboratory suitable for light structural work. This will allow some existing equipment to be moved, thus freeing space at ground level for some of the heavier equipment needed for structural work.

6.1 IN SITU TESTING

Work on in situ testing involves both the development of equipment and the establishment of methods of interpretation for in situ tests. The latter requires use of laboratory and field testing, as well as the development of new theories and analytical methods. A particular feature of the research in Oxford has been the use of large calibration chambers for the study of in situ testing devices in both sand and clay.

6.1.1 Calibration Chambers for In Situ Testing Devices in Sand

G.T.Houlsby

A large calibration chamber, 1.0 m in diameter and 1.5 m high, is available for calibration of in situ testing devices. A specimen of sand is prepared in the chamber using the sand raining technique to achieve a controlled density. The chamber is capable of containing the specimen under controlled conditions of stress in both axial and radial directions, with stresses applied through flexible rubber membranes. Displacements of the membranes may be monitored.

An earlier model of the chamber has been used to carry out a comprehensive series of tests on the Marchetti Dilatometer. The tests were at three different sand densities, and were used to study the influence of stress level, overconsolidation ratio and value. The results indicate that the readings obtained with the dilatometer reflect principally the lateral stress, and are not influenced by the vertical stress. Similar results were obtained for the cone penetrometer and cone pressuremeter in the present chamber, highlighting the importance of horizontal stresses.

A smaller, 450mm 450mm chamber is also available. Both chambers are suitable for other types of test, e.g. pile testing, in addition to their application to in situ testing.

Project support: EPSRC.

6.1.2 Calibration Chamber for In Situ Testing Devices in Clay
G.T. Houlsby

A large calibration chamber, 1.0m in diameter and 1.0m high, is available for the calibration of in situ testing devices in clay. The clay is prepared by one-dimensional consolidation from a slurry. After this initial phase of consolidation is complete, a second phase takes place in which independent vertical and horizontal stresses can be applied to the soil specimen. The vertical stress is applied through a membrane in the base of the chamber, and the lateral stress through a cylindrical membrane around the tank wall. A wide range of consolidation histories can therefore be applied to the specimen. The chamber has recently been used for the study of the Marchetti dilatometer leading to a better understanding of methods of interpretation of this device.

Project support: EPSRC.

6.1.3 The Cone Pressuremeter Test
G.T. Houlsby, N.R.F. Nutt

The Cone Pressuremeter is an in situ testing device which is being developed by Fugro-McClelland Ltd. A pressuremeter is mounted behind a conventional cone penetrometer, and information may be obtained from both the loading and unloading phases of the pressuremeter test. A programme of research has just been completed consisting of laboratory and field studies, and development of analyses. Laboratory studies were being carried out in a large calibration tank using model pressuremeters. Analytical procedures are concentrated on the difference between the installation of the cone pressuremeter and the self-boring pressuremeter. The pressuremeter results are also related to results obtained from the analysis of the cone penetration test.

Calibration chamber tests have recently been carried out on the cone pressuremeter in carbonate sands. These materials present an unusual combination of properties which render them very different from silica sands. The studies add to a previous database of tests on piles in carbonate materials.

Field testing of the Cone Pressuremeter has been carried out at the EPSRC test site at Bothkennar.

Project support: EPSRC, Fugro-McClelland Ltd., BP International.

6.1.4 The Marchetti Dilatometer in Clay

G.T. Houlsby, M.G. Smith

The large calibration chamber for tests in clay is being used to study the behaviour of the Marchetti Dilatometer in clay, with emphasis both on standard measurements and the estimation of consolidation properties. Tests have been carried out in clay with a range of stress states and stress histories, with a view to isolating the quantities which are important in influencing the results of the dilatometer test.

Project support: EPSRC.

6.1.5 Wave Induced Water Pressures in the Seabed

G.C. Sills

In order to predict the behaviour of the seabed as a foundation for offshore structures, it is necessary to understand the fundamental processes controlling this behaviour. One of the ways of achieving this is to examine the response of the seabed to an applied loading. In this programme, the loading considered is the pressure variation on the surface of the seabed due to waves in the overlying water, and the measured response is that of pore water pressures in the seabed. A differential piezometer and data logging system have been developed, and are being deployed in sand, silt and clay seabeds. Pore pressures are measured relative to a constant pressure close to the hydrostatic value in an air-filled bladder. This allows the use of sensitive transducers, thus providing greater accuracy of measurement of pore water pressure than could be achieved by direct measurement.

Experiments show that a small amount of damping of the response occurs with depth into the seabed. These results, and others, are used to assess the applicability of an elastic model for seabed behaviour, which allows the prediction of normal and shear stresses due to wave action.

A further measurement programme has been carried out with a model pipeline instrumented to measure pore pressure, and total stress around the pipeline, due to the wave loading on the seabed.

Project support: EPSRC.

6.1.6 Recording the presence of gas in the ground
G.C. Sills, C. Waddup, J. Lipscomb

Generation of gas such as methane in waste disposal sites, and subsequent leakage into the surrounding ground can present a major hazard. A specialised piezometer, or gas probe, has been developed to allow the presence of gas in the surrounding soil to be confirmed. Pressures recorded by the instrument are sensitive to the presence of gas, and the principle of operation is based on the use of two different designs of transducer housing, one of which registers the effect of gas more quickly than the other. Different readings on the two transducers therefore indicate that gas is present.

Project support: EPSRC

6.1.7 Wave effects on beach processes
G.C. Sills, M. Collins (Southampton University)

A joint measurement programme is being undertaken to determine the interaction between the seabed and the overlying water. Field measurements will be made of wave pressures, current velocities and turbidity, and compared with pore water pressures a little way beneath the seabed surface.

Project support: EC through HCM programme

6.1.8 Analysis of Signals from Sensors in Civil Engineering
G.T. Houlsby, L. Tarassenko, B. Ruck

The project involves an application of neural networks to the analysis of a signal from a remote sensor in a civil engineering application, and is intended to serve as a pilot study for other novel applications of modern signal analysis techniques. The Cone Penetration Test is used in the in situ investigation of the properties of soils. The acoustic signal from the cone is at present not interpreted (other than extremely qualitatively) and the intention is to use a neural network to interpret the FFT of this signal. The network will be trained in a series of calibration tests on known soils, and its ability to identify both soil type, and numerical values of the engineering properties of soils will then be tested. The network will be developed in two stages: the first stage being to develop the Kohonen feature map, and the second layer of the network being an optimal linear transform for the identification of soil properties. Data fusion studies will also be carried out on the possibility of including information from other transducers on the CPT. Other areas of application of similar techniques will be identified.

Project Support: EPSRC

6.1.9 Effects of Geometry and other Factors on Pressuremeter Tests

G.T. Houlsby, M. Yao

A study is being made, using both analytical and calibration chamber methods, of the influence of geometry (length/diameter ratio) and other factors on the results of pressuremeter tests.

6.2 SOFT SOILS, SEDIMENTATION PROCESSES AND ENVIRONMENTAL APPLICATIONS

The behaviour of soft soils deposited through water is important in such areas as dredging programmes, reservoir and estuary siltation, slurry waste disposal and land reclamation. The fundamental behaviour is being examined by introducing soil slurries into 2m high, 100mm diameter acrylic settling columns, and allowing them to settle and consolidate. Accurate, non- destructive measurements of density are made using X-rays transmitted through the soil, detected by a scintillation crystal and photomultiplier assembly. Measurements are also made of pore water pressure by transducers, of shear stiffness by shear wave transmission and of shear strength by a sleeved sensitive shear vane and by fall cone. The stress range is extended by applying a surcharge loading using a piston, or by the

The application of an electrical potential difference to soil induces water movement and consolidation. Under suitable conditions, therefore, it may be used to accelerate the natural self-weight consolidation of waste slurries, or to provide remedial treatment for inadequate liners. Current research is directed towards both of theses considerations, with measurements of the effects of vertical potential differences and of horizontal potential differences. Density and permeability changes are observed, and should lead to a better understanding of the whole electro-kinetic process in soils.

Project support: EPSRC

6.2.4 Self-weight consolidation of a waste slurry

G.C. Sills, F. Yuan

Polluted sediment from the Ketelmeer lake bed in the Netherlands is being recovered and stored in a 30m deep disposal site. In order to plan the operation of the site, the Slufter, settling column experiments are being carried out to assess the influence of methane, generated by bacterial activity in the mud, on the self-weight consolidation process. So far, experiments have shown that the consolidation is reduced both in magnitude and in rate. Collaboration with B. Wichman, of the Rijkswaterstaat, is leading to improvements in numerical modelling of this process.

Project support: Rijkswaterstaat, The Netherlands

6.3 UNSATURATED AND GASSY SOILS

Many soils are unsaturated, with the void spaces occupied by a mixture of liquid (typically water) and gas (typically air or methane). These unsaturated soils occur in both the onshore environment, in the form of compacted fills and natural soils above the water table, and in the offshore environment, where "gassy soils" result from thermogenic or biogenic formation of natural gases within seabed sediments.

Equipment available for testing such soils includes specialised triaxial and oedometer cells, with facilities to separate gas and water volume changes and to control pore water and pore air pressure differences on the sample boundaries.

6.3.1 Development of an Elasto-Plastic Critical State Model for Unsaturated Soil

S.J. Wheeler, V. Sivakumar

An understanding of the mechanics of unsaturated soil is vital for the effective design and analysis of the many foundations, slopes, embankments and retaining structures which incorporate unsaturated compacted fills or unsaturated natural soils. To this end, a generalized elasto-plastic constitutive model for unsaturated soil has been developed by the extension of critical state theory to soils containing two pore fluids. The critical state framework involves five state variables (mean net stress, deviator stress, suction, specific volume and specific water volume), and it is able to represent important features of unsaturated soil behaviour, such as the complex pattern of swelling and collapse on wetting, the increase of shear strength with suction and the variation of compressibility with suction. The model, which has been validated and refined by comparison against results from a programme of controlled suction triaxial stress path tests on samples of unsaturated compacted kaolin, is capable of predicting volumetric strains, shear strains and changes of water content for any stress path and any drainage condition.

Project support: EPSRC

6.3.2 Yielding of Unsaturated Soil

S.J. Wheeler, I. Zakaria (University of Sheffield)

Controlled suction triaxial stress path tests on samples of unsaturated compacted kaolin have been used to examine the shape of the yield surface for unsaturated soil (in a three- dimensional space with axes of mean net stress, deviator stress and suction). Elastic behaviour prior to yielding was also investigated, together with the form of the flow rule governing the ratio of plastic strain increments after yielding. Tests were conducted in a Bishop-Wesley hydraulic triaxial apparatus with axial and lateral strains measured directly on the soil sample using local displacement gauges. Soil suction (the difference between the pore air pressure and the pore water pressure) was controlled using the axis translation technique.

Project support: Malaysian Government.

6.3.3 Influence of Compaction Procedure on the Elasto-Plastic Behaviour of Unsaturated Soil

S.J. Wheeler, V. Sivakumar

Compaction procedure influences the initial fabric of an unsaturated compacted clay and thus affects the subsequent mechanical behaviour of the soil. A series of suction controlled triaxial tests has been performed to investigate the influence of compaction water content, compactive effort and method of compaction (static or dynamic) on the behaviour of unsaturated compacted kaolin. Double-walled triaxial cells have been used for the measurement of sample volume change, and suctions have been controlled by means of the axis translation technique. A sophisticated control system enables any required stress path to be followed. The test results have been interpreted within the framework of an elasto-plastic critical state constitutive model for unsaturated soil.

Project Support: EPSRC, British Council

6.3.4 Mechanical Behaviour of Highly Expansive Unsaturated Clays

S.J. Wheeler, R.S. Sharma

Unsaturated soils containing active clay minerals expand dramatically on wetting. The annual cost of damage to buildings, structures and roads caused by these expansive soils is estimated at £150 million in the UK and many billions of pounds worldwide. Unsaturated expansive clays are also used for engineered clay barriers for environmental protection or in connection with radioactive waste disposal. The mechanical behaviour of a highly expansive unsaturated clay will be investigated in a series of suction controlled triaxial tests. An osmotic method, developed in France, will be used to apply high values of suction. The test results will be used in the development of an elasto-plastic critical state constitutive model for highly expansive unsaturated soils, which takes account of the large irreversible component of swelling that occurs on first wetting of these soils.

Project Support: EPSRC, British Council

6.3.5 Numerical Modelling of Unsaturated Soil

S.J. Wheeler, I.C. Pyrah (University of Sheffield), K. Nesnas (University of Sheffield)

An elasto-plastic critical state constitutive model for unsaturated soil, developed at the Technical University of Catalunya, Barcelona, has been incorporated into the finite element program CRISP. Validation of the coding involved a comprehensive suite of single element tests for both axisymmetric and plane strain conditions. The program was then used to examine the behaviour of foundations built on unsaturated soil, in particular, the effect of inundation (reduction of suction) on deformations and possible collapse.

Project support: Algerian Government.

6.3.6 Behaviour of Gassy Offshore Soils

G.C. Sills, S.J. Wheeler

Where undissolved gas occurs within the seabed it can affect the geotechnical properties and behaviour of the sediments, with important consequences for performance of foundations for offshore structures. An extensive programme of research into the influence of undissolved gas on the behaviour of fine-grained offshore soils (clays and silts) was based on the development of a laboratory technique for the preparation of reconstituted soil samples containing a uniform distribution of gas bubbles. The structure of these samples is similar to that observed in gassy sediment recovered from the seabed, and consists of relatively large gas-filled cavities surrounded by a matrix of saturated soil. Individual projects have investigated the effect of gas bubbles on consolidation behaviour, undrained strength, drained strength, elastic moduli and acoustic properties. Future projects may investigate the cyclic loading response of gassy soils, the performance of piled foundations in gassy soils and the development of an acoustic probe for gas detection and measurement of gas concentration.

Recent applications of this work are in the Caspian Sea, where oil recovery in a multi-national operation will require consideration of the effect of the undissolved gas whose existence has been well documented by Azerbaijani engineers.

6.3.7 The Consolidation of a Gassy Lakebed Sediment

G.C. Sills, F. Yuan

Sediment from the bed of the Ketelmeer in the Netherlands produces gas biogenically. The mud is polluted and is therefore being recovered for disposal elsewhere. In order to predict the magnitude and time-scale of consolidation in the disposal site, a programme of oedometer experiments is under way. In order to model as accurately as possible the in situ stress levels, the applied load is increased steadily, with a corresponding increase in the back pressure. This is important in a gassy soil, where the gas behaviour is influenced by the total stress levels.

Project support: Rijkswaterstaat, Netherlands and EPSRC.

6.4 OFFSHORE FOUNDATIONS

Research on offshore foundations is principally sponsored by oil companies, and covers a variety of topics including piled and shallow foundations and the behaviour of jack-up units.

6.4.1 Combined Loading of Shallow Foundations on Clay

G.T. Houlsby, H.J. Burd, C.L. Ngo Tran

Many foundations, particularly those offshore, are subjected to combined vertical, horizontal and moment loading. Whilst vertical loading is well understood, further work is needed to understand the behaviour of foundations under combined loadings. A project is planned in which three-dimensional finite element methods will be used to study the stability of shallow foundations on clay under a variety of loading conditions.

A three-dimensional finite element model capable of solving a simplified form of the problem has been developed as an initial part of the research. Further work is needed to continue the development of suitable numerical formulations for three-dimensional stability analysis and to establish `benchmark' solutions for the response of circular footings under combined vertical, horizontal and moment loading.

The numerical models developed during this research will be tested by comparison with the results of laboratory scale model tests that have recently been completed at Oxford.

Project support: UGC equipment grant.

6.4.2 Moment Fixity of Spudcan Footings
G.T. Houlsby, C.M. Martin

Both experimental and numerical work has been completed to develop new methods of understand the interaction between the spudcan foundation of a jack-up unit and clay soils. Particular attention was paid to the prediction of moment fixity, which is of importance to the assessment of jack-up units. New analytical models have been developed based on work- hardening plasticity theory. Experimental work was used to verify the new theories, and to provide direct evidence of the shape of the yield locus and other features of the plasticity model. The experiments made use of a computer-controlled rig which can apply any displacement path to a model spudcan. Loads and displacements were monitored. By carrying out a carefully controlled series of tests at different depths of embedment, the behaviour of the spudcan, and the changes of the response with depth, can be determined.

Project support: Noble Denton and Associates, Rhodes Trust.

6.4.4 Tension Loading of Plated Foundations
G.T. Houlsby, J. Mangal

The plated foundation is a new concept for the foundation for a steel jacket offshore production platform. It replaces the mudmat and piles usually used, and consists of an enlarged mudmat with a stiffened skirt approximately 5m deep. Studies have been completed of the capacity of plated foundations under combined vertical, horizontal and moment loading. Model tests have been carried out using a viscous pore fluid to model the drainage process correctly, since at full scale the partial drainage problem is of importance. Of particular interest are tensile vertical loads combined with horizontal and moment loads.

The research is currently being extended into a more general study of shallow foundations subjected to offshore loading. This will aim to provide comprehensive information on the variation of load capacity with loading rate, incorporating the influence of combined loading. The testing involves use of a versatile three degree-of-freedom loading apparatus.

Project support: Kvaerner Engineering, EPSRC

6.5 REINFORCED SOIL

Research in the group is on both the fundamentals of the action of reinforcement, and on applied problems. Several testing facilities have been developed, including a unique 1m cube shear box, for testing reinforced soil.

The properties of soil as an engineering material may be improved in many situations by the inclusion of reinforcing elements. These may consist of metal strips, bars or grids; polymer geotextiles or grids; or even natural materials such as bamboo. The reinforcement may either be incorporated in soil fill during construction of retaining walls, embankments, or road pavements; or inserted (as soil "nails") in natural ground to support excavated slopes or stabilise existing slopes.

A programme of research in soil reinforcement has been in progress at Oxford for more than ten years. It has involved both fundamental investigation of the mechanics of soil- reinforcement interaction, using direct shear and pull out tests, and studies of existing or potential applications of reinforcement in practice. The work has ranged through numerical analyses, laboratory model studies and large scale testing with the aim in all cases of producing rational, straightforward and reliable design procedures. Supporting organisations have included SERC, TRL, Netlon Ltd, and several other industrial firms.

6.5.1 Mechanics of Reinforced Soil Walls

H.J. Burd, D. Lesniewska

A project is underway on the use of two-dimensional finite element methods to study the mechanics of reinforced soil walls. The purpose of this study is to assess the accuracy of the assumptions made in the current design methods for this type of system.

Initial research has concentrated on the development of suitable numerical procedures to model the structure. It is expected that the numerical model will be used to inspect the influence of changes in front-wall stiffness, reinforcement length and reinforcement properties on the behaviour of this type of reinforced soil system.

6.5.2 Centrifuge Testing of Soil Nailed Slopes

G.W.E. Milligan, K. Tei

This recent project studied the behaviour of soil-nailed slopes in cohesionless soil (fine sand) using model tests in the geotechnical centrifuge at City University. Observations were made of slope failure mechanisms, earth pressures, nail forces and force distributions, soil deformations, face deflections and surface settlements. The validity of the modelling process was checked by comparisons between published data from full scale tests and centrifuge models of these tests.

The stability of soil-nailed slopes often depends on the pull-out resistance of the nails, yet this is one of the areas of greatest uncertainty in design. The programme of centrifuge testing was therefore backed up by detailed investigations of pull out forces and mechanisms.

Project support: Tokyu Construction Co.

6.5.3 Pull Out Testing of Soil Nails and Reinforcement

G.W.E. Milligan, K. Tei, K.T. Chang

The pull-out resistance of soil nails or reinforcement is usually an important factor in design. Pull out testing is conceptually simple, but research at Oxford and elsewhere has shown that test procedures often do not model in situ conditions very well and the results are greatly influenced by the test method, boundary conditions and other factors. Three different sizes of test box, including a very large one which holds a soil sample 1.0 x 1.0 x 1.0m, are being used for both direct shear and pull out tests with various boundary conditions and internal measurements of reinforcement strain, soil deformation and other quantities. This will improve understanding of the pull out resistance of reinforcement in different types of soil in realistic field situations.

It is hoped to extend this work in due course to field monitoring of full-scale constructions on site to validate the findings of the laboratory modelling.

Project support: Tokyu Construction Co.

6.5.4 Large Shear Box Facility
G.W.E. Milligan

A large-scale apparatus capable of containing a soil specimen 1.0m x 1.0m x 1.0m in size has been constructed, to allow direct shear and pull-out tests to be carried out using actual reinforcing materials in soil under conditions of controlled boundary stresses. Use of the large scale apparatus has allowed many of the factors causing uncertainty in the interpretation of more conventional tests to be identified and eliminated.

The apparatus has been used recently to investigate the performance of different types of in-situ reinforcement (soil nails), to elucidate the relative contribution of tension and bending resistance and the influence of installation technique.

The apparatus was developed with SERC, TRL and departmental funds. It is available for future projects on soil-reinforcement interaction.

6.5.5 Reinforced Soil in Flexible Culvert Construction
H.J. Burd, G.W.E. Milligan, I.C. Martorano

Flexible steel pipes and arches are used in conjunction with granular soil as an effective and economical way of forming large culverts, underpasses and other constructions. There are problems in their construction, however, and in their design and performance under concentrated loading. A laboratory scale study of the use of soil reinforcement to improve the behaviour of flexible culverts has recently been completed. The current stage of this project consists of the development and application of finite element models of buried culvert behaviour. This work includes the development of large displacement curved beam elements for modelling the culvert and procedures for modelling the interface between the culvert and the soil. It is intended that this model will be used to carry out back-analysis calculations of full scale tests for which data is available.

Project support: EPSRC, TRL, Asset International, Brazilian Government.

6.5.6 Reinforced Soil Design
G.W.E. Milligan, G.T. Houlsby, H.J. Burd

As well as fundamental experimental investigations into reinforced soil behaviour and applications (described above), work at Oxford is in progress on calculations and design methods for practical application. These methods stem from the understanding of behaviour developed through laboratory research and instrumented field experiments.

First it is important to establish a rational means of selecting design parameters and allowing for safety in reinforced soil, particularly for cases where new polymer reinforcement materials are used. Subsequent analyses may then be presented in a uniform and consistent way. Work has recently been focused on the use of reinforcement over poor ground for the construction of embankments and unpaved roads. New analyses have been developed for both cases, using plasticity theory for the embankment and a limit equilibrium analysis for unpaved roads.

Work has also been completed on reinforced soil walls concentrating on the prediction of deformation in walls reinforced by polymer (geotextile) reinforcement materials. The analysis for deformation accurately predicted under Class A conditions (prediction before construction) the behaviour of two full scale trial walls built in Canada under the NATO Applied Science funding scheme. This work has recently been extended to the use of finite element methods to study wall behaviour.

The findings from research at Oxford have been widely distributed through short courses run in Oxford at the Department of External Studies and with Universities abroad. A course on fundamental behaviour and analysis has been run in Australia, Canada, Holland, Hong Kong, UK and USA. Courses are run in cooperation with Prof. C.J.F.P. Jones (Newcastle University) and Dr R.A. Jewell (GeoSyntec).

6.6 TRENCHLESS CONSTRUCTION

Trenchless construction technologies involve a wide range of methods of installing, replacing or renovating service pipes, ducts and small diameter tunnels with minimal excavation from the service. They include moling, directional drilling, microtunnelling, pipe bursting, pipe jacking etc. Oxford's civil engineering research group has been at the forefront of research on some of these techniques. Ground movements due to pipe bursting have been investigated using laboratory modelling, in a project sponsored by British Gas and EPSRC; while pipe jacking has been the subject of an ongoing series of major projects supported by EPSRC, the Pipe Jacking Association and a consortium of water service companies (Northumbrian, North West, Severn Trent, Thames and Yorkshire).

Pipe jacking is a method of forming small diameter tunnels by progressively jacking a line of pipes through the ground as excavation proceeds at the tunnel face. The way in which the pipes interact with the ground, particularly when successive pipe sections become slightly misaligned, is not well understood. Nor is enough known about how the stresses in the pipes are related to soil conditions, jacking forces, joint details etc, for a safe yet economical design to be obtained in all cases.

The first stage of the pipe jacking research work again involved small-scale model tests in the laboratory, while the second stage comprised a series of five full scale schemes on active sites. One of the pipes in each scheme was heavily instrumented to measure overall jacking forces and pipe movements, joint articulations and local contact stresses between pipes, longitudinal pipe strains, total and effective radial and shear contact stresses between pipe and ground; where possible, ground movements around the pipe were also measured. The instrumentation and procedures developed for this have proved extremely successful, and large quantities of high-quality data have been collected. The results of this work are already being used to improve industrial practice.

6.6.1 Field Performance of Jacked Pipes

G.W.E. Milligan, M. Marshall

Stage 3 of the project continues with monitoring of the performance in the field of the jacking of reinforced concrete pipes. This stage will concentrate on the interaction between the pipes and the ground, to extend the information obtained from the earlier stages, in conjunction with detailed measurements of ground stiffness, initial stresses and ground movements due to the tunnelling operation.

In addition to providing direct information on ground movements, this work should allow further progress to be made towards the ultimate aim of predicting accurately the required jacking load for any combination of ground conditions, tunnel length, method and accuracy of construction etc. This in turn will allow rational design of pipes, jacking equipment, thrust walls and other components.

Project support: EPSRC, the Pipe Jacking Association, and a consortium of five water service companies.

6.6.2. Analysis and Design of Jacking Pipes

G.W.E. Milligan, H.J. Burd and J.Q. Zhou

This project (Stage 4 of the overall programme) takes, as input data, the results from the field work on the maximum jacking loads, misalignment angles between pipes and resulting stress concentrations in pipe joints. The intention is to investigate by numerical and physical modelling possible improvements to pipe, and more particularly pipe joint, design. These might include changes to joint geometry, reinforcement layout, or packing material dimensions and characteristics. The most successful theoretical designs may then be checked by laboratory tests or site monitoring on an actual scheme.

An initial stage of numerical modelling used a two-dimensional elastic model to study pipe joint behaviour. More detailed work is now in progress in which a three-dimensional finite element model will be used to investigate the interaction between pipes and between the soil and the pipes. This work has included the development of a suitable numerical model for concrete for implementation in the finite element program OXFEM.

Project support: EPSRC, the Pipe Jacking Association, and a consortium of five water service companies.

6.7 PILING ENGINEERING

6.7.1 Pile-Soil Interaction

H.J. Burd, M.S. Williams, A.R. Chaudhry

A theoretical study of the behaviour of single piles and pile groups under vertical and lateral loading is currently under way. This work is intended to provide an improved understanding of the soil-structure interaction processes that occur in piled foundations particularly for closely spaced piles subjected to lateral loads. Initial studies have been carried out using finite element and boundary element methods to study the static behaviour of a pile embedded in an elastic half-space. Further work has included the use of plane strain finite element models to study the mechanisms of interaction between closely spaced piles in clay. The work is currently being extended to the analysis of pile groups in sand where the dilational characteristics of the soil have an important influence on behaviour.

A review is being carried out of the methods that are available for the prediction of the behaviour of pile groups under lateral loading.

Project Support: ICI Scholarship and Travel Scholarship from Mott MacDonald.

6.8 DYNAMICS OF CIVIL ENGINEERING STRUCTURES

Structural dynamics research at Oxford deals with civil engineering problems arising from sources as diverse as earthquakes, wind- and traffic-induced vibrations of bridges, wave loading of offshore structures and occupant-induced vibrations in buildings. Work in progress combines field testing with analytical and computer modelling, plus it is intended to supplement this with extensive laboratory work in the near future.

Previous work in the area has included the testing of novel bracing techniques for aseismic design, work on the dynamic behaviour of prestressed elements on demolition, field monitoring of large structures to determine the actual performance of the structures in comparison with analytical models

6.8.1 Vibrations in Prestressed Concrete Floors

M.S. Williams, S. Falati

Recent advances in prestressing have enabled engineers to construct floors with very large span/depth ratios, with the result that vibration behaviour is now one of the most important design criteria. Vibration problems range from annoyance to occupants of office buildings due to excitations as small as a single human footfall, to large amplitude motions caused by group activities in, for example, dancehalls or sports stadia. While the loading and the human perception of vibrations are quite well understood, considerable doubt persists over the dynamic characteristics of the floor slabs themselves.

Research at Oxford is aimed at gaining a greater understanding of floor vibrations, and developing a design approach which accounts for vibration problems. A large programme of in-situ vibration monitoring of concrete floor slabs has recently been completed. The natural frequencies, mode shapes and damping characteristics of fifteen floors have been determined, together with their responses to a range of forced vibration inputs. Test results are compared with those obtained from a simple finite element model. Results are being used to evaluate currently used predictive methods and design guidelines, most of which appear to be excessively conservative. Work now in progress is aimed at gaining a more detailed understanding of the damping mechanisms present in the floor system using a combination of laboratory models and further field testing, and at developing more realistic, theoretically based design methods.

Project support: EPSRC

6.8.2 Dynamics of Offshore Jack-Up Platforms

M.S. Williams, G.T. Houlsby, R.S.G. Thompson

Jack-ups are mobile drilling units which are widely used for exploration activities in the North Sea. The dynamic behaviour of these platforms under storm loading has received relatively little attention, and uncertainty persists over a number of aspects of the analysis and design methods currently used. This project aims to provide a fuller understanding of the dynamic behaviour of jack-ups, thus enabling them to be used with confidence in deeper seas than at present. A series of finite element time-stepping analyses of varying complexity are being developed, including large displacement effects and of non-linearities at the leg/deck interface. Particular attention is paid to the influence of the conical "spud-can" footings, whose behaviour under static loadings has already been studied in depth by members of the Civil Engineering Group.

Project support: EPSRC.

6.8.3 Seismic Assessment and Retrofit of Reinforced Concrete Bridges

M.S. Williams

One of the major problems facing many seismically vulnerable regions is the assessment and retrofit of existing structures. Since it is impractical to bring all older structures up to present-day code standards, those most in need of retrofit must be identified. This requires an assessment of the likelihood of damage and its consequences; a major difficulty is the need to define and quantify structural damage.

This project aims to develop an analytically-based assessment procedure for reinforced concrete bridges. Non-linear dynamic analyses of bridges are performed, and the results are used to calculate seismic damage indices, which give a simple numerical indication of the level of damage sustained by a structure. The analysis method and the reliability of the indices are being evaluated by comparison with the results of cyclic tests on half-scale bridge bents and small-scale deep beam elements. The indices will then form one component of a decision-making algorithm, which will allow retrofit needs to be decided on a more rational basis than is currently possible.

Project support: NSERC, British Council

6.8.4 Damage Detection in Concrete Structures Using Vibration Measurement

M.S. Williams

Damage causes a change in stiffness, and therefore in the dynamic properties, of structures. Parameters based on changes in natural frequency can therefore be used as global damage measures, while changes in the vibration mode shapes can provide an indication of the location of damage. However, it is likely that the modal data for concrete structures would be particularly difficult to interpret, due to the non-uniformity of the material. Tests are being performed on simple reinforced concrete beam elements having a variety of damage locations and failure modes, in an effort to establish the feasibility of such assessment methods for concrete structures. Structures are loaded incrementally, with the dynamic characteristics determined between load increments using impact testing. Interpretation of the test data will aim to identify the magnitude, location and type of structural damage.

6.8.5 Impact Loading of Concrete Structures

M.S. Williams

This work involves a study of concrete material behaviour under extreme dynamic loads, with the aim of developing a model for use in the analysis of impact loading of concrete structures. The theoretical development requires a detailed understanding of the mechanisms of failure induced by the impact; these vary with impactor size, shape and velocity, and with concrete element thickness. It is also necessary to account for the strain rate dependence of concrete material properties. The formulation of the model aims to avoid excessive complexity by incorporating a number of simplifying assumptions and empirical factors. It is intended that the model should be incorporated into an existing software package and validated by comparison with an existing database of test results.

Project support: The Nuffield Foundation.

6.8.6 Post-Earthquake Field Investigations

M.S. Williams, A. Blakeborough

Our understanding of structural behaviour under seismic loading can be greatly enhanced by observations and data gathering in the immediate aftermath of large damaging earthquakes. To this end teams of UK engineers undertake field missions whenever possible. Missions aim to assess structural performance, to reach conclusions on the adequacy of design codes, to identify any special or unusual factors, and to make recommendations for improvements in design and construction procedures. Researchers from Oxford have played major roles in earthquake investigations in Loma Prieta, California (1989), Erzincan, Turkey (1992) and Northridge, California (1994). The data gathered on these trips have led to the creation of a large seismic damage database and the validation of a new seismic intensity scale. There have also been numerous opportunities for the back-analysis of damaged structures, enabling engineers to evaluate the suitability of widely used analysis methods.

Project support: EPSRC

6.8.7 Calibration of the size of earthquakes by the ringing of church bells

A. Blakeborough and Prof. D.E. Key (CEP)

The modified Mercalli scale of earthquake intensity (MMI) is used to assess the effects of an earthquake on buildings, and hence to estimate the degree of shaking at a particular spot. One of the effects frequently recorded, and included in the MM scale is the ringing of church bells.

In a recent study, reports of bells being rung by historical British earthquakes have been assessed and the size of shaking required to ring a church bell determined analytically and experimentally on the EPSRC shaking table at Bristol.

6.8.8 Hydrodynamic and nonlinear seismic behaviour of concrete dams

Dr A. Blakeborough, Dr W.E. Daniell (University of Bristol) and Dr C.A. Taylor (University of Bristol)

Recent work on assessing the seismic risk to dams in the UK has drawn attention to the dependence of current analytical techniques on some very simple approximations used to estimate the effective added mass of the reservoir, the stiffness of the foundation rock and the damping both the reservoir and the foundation introduces. Work underway is monitoring the dynamic properties of a concrete gravity dam in Wales, including the measurement of hydrodynamic water pressures to assess the validity of a new class of Lagrangian fluid finite elements to model the reservoir.

Future work will assess potential seismic failure mechanisms by finite element analysis and shaking table model studies.

Support: EPSRC

6.8.9 Determining the dynamic properties of civil engineering structures by field testing and monitoring
A. Blakeborough

Monitoring the performance of structures in service is an important step feeding back data into the design process. It is also essential when the state of a particular structure is in question. The design and assessment of civil engineering structures under dynamic loads requires a detailed analytical model of the structure to be developed which if it is to be relied upon must be calibrated with actual performance data.

Recent cases where field testing has been used is in the assessment of church towers to ascertain the likely response to the bells being rung, measuring the wind climate around the Kessock bridge as well as the dynamic behaviour of the structure an additionally measuring the tension in the cables of the bridge by vibration measurement. The data collected is used to build a model of the dynamic performance of each structure which can then be used to model the effects of other sorts of loading, earthquakes for example. Also the change in dynamic characteristics as the state of the structure changes, due to temperature changes or wind speed can also be determined and used as indicators in the reverse process of assessing the state of the structure at a later date.

6.8.10 Shaking Table Investigation of Dynamic Behaviour of

Masonry Infill Panels
A. Blakeborough, C.N.N. Damage (University of Bristol) and Dr C.A. Taylor (University of Bristol)

Masonry panels, frequently used to fill in structural frames, can be either load-bearing, for which some calculations are made, or non load-bearing, in which case no calculations are made on how the wall will affect the structural behaviour. In any case for seismic loading the presence of infill, either load-bearing or not, will alter the load path in the frame and may transfer loads to parts of the structure not designed to carry them. Also, little is known of the out of plane behaviour of the panels in earthquakes, especially when this out of plane loading is combined with in plane loading.

A series of tests is underway using the EPSRC Shaking Table at Bristol investigating the seismic behaviour of a single steel bay with masonry infill to both in-plane and a combination of in-plane and out-of-plane excitation. The results will be used to calibrate analytical models of masonry behaviour, and predict the earthquake behaviour of masonry infilled frames.

Support: EU, British Council

6.9 SETTLEMENT DAMAGE

Work on tunnelling is motivated principally by current and future projects involving tunnelling in urban areas. In particular the development of ground movements around tunnels is of interest.

6.9.1 Settlement Damage to Masonry Structures
H.J. Burd, G.T. Houlsby, C. Augarde, G. Liu

This project consists of the study of damage to existing structures caused by tunnelling or other earthworks. The project is prompted by the extensive current interest in new underground developments, particularly in London. The Jubilee Line extension, CrossRail and other projects involve tunnelling under many important masonry buildings. The accurate identification of buildings at risk, and the assessment of possible damage is essential if appropriate procedures for settlement control are to be designed.

An initial stage of this research has been completed in which two-dimensional finite element models were developed to predict the ground surface settlements associated with tunnelling. In order to make realistic predictions of surface settlements, it is necessary to take care in the choice of constitutive model for the soil; a suitable soil model was identified for the prediction of surface settlements for tunnels driven in over-consolidated clay.

Development is in progress of a three-dimensional finite element model to represent both the soil deformations associated with tunnelling and the resulting interaction with a nearby masonry structure. When this model is complete, comparisons will be made with measurements made on real structures.

Project Support: EPSRC

6.9.2 Effects of Tunnelling Operations on existing nearby Tunnels

H.J. Burd, G.W.E. Milligan, S.H. Kim

Construction of a tunnel inevitably causes deformations in the ground around it as a result of stress relief, ground loss, deformation of the tunnel lining etc. The deformation pattern will generally follow a complex three-dimensional front as the tunnel face is advanced. The resulting deformations will affect other structures in the ground nearby, including building foundations and other tunnels. The latter is a particularly common and important problem in cities such as London with a well-developed system of tunnels for railways, the underground system, main sewers etc., when efforts are made to add to these systems (for example the Cross-Rail project and Jubilee Line extension in London). At the same time, design and construction of the new tunnels will be affected by the presence of the existing tunnels and the local ground stresses existing after their construction.

This project is concerned with the study of interactions between closely spaced tunnels in clay using a set of carefully controlled model tests. Instrumented tunnel linings are installed in the clay sample using a specially designed tunnelling machine and experiments are carried out for a range of tunnel spacings and orientations.

Project Support: Dong-Ah Construction Company, EPSRC.

6.10 THEORETICAL MODELLING OF SOILS

Applications of theoretical analysis to problems in soil mechanics forms an important part of the work of the group, and this is supported by more fundamental work on soil modelling.

6.10.1 Constitutive Models in Geotechnical Engineering
G.T. Houlsby, H.J. Burd

A review is being conducted of current practice in the application of constitutive models in geotechnical engineering, with a view to making future recommendations for research.

Project support: EPSRC.

6.10.2 Development of Finite Element Software
H.J. Burd, G.T. Houlsby

Extensive use is made in the Civil Engineering Research Group of finite element analysis. In order to support this research, a suite of finite element software (called "OXFEM") is available for general use.

OXFEM, and related computer software, is under continuous development. A special project is currently in progress, however, to revise the program incorporating recent development work completed within the research group.

Research in Civil Engineering

The following is an extract (Chapter 6) from the latest Research Summary published by the Department of Engineering Science. It contains the following subsections:

- In situ testing
- Soft soils, sedimentation processes and environmental applications
- Unsaturated and gassy soils
- Offshore foundations
- Reinforced soil
- Trenchless construction
- Piling engineering
- Dynamics of civil engineering structures
- Settlement damage
- Theoretical modelling of soils

6.0 CIVIL ENGINEERING

Research at Oxford in Civil Engineering involves a diverse group of topics. While the work in soil mechanics and structures is listed here, many research projects with applications to civil engineering are also found in other chapters of this report. Much of the work of the Wind Engineering research group has civil engineering applications. Research in geophysics has applications in mining engineering. Several of the topics listed under Coastal and Offshore Engineering are also of direct concern to civil engineers.

The work of the soil mechanics group involves both fundamental studies of soil properties and behaviour, and also applied work on geotechnical engineering problems. Research techniques involve theoretical studies, both analytical and numerical, laboratory testing and field testing. The group has particular strengths in scale model testing and in applications of finite element analysis. Research in the dynamics of civil engineering structures combines the measured behaviour of actual structures, both at full and model scale with the predictions of analytical models. It is intended to expand the current work in this area. Existing facilities are to be extended by the addition of a first-floor laboratory suitable for light structural work. This will allow some existing equipment to be moved, thus freeing space at ground level for some of the heavier equipment needed for structural work.

6.1 IN SITU TESTING

Work on in situ testing involves both the development of equipment and the establishment of methods of interpretation for in situ tests. The latter requires use of laboratory and field testing, as well as the development of new theories and analytical methods. A particular feature of the research in Oxford has been the use of large calibration chambers for the study of in situ testing devices in both sand and clay.

6.1.1 Calibration Chambers for In Situ Testing Devices in Sand

G.T.Houlsby

A large calibration chamber, 1.0 m in diameter and 1.5 m high, is available for calibration of in situ testing devices. A specimen of sand is prepared in the chamber using the sand raining technique to achieve a controlled density. The chamber is capable of containing the specimen under controlled conditions of stress in both axial and radial directions, with stresses applied through flexible rubber membranes. Displacements of the membranes may be monitored.

An earlier model of the chamber has been used to carry out a comprehensive series of tests on the Marchetti Dilatometer. The tests were at three different sand densities, and were used to study the influence of stress level, overconsolidation ratio and value. The results indicate that the readings obtained with the dilatometer reflect principally the lateral stress, and are not influenced by the vertical stress. Similar results were obtained for the cone penetrometer and cone pressuremeter in the present chamber, highlighting the importance of horizontal stresses.

A smaller, 450mm 450mm chamber is also available. Both chambers are suitable for other types of test, e.g. pile testing, in addition to their application to in situ testing.

Project support: EPSRC.

6.1.2 Calibration Chamber for In Situ Testing Devices in Clay
G.T. Houlsby

A large calibration chamber, 1.0m in diameter and 1.0m high, is available for the calibration of in situ testing devices in clay. The clay is prepared by one-dimensional consolidation from a slurry. After this initial phase of consolidation is complete, a second phase takes place in which independent vertical and horizontal stresses can be applied to the soil specimen. The vertical stress is applied through a membrane in the base of the chamber, and the lateral stress through a cylindrical membrane around the tank wall. A wide range of consolidation histories can therefore be applied to the specimen. The chamber has recently been used for the study of the Marchetti dilatometer leading to a better understanding of methods of interpretation of this device.

Project support: EPSRC.

6.1.3 The Cone Pressuremeter Test
G.T. Houlsby, N.R.F. Nutt

The Cone Pressuremeter is an in situ testing device which is being developed by Fugro-McClelland Ltd. A pressuremeter is mounted behind a conventional cone penetrometer, and information may be obtained from both the loading and unloading phases of the pressuremeter test. A programme of research has just been completed consisting of laboratory and field studies, and development of analyses. Laboratory studies were being carried out in a large calibration tank using model pressuremeters. Analytical procedures are concentrated on the difference between the installation of the cone pressuremeter and the self-boring pressuremeter. The pressuremeter results are also related to results obtained from the analysis of the cone penetration test.

Calibration chamber tests have recently been carried out on the cone pressuremeter in carbonate sands. These materials present an unusual combination of properties which render them very different from silica sands. The studies add to a previous database of tests on piles in carbonate materials.

Field testing of the Cone Pressuremeter has been carried out at the EPSRC test site at Bothkennar.

Project support: EPSRC, Fugro-McClelland Ltd., BP International.

6.1.4 The Marchetti Dilatometer in Clay
G.T. Houlsby, M.G. Smith

The large calibration chamber for tests in clay is being used to study the behaviour of the Marchetti Dilatometer in clay, with emphasis both on standard measurements and the estimation of consolidation properties. Tests have been carried out in clay with a range of stress states and stress histories, with a view to isolating the quantities which are important in influencing the results of the dilatometer test.

Project support: EPSRC.

6.1.5 Wave Induced Water Pressures in the Seabed
G.C. Sills

In order to predict the behaviour of the seabed as a foundation for offshore structures, it is necessary to understand the fundamental processes controlling this behaviour. One of the ways of achieving this is to examine the response of the seabed to an applied loading. In this programme, the loading considered is the pressure variation on the surface of the seabed due to waves in the overlying water, and the measured response is that of pore water pressures in the seabed. A differential piezometer and data logging system have been developed, and are being deployed in sand, silt and clay seabeds. Pore pressures are measured relative to a constant pressure close to the hydrostatic value in an air-filled bladder. This allows the use of sensitive transducers, thus providing greater accuracy of measurement of pore water pressure than could be achieved by direct measurement.

Experiments show that a small amount of damping of the response occurs with depth into the seabed. These results, and others, are used to assess the applicability of an elastic model for seabed behaviour, which allows the prediction of normal and shear stresses due to wave action.

A further measurement programme has been carried out with a model pipeline instrumented to measure pore pressure, and total stress around the pipeline, due to the wave loading on the seabed.

Project support: EPSRC.

6.1.6 Recording the presence of gas in the ground
G.C. Sills, C. Waddup, J. Lipscomb

Generation of gas such as methane in waste disposal sites, and subsequent leakage into the surrounding ground can present a major hazard. A specialised piezometer, or gas probe, has been developed to allow the presence of gas in the surrounding soil to be confirmed. Pressures recorded by the instrument are sensitive to the presence of gas, and the principle of operation is based on the use of two different designs of transducer housing, one of which registers the effect of gas more quickly than the other. Different readings on the two transducers therefore indicate that gas is present.

Project support: EPSRC

6.1.7 Wave effects on beach processes
G.C. Sills, M. Collins (Southampton University)

A joint measurement programme is being undertaken to determine the interaction between the seabed and the overlying water. Field measurements will be made of wave pressures, current velocities and turbidity, and compared with pore water pressures a little way beneath the seabed surface.

Project support: EC through HCM programme

6.1.8 Analysis of Signals from Sensors in Civil Engineering
G.T. Houlsby, L. Tarassenko, B. Ruck

The project involves an application of neural networks to the analysis of a signal from a remote sensor in a civil engineering application, and is intended to serve as a pilot study for other novel applications of modern signal analysis techniques. The Cone Penetration Test is used in the in situ investigation of the properties of soils. The acoustic signal from the cone is at present not interpreted (other than extremely qualitatively) and the intention is to use a neural network to interpret the FFT of this signal. The network will be trained in a series of calibration tests on known soils, and its ability to identify both soil type, and numerical values of the engineering properties of soils will then be tested. The network will be developed in two stages: the first stage being to develop the Kohonen feature map, and the second layer of the network being an optimal linear transform for the identification of soil properties. Data fusion studies will also be carried out on the possibility of including information from other transducers on the CPT. Other areas of application of similar techniques will be identified.

Project Support: EPSRC

6.1.9 Effects of Geometry and other Factors on Pressuremeter Tests

G.T. Houlsby, M. Yao

A study is being made, using both analytical and calibration chamber methods, of the influence of geometry (length/diameter ratio) and other factors on the results of pressuremeter tests.

6.2 SOFT SOILS, SEDIMENTATION PROCESSES AND ENVIRONMENTAL APPLICATIONS

The behaviour of soft soils deposited through water is important in such areas as dredging programmes, reservoir and estuary siltation, slurry waste disposal and land reclamation. The fundamental behaviour is being examined by introducing soil slurries into 2m high, 100mm diameter acrylic settling columns, and allowing them to settle and consolidate. Accurate, non- destructive measurements of density are made using X-rays transmitted through the soil, detected by a scintillation crystal and photomultiplier assembly. Measurements are also made of pore water pressure by transducers, of shear stiffness by shear wave transmission and of shear strength by a sleeved sensitive shear vane and by fall cone. The stress range is extended by applying a surcharge loading using a piston, or by the use of oedometers designed for soft soils. Field instruments include in situ densimeter and coring equipment.

Previous research programmes have examined the effects of rate of deposition of sediment, initial density and pore water chemistry. The results show that soft soils exhibit creep and time dependent strength increases. The rate of sedimentation has a significant effect on the structure, with a low rate producing a less dense soil than a fast one. Comparisons have been made with field measurements in the bed of the Irish Sea and laboratory simulations.

6.2.1 The Effect of Deposition History on the Development of Sediment Beds, with Particular Reference to Bothkennar

G.C. Sills

The behaviour of a particular soil is likely to be dependent upon the conditions under which it was deposited, and an understanding of the fundamental processes involved is important if predictions of future behaviour are to be successful. Sediment from Bothkennar, the SERC soft clay test bed site, is introduced into the settling columns under computer control to provide a range of deposition histories. The consolidation and strength properties are examined and compared with those of the undisturbed soil.

Project support: EPSRC.

6.2.2 The effect of chemicals on the state of soil

G.C. Sills, S. Walsh, A. Fuller-Lewis

Oedometers have been specially developed to allow the pore fluid chemistry of the soil to be exchanged while the resulting changes in the soil state are monitored through accurate local density and permeability measurements. This work has important applications in the long term design of slurry trench walls to contain contaminated waste.

Project support: EPSRC

6.2.3 The effect of electro-osmosis on soil behaviour

G.C. Sills, M. Lee, S. Tadros, N. Allaby

The application of an electrical potential difference to soil induces water movement and consolidation. Under suitable conditions, therefore, it may be used to accelerate the natural self-weight consolidation of waste slurries, or to provide remedial treatment for inadequate liners. Current research is directed towards both of theses considerations, with measurements of the effects of vertical potential differences and of horizontal potential differences. Density and permeability changes are observed, and should lead to a better understanding of the whole electro-kinetic process in soils.

Project support: EPSRC

6.2.4 Self-weight consolidation of a waste slurry

G.C. Sills, F. Yuan

Polluted sediment from the Ketelmeer lake bed in the Netherlands is being recovered and stored in a 30m deep disposal site. In order to plan the operation of the site, the Slufter, settling column experiments are being carried out to assess the influence of methane, generated by bacterial activity in the mud, on the self-weight consolidation process. So far, experiments have shown that the consolidation is reduced both in magnitude and in rate. Collaboration with B. Wichman, of the Rijkswaterstaat, is leading to improvements in numerical modelling of this process.

Project support: Rijkswaterstaat, The Netherlands

6.3 UNSATURATED AND GASSY SOILS

Many soils are unsaturated, with the void spaces occupied by a mixture of liquid (typically water) and gas (typically air or methane). These unsaturated soils occur in both the onshore environment, in the form of compacted fills and natural soils above the water table, and in the offshore environment, where "gassy soils" result from thermogenic or biogenic formation of natural gases within seabed sediments.

Equipment available for testing such soils includes specialised triaxial and oedometer cells, with facilities to separate gas and water volume changes and to control pore water and pore air pressure differences on the sample boundaries.

6.3.1 Development of an Elasto-Plastic Critical State Model for Unsaturated Soil

S.J. Wheeler, V. Sivakumar

An understanding of the mechanics of unsaturated soil is vital for the effective design and analysis of the many foundations, slopes, embankments and retaining structures which incorporate unsaturated compacted fills or unsaturated natural soils. To this end, a generalized elasto-plastic constitutive model for unsaturated soil has been developed by the extension of critical state theory to soils containing two pore fluids. The critical state framework involves five state variables (mean net stress, deviator stress, suction, specific volume and specific water volume), and it is able to represent important features of unsaturated soil behaviour, such as the complex pattern of swelling and collapse on wetting, the increase of shear strength with suction and the variation of compressibility with suction. The model, which has been validated and refined by comparison against results from a programme of controlled suction triaxial stress path tests on samples of unsaturated compacted kaolin, is capable of predicting volumetric strains, shear strains and changes of water content for any stress path and any drainage condition.

Project support: EPSRC

6.3.2 Yielding of Unsaturated Soil

S.J. Wheeler, I. Zakaria (University of Sheffield)

Controlled suction triaxial stress path tests on samples of unsaturated compacted kaolin have been used to examine the shape of the yield surface for unsaturated soil (in a three- dimensional space with axes of mean net stress, deviator stress and suction). Elastic behaviour prior to yielding was also investigated, together with the form of the flow rule governing the ratio of plastic strain increments after yielding. Tests were conducted in a Bishop-Wesley hydraulic triaxial apparatus with axial and lateral strains measured directly on the soil sample using local displacement gauges. Soil suction (the difference between the pore air pressure and the pore water pressure) was controlled using the axis translation technique.

Project support: Malaysian Government.

6.3.3 Influence of Compaction Procedure on the Elasto-Plastic Behaviour of Unsaturated Soil

S.J. Wheeler, V. Sivakumar

Compaction procedure influences the initial fabric of an unsaturated compacted clay and thus affects the subsequent mechanical behaviour of the soil. A series of suction controlled triaxial tests has been performed to investigate the influence of compaction water content, compactive effort and method of compaction (static or dynamic) on the behaviour of unsaturated compacted kaolin. Double-walled triaxial cells have been used for the measurement of sample volume change, and suctions have been controlled by means of the axis translation technique. A sophisticated control system enables any required stress path to be followed. The test results have been interpreted within the framework of an elasto-plastic critical state constitutive model for unsaturated soil.

Project Support: EPSRC, British Council

6.3.4 Mechanical Behaviour of Highly Expansive Unsaturated Clays

S.J. Wheeler, R.S. Sharma

Unsaturated soils containing active clay minerals expand dramatically on wetting. The annual cost of damage to buildings, structures and roads caused by these expansive soils is estimated at £150 million in the UK and many billions of pounds worldwide. Unsaturated expansive clays are also used for engineered clay barriers for environmental protection or in connection with radioactive waste disposal. The mechanical behaviour of a highly expansive unsaturated clay will be investigated in a series of suction controlled triaxial tests. An osmotic method, developed in France, will be used to apply high values of suction. The test results will be used in the development of an elasto-plastic critical state constitutive model for highly expansive unsaturated soils, which takes account of the large irreversible component of swelling that occurs on first wetting of these soils.

Project Support: EPSRC, British Council

6.3.5 Numerical Modelling of Unsaturated Soil

S.J. Wheeler, I.C. Pyrah (University of Sheffield), K. Nesnas (University of Sheffield)

An elasto-plastic critical state constitutive model for unsaturated soil, developed at the Technical University of Catalunya, Barcelona, has been incorporated into the finite element program CRISP. Validation of the coding involved a comprehensive suite of single element tests for both axisymmetric and plane strain conditions. The program was then used to examine the behaviour of foundations built on unsaturated soil, in particular, the effect of inundation (reduction of suction) on deformations and possible collapse.

Project support: Algerian Government.

6.3.6 Behaviour of Gassy Offshore Soils

G.C. Sills, S.J. Wheeler

Where undissolved gas occurs within the seabed it can affect the geotechnical properties and behaviour of the sediments, with important consequences for performance of foundations for offshore structures. An extensive programme of research into the influence of undissolved gas on the behaviour of fine-grained offshore soils (clays and silts) was based on the development of a laboratory technique for the preparation of reconstituted soil samples containing a uniform distribution of gas bubbles. The structure of these samples is similar to that observed in gassy sediment recovered from the seabed, and consists of relatively large gas-filled cavities surrounded by a matrix of saturated soil. Individual projects have investigated the effect of gas bubbles on consolidation behaviour, undrained strength, drained strength, elastic moduli and acoustic properties. Future projects may investigate the cyclic loading response of gassy soils, the performance of piled foundations in gassy soils and the development of an acoustic probe for gas detection and measurement of gas concentration.

Recent applications of this work are in the Caspian Sea, where oil recovery in a multi-national operation will require consideration of the effect of the undissolved gas whose existence has been well documented by Azerbaijani engineers.

6.3.7 The Consolidation of a Gassy Lakebed Sediment

G.C. Sills, F. Yuan

Sediment from the bed of the Ketelmeer in the Netherlands produces gas biogenically. The mud is polluted and is therefore being recovered for disposal elsewhere. In order to predict the magnitude and time-scale of consolidation in the disposal site, a programme of oedometer experiments is under way. In order to model as accurately as possible the in situ stress levels, the applied load is increased steadily, with a corresponding increase in the back pressure. This is important in a gassy soil, where the gas behaviour is influenced by the total stress levels.

Project support: Rijkswaterstaat, Netherlands and EPSRC.

6.4 OFFSHORE FOUNDATIONS

Research on offshore foundations is principally sponsored by oil companies, and covers a variety of topics including piled and shallow foundations and the behaviour of jack-up units.

6.4.1 Combined Loading of Shallow Foundations on Clay

G.T. Houlsby, H.J. Burd, C.L. Ngo Tran

Many foundations, particularly those offshore, are subjected to combined vertical, horizontal and moment loading. Whilst vertical loading is well understood, further work is needed to understand the behaviour of foundations under combined loadings. A project is planned in which three-dimensional finite element methods will be used to study the stability of shallow foundations on clay under a variety of loading conditions.

A three-dimensional finite element model capable of solving a simplified form of the problem has been developed as an initial part of the research. Further work is needed to continue the development of suitable numerical formulations for three-dimensional stability analysis and to establish `benchmark' solutions for the response of circular footings under combined vertical, horizontal and moment loading.

The numerical models developed during this research will be tested by comparison with the results of laboratory scale model tests that have recently been completed at Oxford.

Project support: UGC equipment grant.

6.4.2 Moment Fixity of Spudcan Footings

G.T. Houlsby, C.M. Martin

Both experimental and numerical work has been completed to develop new methods of understand the interaction between the spudcan foundation of a jack-up unit and clay soils. Particular attention was paid to the prediction of moment fixity, which is of importance to the assessment of jack-up units. New analytical models have been developed based on work- hardening plasticity theory. Experimental work was used to verify the new theories, and to provide direct evidence of the shape of the yield locus and other features of the plasticity model. The experiments made use of a computer-controlled rig which can apply any displacement path to a model spudcan. Loads and displacements were monitored. By carrying out a carefully controlled series of tests at different depths of embedment, the behaviour of the spudcan, and the changes of the response with depth, can be determined.

Project support: Noble Denton and Associates, Rhodes Trust.

6.4.4 Tension Loading of Plated Foundations

G.T. Houlsby, J. Mangal

The plated foundation is a new concept for the foundation for a steel jacket offshore production platform. It replaces the mudmat and piles usually used, and consists of an enlarged mudmat with a stiffened skirt approximately 5m deep. Studies have been completed of the capacity of plated foundations under combined vertical, horizontal and moment loading. Model tests have been carried out using a viscous pore fluid to model the drainage process correctly, since at full scale the partial drainage problem is of importance. Of particular interest are tensile vertical loads combined with horizontal and moment loads.

The research is currently being extended into a more general study of shallow foundations subjected to offshore loading. This will aim to provide comprehensive information on the variation of load capacity with loading rate, incorporating the influence of combined loading. The testing involves use of a versatile three degree-of-freedom loading apparatus.

Project support: Kvaerner Engineering, EPSRC

6.5 REINFORCED SOIL

Research in the group is on both the fundamentals of the action of reinforcement, and on applied problems. Several testing facilities have been developed, including a unique 1m cube shear box, for testing reinforced soil.

The properties of soil as an engineering material may be improved in many situations by the inclusion of reinforcing elements. These may consist of metal strips, bars or grids; polymer geotextiles or grids; or even natural materials such as bamboo. The reinforcement may either be incorporated in soil fill during construction of retaining walls, embankments, or road pavements; or inserted (as soil "nails") in natural ground to support excavated slopes or stabilise existing slopes.

A programme of research in soil reinforcement has been in progress at Oxford for more than ten years. It has involved both fundamental investigation of the mechanics of soil- reinforcement interaction, using direct shear and pull out tests, and studies of existing or potential applications of reinforcement in practice. The work has ranged through numerical analyses, laboratory model studies and large scale testing with the aim in all cases of producing rational, straightforward and reliable design procedures. Supporting organisations have included SERC, TRL, Netlon Ltd, and several other industrial firms.

6.5.1 Mechanics of Reinforced Soil Walls

H.J. Burd, D. Lesniewska

A project is underway on the use of two-dimensional finite element methods to study the mechanics of reinforced soil walls. The purpose of this study is to assess the accuracy of the assumptions made in the current design methods for this type of system.

Initial research has concentrated on the development of suitable numerical procedures to model the structure. It is expected that the numerical model will be used to inspect the influence of changes in front-wall stiffness, reinforcement length and reinforcement properties on the behaviour of this type of reinforced soil system.

6.5.2 Centrifuge Testing of Soil Nailed Slopes

G.W.E. Milligan, K. Tei

This recent project studied the behaviour of soil-nailed slopes in cohesionless soil (fine sand) using model tests in the geotechnical centrifuge at City University. Observations were made of slope failure mechanisms, earth pressures, nail forces and force distributions, soil deformations, face deflections and surface settlements. The validity of the modelling process was checked by comparisons between published data from full scale tests and centrifuge models of these tests.

The stability of soil-nailed slopes often depends on the pull-out resistance of the nails, yet this is one of the areas of greatest uncertainty in design. The programme of centrifuge testing was therefore backed up by detailed investigations of pull out forces and mechanisms.

Project support: Tokyu Construction Co.

6.5.3 Pull Out Testing of Soil Nails and Reinforcement

G.W.E. Milligan, K. Tei, K.T. Chang

The pull-out resistance of soil nails or reinforcement is usually an important factor in design. Pull out testing is conceptually simple, but research at Oxford and elsewhere has shown that test procedures often do not model in situ conditions very well and the results are greatly influenced by the test method, boundary conditions and other factors. Three different sizes of test box, including a very large one which holds a soil sample 1.0 x 1.0 x 1.0m, are being used for both direct shear and pull out tests with various boundary conditions and internal measurements of reinforcement strain, soil deformation and other quantities. This will improve understanding of the pull out resistance of reinforcement in different types of soil in realistic field situations.

It is hoped to extend this work in due course to field monitoring of full-scale constructions on site to validate the findings of the laboratory modelling.

Project support: Tokyu Construction Co.

6.5.4 Large Shear Box Facility
G.W.E. Milligan

A large-scale apparatus capable of containing a soil specimen 1.0m x 1.0m x 1.0m in size has been constructed, to allow direct shear and pull-out tests to be carried out using actual reinforcing materials in soil under conditions of controlled boundary stresses. Use of the large scale apparatus has allowed many of the factors causing uncertainty in the interpretation of more conventional tests to be identified and eliminated.

The apparatus has been used recently to investigate the performance of different types of in-situ reinforcement (soil nails), to elucidate the relative contribution of tension and bending resistance and the influence of installation technique.

The apparatus was developed with SERC, TRL and departmental funds. It is available for future projects on soil-reinforcement interaction.

6.5.5 Reinforced Soil in Flexible Culvert Construction
H.J. Burd, G.W.E. Milligan, I.C. Martorano

Flexible steel pipes and arches are used in conjunction with granular soil as an effective and economical way of forming large culverts, underpasses and other constructions. There are problems in their construction, however, and in their design and performance under concentrated loading. A laboratory scale study of the use of soil reinforcement to improve the behaviour of flexible culverts has recently been completed. The current stage of this project consists of the development and application of finite element models of buried culvert behaviour. This work includes the development of large displacement curved beam elements for modelling the culvert and procedures for modelling the interface between the culvert and the soil. It is intended that this model will be used to carry out back-analysis calculations of full scale tests for which data is available.

Project support: EPSRC, TRL, Asset International, Brazilian Government.

6.5.6 Reinforced Soil Design

G.W.E. Milligan, G.T. Houlsby, H.J. Burd

As well as fundamental experimental investigations into reinforced soil behaviour and applications (described above), work at Oxford is in progress on calculations and design methods for practical application. These methods stem from the understanding of behaviour developed through laboratory research and instrumented field experiments.

First it is important to establish a rational means of selecting design parameters and allowing for safety in reinforced soil, particularly for cases where new polymer reinforcement materials are used. Subsequent analyses may then be presented in a uniform and consistent way. Work has recently been focused on the use of reinforcement over poor ground for the construction of embankments and unpaved roads. New analyses have been developed for both cases, using plasticity theory for the embankment and a limit equilibrium analysis for unpaved roads.

Work has also been completed on reinforced soil walls concentrating on the prediction of deformation in walls reinforced by polymer (geotextile) reinforcement materials. The analysis for deformation accurately predicted under Class A conditions (prediction before construction) the behaviour of two full scale trial walls built in Canada under the NATO Applied Science funding scheme. This work has recently been extended to the use of finite element methods to study wall behaviour.

The findings from research at Oxford have been widely distributed through short courses run in Oxford at the Department of External Studies and with Universities abroad. A course on fundamental behaviour and analysis has been run in Australia, Canada, Holland, Hong Kong, UK and USA. Courses are run in cooperation with Prof. C.J.F.P. Jones (Newcastle University) and Dr R.A. Jewell (GeoSyntec).

6.6 TRENCHLESS CONSTRUCTION

Trenchless construction technologies involve a wide range of methods of installing, replacing or renovating service pipes, ducts and small diameter tunnels with minimal excavation from the service. They include moling, directional drilling, microtunnelling, pipe bursting, pipe jacking etc. Oxford's civil engineering research group has been at the forefront of research on some of these techniques. Ground movements due to pipe bursting have been investigated using laboratory modelling, in a project sponsored by British Gas and EPSRC; while pipe jacking has been the subject of an ongoing series of major projects supported by EPSRC, the Pipe Jacking Association and a consortium of water service companies (Northumbrian, North West, Severn Trent, Thames and Yorkshire).

Pipe jacking is a method of forming small diameter tunnels by progressively jacking a line of pipes through the ground as excavation proceeds at the tunnel face. The way in which the pipes interact with the ground, particularly when successive pipe sections become slightly misaligned, is not well understood. Nor is enough known about how the stresses in the pipes are related to soil conditions, jacking forces, joint details etc, for a safe yet economical design to be obtained in all cases.

The first stage of the pipe jacking research work again involved small-scale model tests in the laboratory, while the second stage comprised a series of five full scale schemes on active sites. One of the pipes in each scheme was heavily instrumented to measure overall jacking forces and pipe movements, joint articulations and local contact stresses between pipes, longitudinal pipe strains, total and effective radial and shear contact stresses between pipe and ground; where possible, ground movements around the pipe were also measured. The instrumentation and procedures developed for this have proved extremely successful, and large quantities of high-quality data have been collected. The results of this work are already being used to improve industrial practice.

6.6.1 Field Performance of Jacked Pipes

G.W.E. Milligan, M. Marshall

Stage 3 of the project continues with monitoring of the performance in the field of the jacking of reinforced concrete pipes. This stage will concentrate on the interaction between the pipes and the ground, to extend the information obtained from the earlier stages, in conjunction with detailed measurements of ground stiffness, initial stresses and ground movements due to the tunnelling operation.

In addition to providing direct information on ground movements, this work should allow further progress to be made towards the ultimate aim of predicting accurately the required jacking load for any combination of ground conditions, tunnel length, method and accuracy of construction etc. This in turn will allow rational design of pipes, jacking equipment, thrust walls and other components.

Project support: EPSRC, the Pipe Jacking Association, and a consortium of five water service companies.

6.6.2. Analysis and Design of Jacking Pipes

G.W.E. Milligan, H.J. Burd and J.Q. Zhou

This project (Stage 4 of the overall programme) takes, as input data, the results from the field work on the maximum jacking loads, misalignment angles between pipes and resulting stress concentrations in pipe joints. The intention is to investigate by numerical and physical modelling possible improvements to pipe, and more particularly pipe joint, design. These might include changes to joint geometry, reinforcement layout, or packing material dimensions and characteristics. The most successful theoretical designs may then be checked by laboratory tests or site monitoring on an actual scheme.

An initial stage of numerical modelling used a two-dimensional elastic model to study pipe joint behaviour. More detailed work is now in progress in which a three-dimensional finite element model will be used to investigate the interaction between pipes and between the soil and the pipes. This work has included the development of a suitable numerical model for concrete for implementation in the finite element program OXFEM.

Project support: EPSRC, the Pipe Jacking Association, and a consortium of five water service companies.

6.7 PILING ENGINEERING

6.7.1 Pile-Soil Interaction

H.J. Burd, M.S. Williams, A.R. Chaudhry

A theoretical study of the behaviour of single piles and pile groups under vertical and lateral loading is currently under way. This work is intended to provide an improved understanding of the soil-structure interaction processes that occur in piled foundations particularly for closely spaced piles subjected to lateral loads. Initial studies have been carried out using finite element and boundary element methods to study the static behaviour of a pile embedded in an elastic half-space. Further work has included the use of plane strain finite element models to study the mechanisms of interaction between closely spaced piles in clay. The work is currently being extended to the analysis of pile groups in sand where the dilational characteristics of the soil have an important influence on behaviour.

A review is being carried out of the methods that are available for the prediction of the behaviour of pile groups under lateral loading.

Project Support: ICI Scholarship and Travel Scholarship from Mott MacDonald.

6.8 DYNAMICS OF CIVIL ENGINEERING STRUCTURES

Structural dynamics research at Oxford deals with civil engineering problems arising from sources as diverse as earthquakes, wind- and traffic-induced vibrations of bridges, wave loading of offshore structures and occupant-induced vibrations in buildings. Work in progress combines field testing with analytical and computer modelling, plus it is intended to supplement this with extensive laboratory work in the near future.

Previous work in the area has included the testing of novel bracing techniques for aseismic design, work on the dynamic behaviour of prestressed elements on demolition, field monitoring of large structures to determine the actual performance of the structures in comparison with analytical models

6.8.1 Vibrations in Prestressed Concrete Floors

M.S. Williams, S. Falati

Recent advances in prestressing have enabled engineers to construct floors with very large span/depth ratios, with the result that vibration behaviour is now one of the most important design criteria. Vibration problems range from annoyance to occupants of office buildings due to excitations as small as a single human footfall, to large amplitude motions caused by group activities in, for example, dancehalls or sports stadia. While the loading and the human perception of vibrations are quite well understood, considerable doubt persists over the dynamic characteristics of the floor slabs themselves.

Research at Oxford is aimed at gaining a greater understanding of floor vibrations, and developing a design approach which accounts for vibration problems. A large programme of in-situ vibration monitoring of concrete floor slabs has recently been completed. The natural frequencies, mode shapes and damping characteristics of fifteen floors have been determined, together with their responses to a range of forced vibration inputs. Test results are compared with those obtained from a simple finite element model. Results are being used to evaluate currently used predictive methods and design guidelines, most of which appear to be excessively conservative. Work now in progress is aimed at gaining a more detailed understanding of the damping mechanisms present in the floor system using a combination of laboratory models and further field testing, and at developing more realistic, theoretically based design methods.

Project support: EPSRC

6.8.2 Dynamics of Offshore Jack-Up Platforms

M.S. Williams, G.T. Houlsby, R.S.G. Thompson

Jack-ups are mobile drilling units which are widely used for exploration activities in the North Sea. The dynamic behaviour of these platforms under storm loading has received relatively little attention, and uncertainty persists over a number of aspects of the analysis and design methods currently used. This project aims to provide a fuller understanding of the dynamic behaviour of jack-ups, thus enabling them to be used with confidence in deeper seas than at present. A series of finite element time-stepping analyses of varying complexity are being developed, including large displacement effects and of non-linearities at the leg/deck interface. Particular attention is paid to the influence of the conical "spud-can" footings, whose behaviour under static loadings has already been studied in depth by members of the Civil Engineering Group.

Project support: EPSRC.

6.8.3 Seismic Assessment and Retrofit of Reinforced Concrete Bridges

M.S. Williams

One of the major problems facing many seismically vulnerable regions is the assessment and retrofit of existing structures. Since it is impractical to bring all older structures up to present-day code standards, those most in need of retrofit must be identified. This requires an assessment of the likelihood of damage and its consequences; a major difficulty is the need to define and quantify structural damage.

This project aims to develop an analytically-based assessment procedure for reinforced concrete bridges. Non-linear dynamic analyses of bridges are performed, and the results are used to calculate seismic damage indices, which give a simple numerical indication of the level of damage sustained by a structure. The analysis method and the reliability of the indices are being evaluated by comparison with the results of cyclic tests on half-scale bridge bents and small-scale deep beam elements. The indices will then form one component of a decision-making algorithm, which will allow retrofit needs to be decided on a more rational basis than is currently possible.

Project support: NSERC, British Council

6.8.4 Damage Detection in Concrete Structures Using Vibration Measurement

M.S. Williams

Damage causes a change in stiffness, and therefore in the dynamic properties, of structures. Parameters based on changes in natural frequency can therefore be used as global damage measures, while changes in the vibration mode shapes can provide an indication of the location of damage. However, it is likely that the modal data for concrete structures would be particularly difficult to interpret, due to the non-uniformity of the material. Tests are being performed on simple reinforced concrete beam elements having a variety of damage locations and failure modes, in an effort to establish the feasibility of such assessment methods for concrete structures. Structures are loaded incrementally, with the dynamic characteristics determined between load increments using impact testing. Interpretation of the test data will aim to identify the magnitude, location and type of structural damage.

6.8.5 Impact Loading of Concrete Structures

M.S. Williams

This work involves a study of concrete material behaviour under extreme dynamic loads, with the aim of developing a model for use in the analysis of impact loading of concrete structures. The theoretical development requires a detailed understanding of the mechanisms of failure induced by the impact; these vary with impactor size, shape and velocity, and with concrete element thickness. It is also necessary to account for the strain rate dependence of concrete material properties. The formulation of the model aims to avoid excessive complexity by incorporating a number of simplifying assumptions and empirical factors. It is intended that the model should be incorporated into an existing software package and validated by comparison with an existing database of test results.

Project support: The Nuffield Foundation.

6.8.6 Post-Earthquake Field Investigations

M.S. Williams, A. Blakeborough

Our understanding of structural behaviour under seismic loading can be greatly enhanced by observations and data gathering in the immediate aftermath of large damaging earthquakes. To this end teams of UK engineers undertake field missions whenever possible. Missions aim to assess structural performance, to reach conclusions on the adequacy of design codes, to identify any special or unusual factors, and to make recommendations for improvements in design and construction procedures. Researchers from Oxford have played major roles in earthquake investigations in Loma Prieta, California (1989), Erzincan, Turkey (1992) and Northridge, California (1994). The data gathered on these trips have led to the creation of a large seismic damage database and the validation of a new seismic intensity scale. There have also been numerous opportunities for the back-analysis of damaged structures, enabling engineers to evaluate the suitability of widely used analysis methods.

Project support: EPSRC

6.8.7 Calibration of the size of earthquakes by the ringing of church bells

A. Blakeborough and Prof. D.E. Key (CEP)

The modified Mercalli scale of earthquake intensity (MMI) is used to assess the effects of an earthquake on buildings, and hence to estimate the degree of shaking at a particular spot. One of the effects frequently recorded, and included in the MM scale is the ringing of church bells.

In a recent study, reports of bells being rung by historical British earthquakes have been assessed and the size of shaking required to ring a church bell determined analytically and experimentally on the EPSRC shaking table at Bristol.

6.8.8 Hydrodynamic and nonlinear seismic behaviour of concrete dams

Dr A. Blakeborough, Dr W.E. Daniell (University of Bristol) and Dr C.A. Taylor (University of Bristol)

Recent work on assessing the seismic risk to dams in the UK has drawn attention to the dependence of current analytical techniques on some very simple approximations used to estimate the effective added mass of the reservoir, the stiffness of the foundation rock and the damping both the reservoir and the foundation introduces. Work underway is monitoring the dynamic properties of a concrete gravity dam in Wales, including the measurement of hydrodynamic water pressures to assess the validity of a new class of Lagrangian fluid finite elements to model the reservoir.

Future work will assess potential seismic failure mechanisms by finite element analysis and shaking table model studies.

Support: EPSRC

6.8.9 Determining the dynamic properties of civil engineering structures by field testing and monitoring

A. Blakeborough

Monitoring the performance of structures in service is an important step feeding back data into the design process. It is also essential when the state of a particular structure is in question. The design and assessment of civil engineering structures under dynamic loads requires a detailed analytical model of the structure to be developed which if it is to be relied upon must be calibrated with actual performance data.

Recent cases where field testing has been used is in the assessment of church towers to ascertain the likely response to the bells being rung, measuring the wind climate around the Kessock bridge as well as the dynamic behaviour of the structure an additionally measuring the tension in the cables of the bridge by vibration measurement. The data collected is used to build a model of the dynamic performance of each structure which can then be used to model the effects of other sorts of loading, earthquakes for example. Also the change in dynamic characteristics as the state of the structure changes, due to temperature changes or wind speed can also be determined and used as indicators in the reverse process of assessing the state of the structure at a later date.

6.8.10 Shaking Table Investigation of Dynamic Behaviour of

Masonry Infill Panels

A. Blakeborough, C.N.N. Damage (University of Bristol) and Dr C.A. Taylor (University of Bristol)

Masonry panels, frequently used to fill in structural frames, can be either load-bearing, for which some calculations are made, or non load-bearing, in which case no calculations are made on how the wall will affect the structural behaviour. In any case for seismic loading the presence of infill, either load-bearing or not, will alter the load path in the frame and may transfer loads to parts of the structure not designed to carry them. Also, little is known of the out of plane behaviour of the panels in earthquakes, especially when this out of plane loading is combined with in plane loading.

A series of tests is underway using the EPSRC Shaking Table at Bristol investigating the seismic behaviour of a single steel bay with masonry infill to both in-plane and a combination of in-plane and out-of-plane excitation. The results will be used to calibrate analytical models of masonry behaviour, and predict the earthquake behaviour of masonry infilled frames.

Support: EU, British Council

6.9 SETTLEMENT DAMAGE

Work on tunnelling is motivated principally by current and future projects involving tunnelling in urban areas. In particular the development of ground movements around tunnels is of interest.

6.9.1 Settlement Damage to Masonry Structures

H.J. Burd, G.T. Houlsby, C. Augarde, G. Liu

This project consists of the study of damage to existing structures caused by tunnelling or other earthworks. The project is prompted by the extensive current interest in new underground developments, particularly in London. The Jubilee Line extension, CrossRail and other projects involve tunnelling under many important masonry buildings. The accurate identification of buildings at risk, and the assessment of possible damage is essential if appropriate procedures for settlement control are to be designed.

An initial stage of this research has been completed in which two-dimensional finite element models were developed to predict the ground surface settlements associated with tunnelling. In order to make realistic predictions of surface settlements, it is necessary to take care in the choice of constitutive model for the soil; a suitable soil model was identified for the prediction of surface settlements for tunnels driven in over-consolidated clay.

Development is in progress of a three-dimensional finite element model to represent both the soil deformations associated with tunnelling and the resulting interaction with a nearby masonry structure. When this model is complete, comparisons will be made with measurements made on real structures.

Project Support: EPSRC

6.9.2 Effects of Tunnelling Operations on existing nearby Tunnels

H.J. Burd, G.W.E. Milligan, S.H. Kim

Construction of a tunnel inevitably causes deformations in the ground around it as a result of stress relief, ground loss, deformation of the tunnel lining etc. The deformation pattern will generally follow a complex three-dimensional front as the tunnel face is advanced. The resulting deformations will affect other structures in the ground nearby, including building foundations and other tunnels. The latter is a particularly common and important problem in cities such as London with a well-developed system of tunnels for railways, the underground system, main sewers etc., when efforts are made to add to these systems (for example the Cross-Rail project and Jubilee Line extension in London). At the same time, design and construction of the new tunnels will be affected by the presence of the existing tunnels and the local ground stresses existing after their construction.

This project is concerned with the study of interactions between closely spaced tunnels in clay using a set of carefully controlled model tests. Instrumented tunnel linings are installed in the clay sample using a specially designed tunnelling machine and experiments are carried out for a range of tunnel spacings and orientations.

Project Support: Dong-Ah Construction Company, EPSRC.

6.10 THEORETICAL MODELLING OF SOILS

Applications of theoretical analysis to problems in soil mechanics forms an important part of the work of the group, and this is supported by more fundamental work on soil modelling.

6.10.1 Constitutive Models in Geotechnical Engineering

G.T. Houlsby, H.J. Burd

A review is being conducted of current practice in the application of constitutive models in geotechnical engineering, with a view to making future recommendations for research.

Project support: EPSRC.

6.10.2 Development of Finite Element Software

H.J. Burd, G.T. Houlsby

Extensive use is made in the Civil Engineering Research Group of finite element analysis. In order to support this research, a suite of finite element software (called "OXFEM") is available for general use.

OXFEM, and related computer software, is under continuous development. A special project is currently in progress, however, to revise the program incorporating recent development work completed within the research group.

SLOPE DESIGN

Developed by Helen Connolly (1996/7), now maintained by David Toll d.g.toll@durham.ac.uk

Please note:-This set of pages is still under construction

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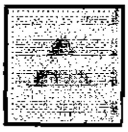

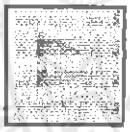

SLOPE DESIGN

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Please note:-This set of pages is still under construction

To Top Of Page

www.dur.ac.uk/~desowww4/cal/slopes/index.htm

SLOPE STABILITY ANALYSIS:-

To Be Considered in Assessment of Stability

- Ground Investigation
- Most Critical Slip Surface
- Tension Cracks
- Submerged Slopes
- Factor of Safety
- Long and Short-Term Stability
- Effective or Total Stress Parameters?
- Progressive Failure
- Pre-Existing Failure Surfaces
- Assumptions in Limit Equilibrium

Methods of Analysis

Granular Soils:

- The C'=0 Method

Cohesive Soils:

Circular Failure Surface

- The Basic Idea
- Method of Slices
- Fellenius' Method
- Bishop's Method

Non-Circular Failure Surface

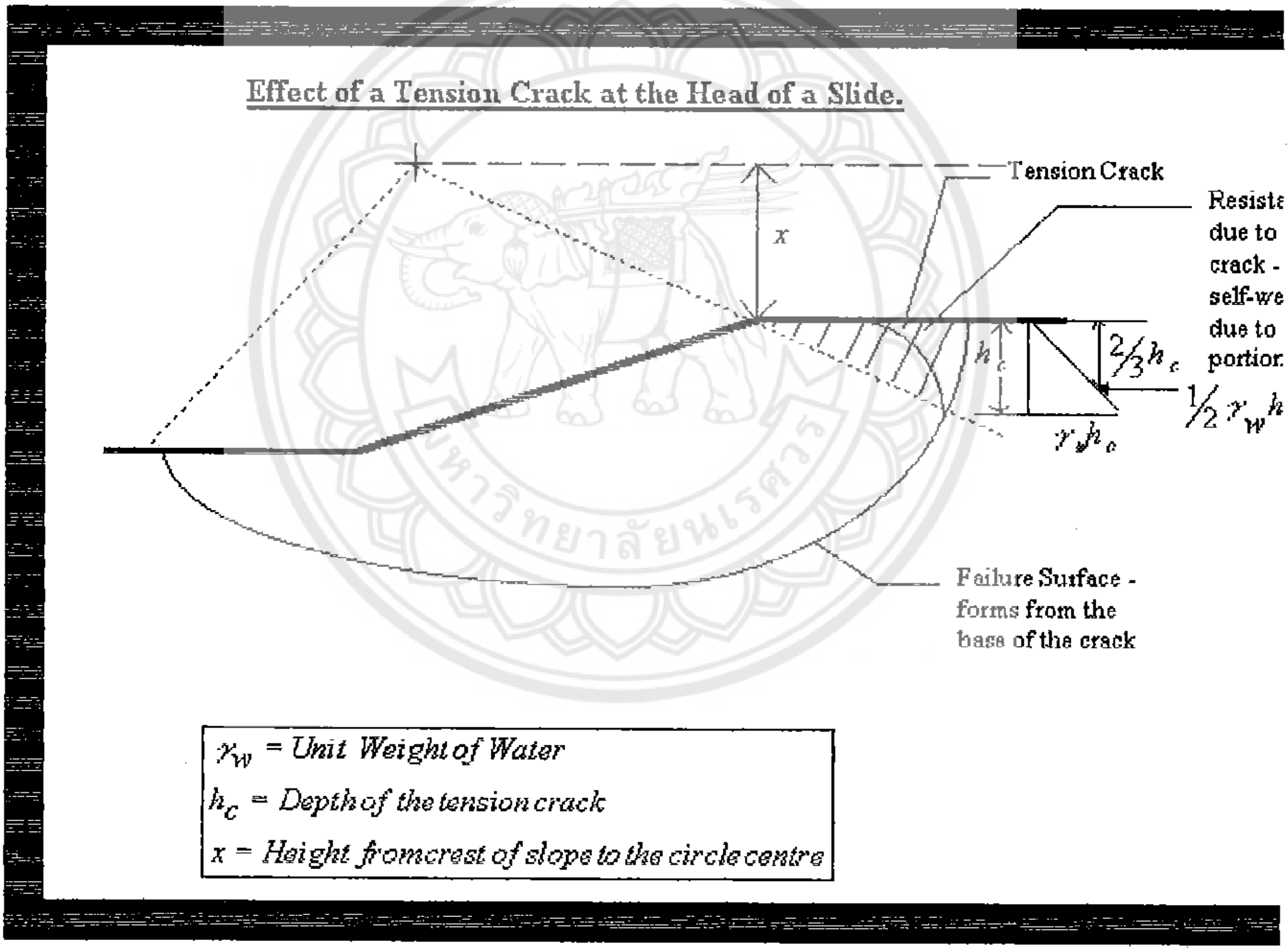
- Janbu's Method
- Infinite Slope Method
- Stability Charts

TENSION CRACKS:

A tension crack at the head of a slide suggests strongly that instability is imminent. Tension cracks are sometimes used in slope stability calculations, and sometimes they are considered to be full of water. If this is the case, then hydrostatic forces develop as shown below:-

Tension cracks are not usually important in stability analysis, but can become so in some special cases. These cases are not covered here but can be referred to in "The Stability of Slopes" by E.Bromhead (p141).***<nb. This link is to Prof. Bromhead's homepage at Kingston University, London.>***

We should therefore assume the cracks don't occur, but take account of them in analysing a slope which has already cracked.



Vibration and Waves Animations

Dan Russell, Ph.D., Assistant Professor of Applied Physics at Kettering University in Flint, MI

The links below contain animations which visualize certain concepts concerning Vibration and Waves (sound and light). The choice of animations coincides with topics covered in the courses **PHYS-230, Physics III: Waves**, and **PHYS-580, Fundamentals of Acoustics**, which I teach at Kettering University.

The animations were created using *Mathematica*, an incredibly powerful symbolic mathematics package with very useful graphing and visualization tools. The documents were originally developed as *Mathematica* notebooks on a NEXTSTEP / Intel workstation and then converted to HTML documents using the perl script `math2html` by H. Edward Donley at Indiana University of PA. Except where otherwise noted, the *Mathematica* notebooks and animations were created by myself (Dan Russell).

- Many of the animations are currently available only as MPEG movies.
- If you are running Netscape a UNIX workstation (Sun or HP) you should be able to view the MPEG movies simply by clicking on them. (*NOTE: the colors of the movies may be different than the colors in the original document figures.*)
- If you are using Netscape or MS Explorer from a PC (Windows 95 or NT) you may need to install a MPEG viewer in order to look at the movies.

The math on some pages will show up best if you are using a browser that is fully HTML 3.2 compliant.

If you have questions, comments, suggestions for an animation, or an animation you have created which I could link to, please email me at: *drussell@kettering.edu*

Updated January 22, 1998

Vibration

Vibration of 1-DOF Simple Oscillators

- Simple Harmonic Oscillator - with and without damping, transfer of energy between kinetic and potential forms
- Damped Harmonic Oscillator - underdamped, overdamped, and critically damped
- Forced Harmonic Oscillator - transient and steady state response to a force applied to the mass

- Base Motion - transient and steady state response of an oscillator to displacement of its support
- The Simple Pendulum - comparing the linear approximation (small angle) with a real pendulum

Vibration of Multi-DOF Systems

- Dynamic Absorbers - J.P. Den Hartog's classical undamped tuned dynamic absorber
- Vibrational modes of a multi-dof system

Vibrational Modes of Continuous Sytsems

- Vibration of a Fixed-Fixed String - mode shapes, and frequency spectra for a plucked string
- Vibration of a bar - (free-free), (cantilever), (fixed-fixed)
- Rectangular Membrane - and degenerate modes of a square membrane [no text yet, but movies work]
- [redacted] Circular Membrane - or how a drum head vibrates
- Circular Plate
- Square Plate
- Tacoma Narrows Bridge - (0.668 MB mpeg movie) - when engineers don't account for resonance when designing structures

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Mechanical Waves (Acoustics)

Basic Wave Phenomena

- Superposition of Two Waves - Interference, Standing Waves, and Beats
- Fourier Decomposition - building a wave shape from sines and cosines [no text yet , but movies work]
- Constructive and Destructive Interference of Two Coherent Wave Sources (*under construction*)

Sound Waves

- Particle Displacement and Wave Motion - Longitudinal, Transverse, Water and Rayleigh Surface Waves

- The Doppler Effect - moving sound sources and sonic booms
- Sound Radiation from Cylindrical Radiators - particle motion and sound fields produced by vibrational modes of a cylinder

More Complicated Wave Phenomema

- Phase changes upon reflection from hard, soft, and mixed boundaries
- Phase Speed versus Group Speed --- Dispersion (wave speed not constant) [under construction, but movies work]
- Examples of Dispersive Waves --- Flexural waves and Quasi-longitudinal waves on a rod
- Trace Velocity - phase speed versus group speed for waves travelling along a surface
- Waveguides - higher order acosutic modes in a duct
- Partial Wave Expansion --- expressing a 3-D plane wave in terms of spherical waves
- Plane Waves, Cylindrical Waves, and Spherical Waves

Human Hearing - How the Ear Works

- Cochlear Mechanics - how our ears distinguish between different frequencies ***(Boys Town National Research Hospital)*** [nice movies and pictures]

Electromagnetic Waves (Optics)

Rays and Ray Tracing

- Waves, Wavefronts, and Rays
- Ray Tracing for Mirrors [no text yet, but movies work]
- Ray Tracing for Lenses [no text yet, but movies work]
- Diffraction - how waves bend around corners

Light as an Electromagnetic Wave

- E and B Fields - electromagnetic wave propagation
- Index of Refraction and Snell's Law

- Single Slit Interference, Double Slit Diffraction, Single Slit Diffraction (*under construction*)

Human Sight - How the Eye Works

- How We See: The First Steps of Human Vision - ***Diane M. Szaflarski, Ph.D***
- New Check out some neat **optical illusions** at Illusions Works and The Science Museum of London

Matter Waves (Particle-Wave Duality)

- Atomic Spectra (Emission and Absorption)
- When Particles Behave Like Waves (in 2-D)

Back to Dr. Russell's Homepage

The Simple Harmonic Oscillator

Simple Harmonic Motion:

In order for mechanical oscillation to occur, a system must posses two quantities: ***elasticity*** and ***inertia***. When the system is displaced from its equilibrium position, the *elasticity* provides a *restoring force* such that the system tries to return to equilibrium. The *inertia* property causes the system to *overshoot* equilibrium. This constant play between the elastic and inertia properties is what allows oscillatory motion to occur. The natural frequency of the oscillation is related to the elastic and inertia properties by:

$$\omega_0 = 2\pi f_0 = \sqrt{\frac{\text{elasticity}}{\text{inertia}}}$$

The simplest example of an oscillating system is a mass connected to a rigid foundation by way of a spring. The spring constant *k* provides the elastic restoring force, and the inertia of the mass *m* provides the overshoot. By applying Newton's second law $F=ma$ to the mass, one can obtain the equation of motion for the system:

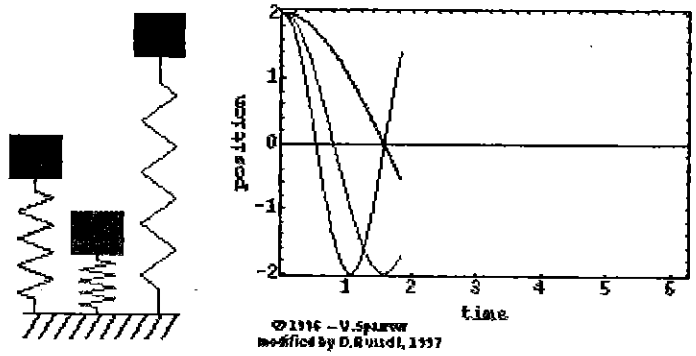
$$m\frac{d^2x}{dt^2} + kx = 0 \quad \rightarrow \quad \frac{d^2x}{dt^2} + \frac{k}{m}x = 0 \quad \rightarrow \quad \frac{d^2x}{dt^2} + \omega_o^2 x = 0$$

where $\omega_o = \sqrt{k/m}$ is the natural oscillating frequency. The solutions to this equation of motion takes the form

$$x(t) = x_m \cos(\omega_o t + \phi)$$

where x_m is the amplitude of the oscillation, and φ is the *phase constant* of the oscillation. Both x_m and φ are constants determined by the initial condition (intial displacement and velocity) at time t=0 when one begins observing the oscillatory motion.

The animated gif at right (click here for mpeg movie) shows the simple harmonic motion of three undamped mass-spring systems, with natural frequencies (from left to right) of ω$_o$, 2ω$_o$, and 3ω$_o$. All three systems are initially at rest, but displaced a distance x_m from equilibrium.



The *period* of the oscillatory motion is defined as the time required for the system to start one position, complete a cycle of motion and return to the starting position.
⇒ From the position versus time plot, can you determine the period for each of the three oscillators?

Energy Swapping:
The elastic property of the oscillating system (spring) stores potential energy

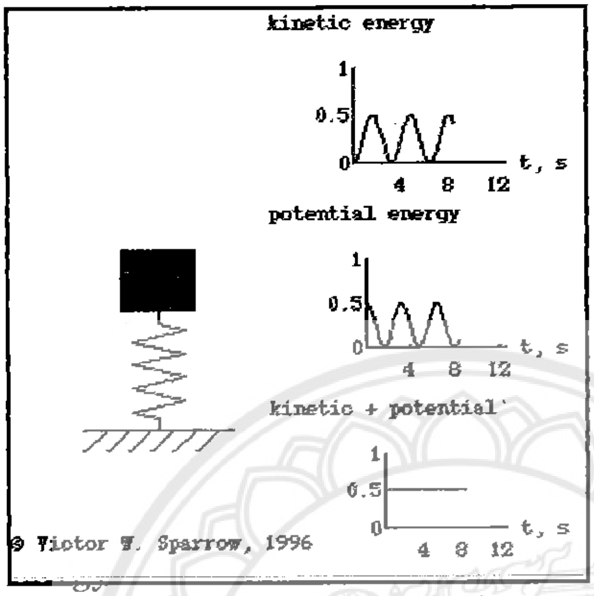
$$\frac{1}{2}kx^2 = \frac{1}{2}kx_m^2 \cos^2(\omega_o t + \phi)$$

and the inertia property (mass) stores kinetic energy

$$\frac{1}{2}mv^2 = \frac{1}{2}m\left(\frac{dx}{dt}\right)^2 = \frac{1}{2}m\omega_o^2 x_m^2 \sin^2(\omega_o t + \phi)$$

As the system oscillates, the total mechanical energy in the system trades back and forth between potential and kinetic energies. The total energy in the system, however, remains constant, and depends only on the spring contant and the maximum displacement (or mass and maximum velocity v_m=ωx_m)

$$
\begin{aligned}
\frac{1}{2}kx^2 + \frac{1}{2}mv^2 &= \frac{1}{2}kx_m^2\cos^2\omega_0 t + \frac{1}{2}m\omega^2 x_m^2 \sin^2\omega_0 t \\
&= \frac{1}{2}kx_m^2\left(\cos^2\omega_0 t + \sin^2\omega_0 t\right) \\
&= \frac{1}{2}kx_m^2 = \frac{1}{2}mv_m^2
\end{aligned}
$$



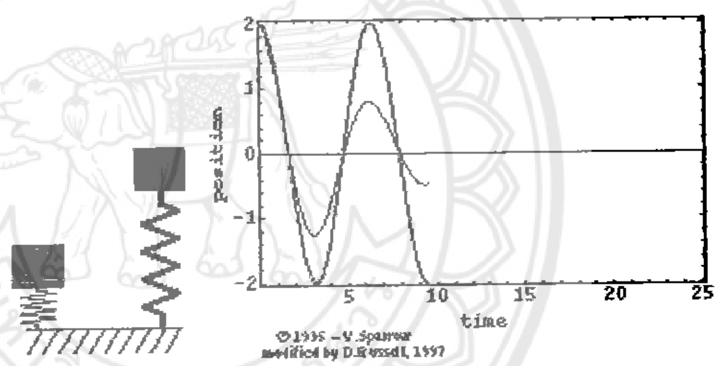
in a simple undamped mass-spring oscillator is traded between ***kinetic*** and ***potential*** energies while the total energy remains constant.

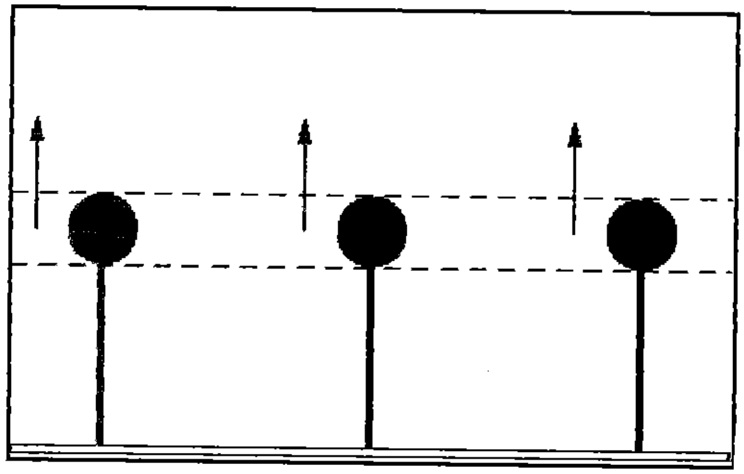
Back to the Vibration and Waves Demos Page

1-DOF Mass-Spring Systems with Damping

With damping:

The animated gif at right (click here for mpg movie) shows two 1-DOF mass-spring systems initially at rest, but displaced from equilibrium by $x=x_{max}$. The black mass is undamped and the blue mass is damped (underdamped). After being released from rest the undamped (black) mass exhibits simple harmonic motion while the damped (blue) mass exhibits an oscillatory motion which decays with time.

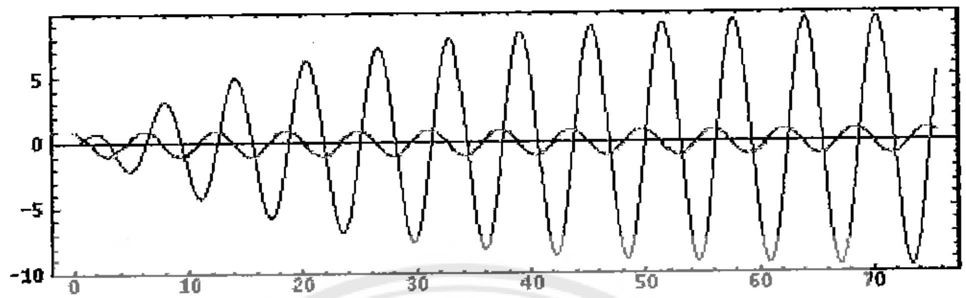




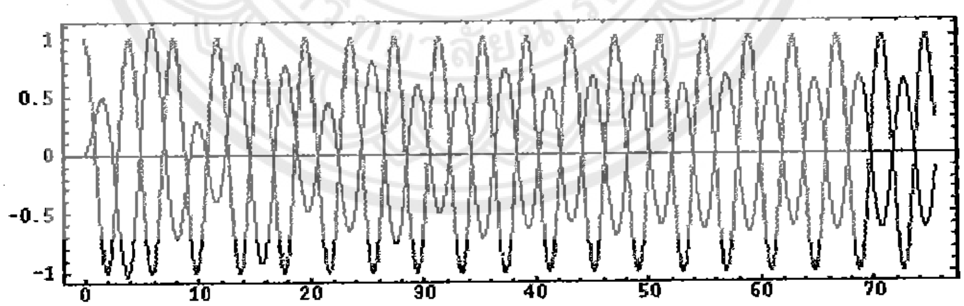
(This is the first frame of a 845624 byte mpg movie. Click on the graph to download the movie)

Back to the Vibration and Waves Demos Page

Since the oscillator is being driven near resonance the amplitude quickly grows to a maximum. After the transient motion decays and the oscillator settles into steady state motion, the displacement 90? out of phase with force (displacement lags the force). Notice, again, that the frequency of the steady state motion of the mass is the driving (forcing) frequency, not the natural frequency of the mass-spring system.



In the plot below the forcing frequency is f=1.6, so that the third oscillator is being driven **above resonance**. The grey curve shows the applied force (positive is upwards), and the red curve shows the displacement of the mass in response to the applied force. Since the oscillator is being driven near resonance the amplitude quickly grows to a maximum. After the transient motion decays and the oscillator settles into steady state motion, the displacement 180? out of phase with force. Notice, again, that the frequency of the steady state motion of the mass is the driving (forcing) frequency, not the natural frequency of the mass-spring system. Also notice that the amplitude of motion is less than when the mass was driven below resonance.



The movie below (0.845 MB mpg movie) shows the three masses from the plots above and their transient response to the applied forces. The direction and magnitude of the forces are indicated by the arrows. The dashed horizontal lines provide a reference to compare magnitudes of resulting steady state displacement.

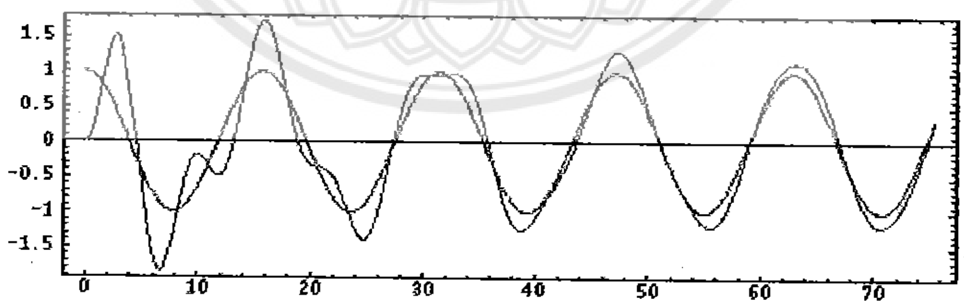
Forced Mass-Spring Systems

Transient and Steady-state response to a sinusoidal excitation force.

Force applied to the mass of a damped 1-DOF oscillator on a rigid foundation

<u>Transient response to an applied force:</u> Three damped 1-DOF mass-spring oscillators, all with natural frequency $f_0=1$, are initially at rest. A time harmonic force $F=F_0\cos(ft)$ is applied to each of three damped 1-DOF mass-spring oscillators starting at time $t=0$.

In the plot below the forcing frequency is $f=0.4$, so that the first oscillator is being driven **below resonance**. The grey curve shows the applied force (positive is upwards), and the green curve shows the displacement of the mass in response to the applied force. After the transient motion decays and the oscillator settles into steady state motion, the displacement is in phase with force. Notice that the frequency of the steady state motion of the mass is the driving (forcing) frequency, not the natural frequency of the mass-spring system.



In the plot below the forcing frequency is $f=1.01$, so that the second oscillator is being driven very **near resonance**. The grey curve shows the applied force (positive is upwards), and the blue curve shows the displacement of the mass in response to the applied force.

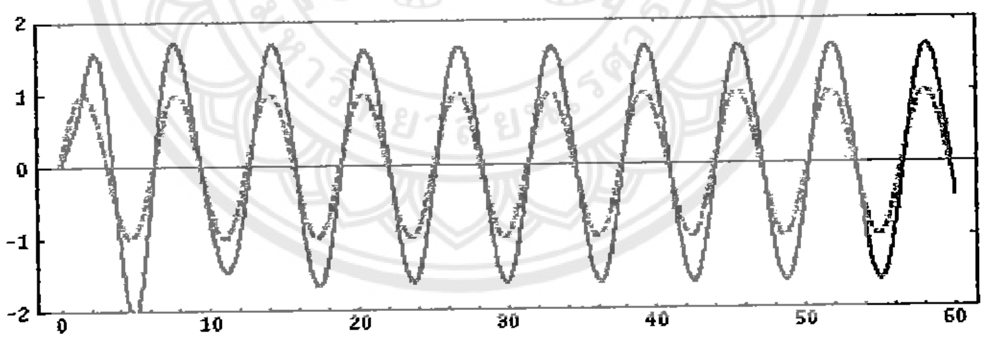
Response of a 1-DOF oscillator to a displacement of its base

Three simple 1-DOF mass-spring oscillators have natural frequencies (from left to right) of f_1= 1.6, f_2= 1, and f_3= 0.63. At time t=0 the base starts moving with sinusoidal displacement s(t) = S_0sin(t) where the driving frequency is f=1.001. The damping rate for all three oscillators is 0.1 so that the initial transient motion decays and a steady-state is obtained.

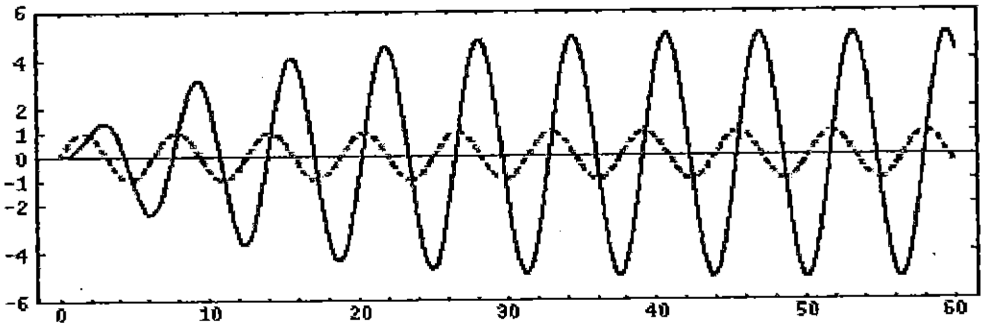
Plots

In all three plots below, the dashed gray curve represents the displacement of the base, while the colored curves represent the displacement of the masses.

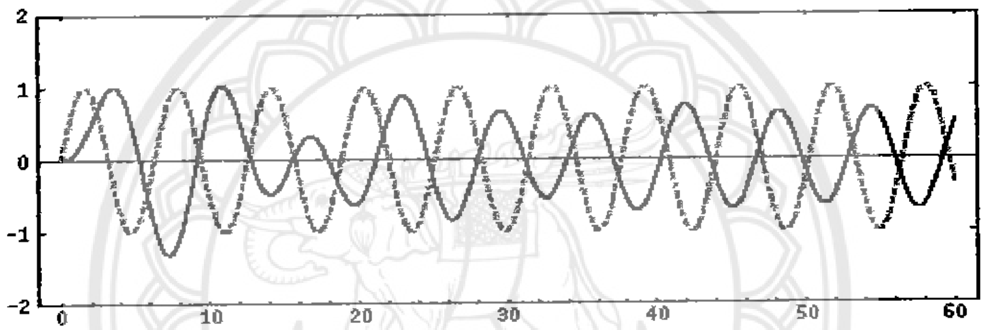
The first oscillator is being driven below its natural frequency. Its motion is in-phase with that of the base and its displacement is slightly larger than the base displacement. In terms of the input mechanical impedance as seen by the base, this oscillator provides an *apparent positive added mass* to the base.



The second oscillator is being driven very near resonance. Its displacement lags that of the base by 90? and it grows until steady state is reached. In terms of the input mechanical impedance as seen by the base, this oscillator provides an *apparent damping*, removing vibrational energy from the base.

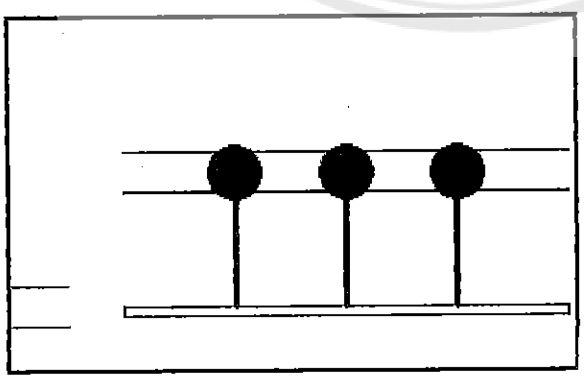


The third oscillator is being driven at twice its natural frequency. The transient behavior takes longer to decay. Once steady state has been achieved, the displacement is less than that of the base and it almost 180? out of phase with the base. In terms of the input mechanical impedance as seen by the base, this oscillator provides an *apparent negative added mass* to the base.



Movie

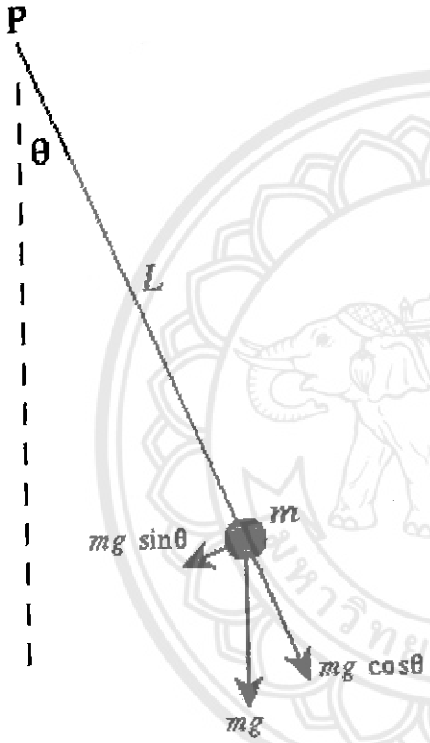
The animation below shows the motion of the base and the resulting motion of all three oscillators together. The masses are color coded to match the graphs above. The horizontal lines indicate the maximum displacement of the base.



(This is the first frame of a 533337 byte mpg movie. Click on the graph to download the movie)

Back to the Acoustics Demos Page

The Simple Pendulum



A simple pendulum consists of a mass m hanging from a string of length L and fixed at a pivot point P. When displaced to an initial angle and released, the pendulum will swing back and forth with periodic motion. By applying Newton's secont law for rotational systems, the equation of motion for the pendulum may be obtained

$$\tau = I\alpha \quad \Rightarrow \quad -mg\sin\theta\, L = mL^2 \frac{d^2\theta}{dt^2},$$

and rearranged as

$$\frac{d^2\theta}{dt^2} + \frac{g}{L}\sin\theta = 0 \, .$$

If the amplitude of angular displacement is small enough that the small angle approximation (sinθ = θ) holds true, then the equation of motion reduces to the equation of simple harmonic motion

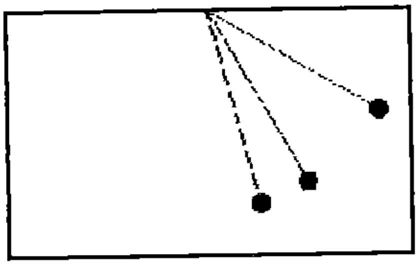
$$\frac{d^2\theta}{dt^2} + \frac{g}{L}\theta = 0 \, .$$

The simple harmonic solution is

$$\theta(t) = \theta_0 \cos(\omega t + \phi)$$

with $\omega = \sqrt{g/L}$ being the natural frequency of the motion.

Small Angle Approximation and Simple Harmonic Motion



With the assumption of small angles, the frequency and period of the pendulum are independent of the initial angular displacement amplitude. All simple pendulums should have the same period regardless of their initial angle (and regardless of their masses). This simple approximation is illustrated in the (48 kB) mpeg movie at left. All three pendulums cycle through one complete oscillation in the same amount of time.

The period for a simple pendulum does not depend on the mass or the initial anglular displacement, but depends only on the length L of the string and the value of the gravitational field strength g, according to

$$T = 2\pi\sqrt{\frac{L}{g}}$$

The mpeg movie at left (39.5 kB) shows two pendula, with different lengths.

- How many complete oscillations does the shorter (blue) pendulum make in the time for one complete oscillation of the longer (black) pendulum?
- From this information and the definition of the period for a simple pendulum, what is the ratio of lengths for the two pendula?

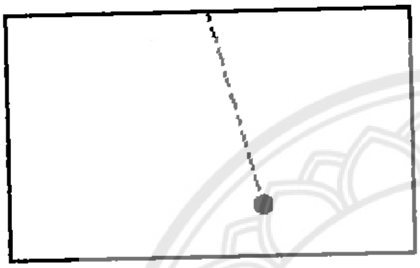
The Real (Nonlinear) Pendulum

When the angular displacement amplitude of the pendulum is large enough that the small angle approximation no longer holds, then the equation of motion must remain in its nonlinear form

$$\frac{d^2\theta}{dt^2} + \frac{g}{L}\sin\theta = 0$$

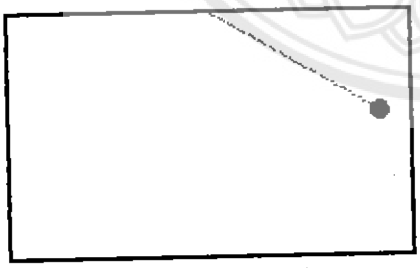
This differential equation does not have a closed form solution, and must be solved numerically using a computer. *Mathematica* numerically solves this differential equation very easily with the built in function `NDSolve[ ]`.

Small Initial Amplitude



The small angle approximation is valid for initial angular displacements of about 20? or less. The (0.132MB) mpeg movie at left shows two pendula: the black pendulum assumes the linear small angle approximation of simple harmonic motion, the grey pendulum (hidded behind the black one) shows the numerical solution of the actual nonlinear differential equation of motion. For small initial angular displacements the error in the small angle approximation becomes evident only after several oscillations.

Large Initial Amplitude



When the initial angular displacement is significantly large that the small angle approximation is no longer valid, the error between the simple harmonic solution and the actual solution becomes apparent almost immediately, and grows as time progresses. In the (0.226MB) mpeg move at left, the dark blue pendulum is the simple approximation, and the light blue pendulum (initially hidden behind the dark blue one) shows the numerical solution of the nonlinear differential equation of motion.

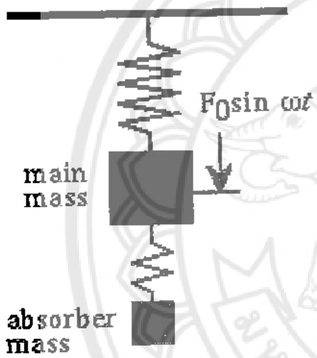
Back to the Vibrations and Waves Demo Page

Den Hartog's Dynamic Vibration Absorber

This page demonstrates the behavior of the classical undamped dynamic absorber, introduced into the literature in 1928 by J. Ormondroyd and J.P. Den Hartog. The results below were calculated using the mathematical derivation on pages 87-106 of Den Hartog's book *Mechanical Vibrations*, 4th Edition, (Dover, 1985).

The Classical Undamped Tuned Dynamic Absorber

[from Equations (3.15a,b), p.89 and Figures 3.8(a) and (b) p. 91]



A sinusoidal force $F_0 \sin \omega t$ acts on an undamped main mass-spring system (without the absorber mass attached). When the forcing frequency equals the natural frequency of the main mass the response is infinite. This is called resonance, and it can cause severe problems for vibrating systems.

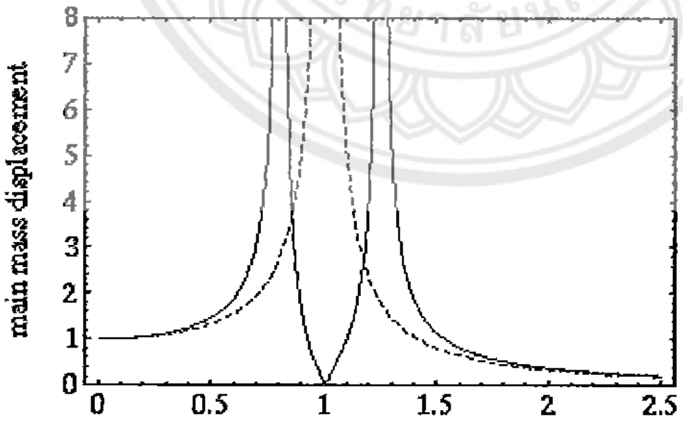
When an absorbing mass-spring system is attached to the main mass and the resonance of the absorber is tuned to match that of the main mass, the motion of the main mass is reduced to zero at its resonance frequency. Thus, the energy of the main mass is apparently "absorbed" by the tuned dynamic absorber. It is interesting to note that the motion of the absorber is ***finite*** at this resonance frequency, even though there is ***NO*** damping in either oscillator. This is because the system has changed from a 1-DOF system to a 2-DOF system and now has **two** resonance frequencies, neither of which equals the original resonance frequency of the main mass (and also the absorber).

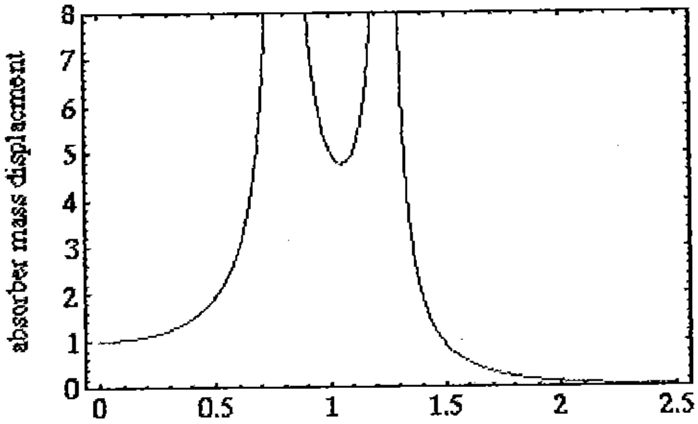
If no damping is present, the response of the 2-DOF system is infinite at these new frequencies. While this may not be a problem when the machine is running at its natural frequency, an infinite response can cause problems during startup and shutdown. A finite amount of damping for both masses will prevent the motion of either mass from becoming infinite at either of the new resonance frequencies. **However** if damping is present in **either** mass-spring element, the response of the main mass will **no longer be zero** at the target frequency.

Displacement of the main mass and absorber mass

The plots below show the displacements as a function of normalized frequency (driving frequency divided by natural frequency of main mass). The red dashed curve shows the displacement response of the undamped main mass alone. Notice that when the driving frequency matches the natural frequency, the response is inifinite.

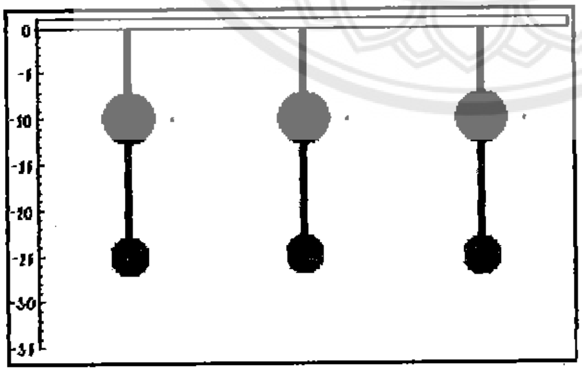
An absorber mass (20% of the main mass) is tuned to the resonance frequency of the main mass and attached. The blue curve represents the displacement of the main mass after the classical undamped tuned dynamic absorber has been attached. Notice that the main mass has zero displacement at the original problem frequency. Notice, also, that there are now two new resonance frequencies. The green curve represents the displacement of the absorber mass. Notice that the displacement is infinite at the same two resonance frequencies, but that the response at the target frequency is finite (approximately 4.8).





Movie of the main mass and dynamic absorber behavior at three frequencies.

The 2-DOF system has two natural frequencies, corresponding to the two natural modes of vibration for the system. In the lower frequency mode both masses move in the same direction, in-phase with each other. In the higher frequency mode the two masses move in opposite direction, 180? out of phase with each other. The movie below shows the motion of the 2-DOF system at normalized forcing frequencies of f_{left}=0.67 (in-phase mode), f_{middle}=1 (undamped classical tuned dynamid absorber), and f_{right}= 1.3 (opposite-phase mode). The arrows in the movie represent the magnitude and phase of the force applied to the main mass.



(This is the first frame of a 151038 byte mpg movie. Click on the graph to download the movie)

The Vibration of a Fixed-Fixed String

The natural modes of a fixed-fixed string

When the end of a string is fixed, the displacement of the string at that end must be zero. A transverse wave travelling along the string towards a fixed end will be reflected in the opposite direction. When a string is fixed at both ends, two waves travelling in opposite directions simply bounce back and forth between the ends.

$$y(x,t) = y_m \sin(kx - \omega t) + y_m \sin(kx + \omega t)$$

The vibrational behavior of the string depends on the frequency (and wavelenth) of the waves reflecting back and forth from the ends.

A string which is fixed at both ends will exhibit strong vibrational response only at the resonance frequncies

$$f_n = \frac{nv}{2L} \quad \text{where} \quad v = \sqrt{\tau/\rho}$$

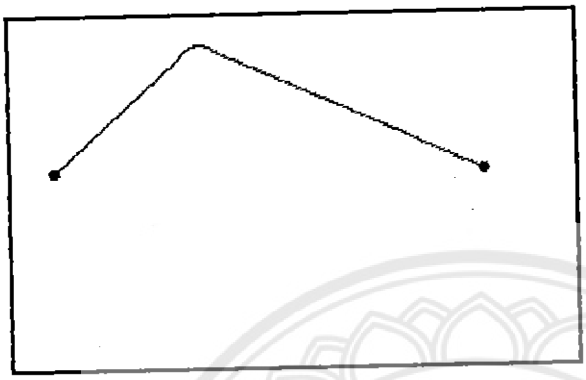
is the speed of transverse mechanical waves on the string, L is the string length, and n is an integer. At any other frequencies, the string will not vibrate with any significant amplitude. The resonance frequencies of the fixed-fixed string are harmonics (integer multiples) of the fundamental frequency (n=1).

The vibrational pattern (mode shape) of the string at resonance will have the form

$$y(x,t) = y_m \sin\left(\frac{n\pi}{L}x\right)\cos(2\pi f t)$$

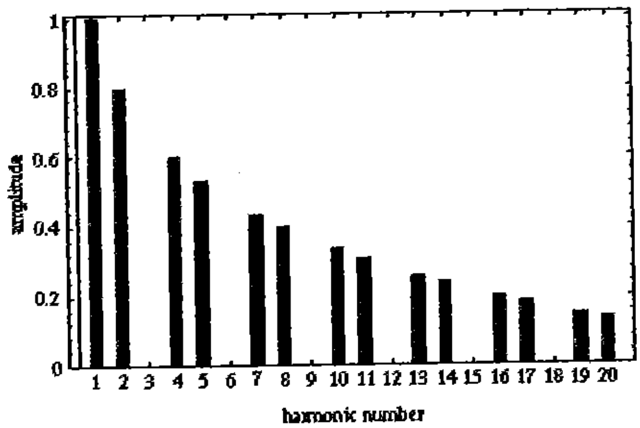
This equation represents a standing wave. There will be locations on the string which undergo maximum displacement (**antinodes**) and locations which to not move at all (nodes). In fact, the string may be touched at a **node** without altering the string vibration. The mpeg movie below (0.178MB) shows the vibration of a fixed-fixed string in its first four resonant modes.

The vibration of fixed-fixed string plucked at a distance 1/3 of the length



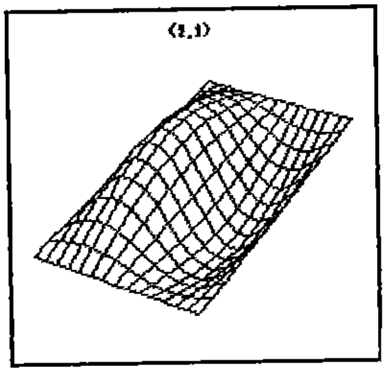
When a fixed-fixed string is set into vibration by plucking it, the string will vibrate at many of its natural resonance frequencies at the same time. Exacly which resonance frequencies (and thus which mode shapes) make up the final string vibration depends on the shape of the initial string displacement. The movie at left (0.58MB mpeg) shows the vibration of a fixed-fixed string which has been plucked at a point 1/3 of its length from the left end ($x = 1/3L$). As you observe the vibration you should be able to visualize two wave pulses, one travelling clockwise, the other travelling counterclockwise. The time for one complete trip equals one period - if the string wave vibrating with a fundamental frequency of 440 Hz, then this vibration cycle would repeat itself 440 times per second.

Fourier's theorem says that any periodic function *f(t)* may be constructed from a combination of sin(w t) and cos(w t) functions with appropriate amplitudes and frequencies. The picture at left shows the amplitude and phase of the first 6 string modes which add up to produce the initial string position (plucked at $x = 1/3L$). [color code: **sum, n=1, n=2,** , **n=4, n=5,** n=6] You should notice that modes corresponding to $n=3$ and $n=6$ are missing. This is because standing wave patterns which have a **node** at the pluck point will not be excited. Since any mode which is an integer multiple of $n=3$ will have a node at position $x=L/3$ these standing wave patterns will not be excited.



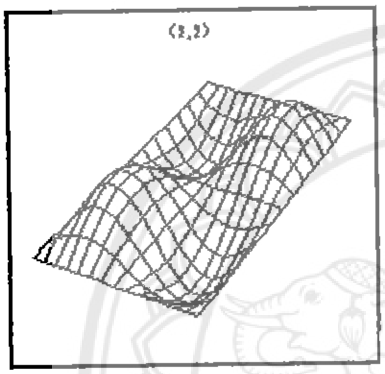
A "frequency spectrum" may be constructed for this plucked string vibration by determining the standing wave mode number (resonance frequency) and amplitude for all mode shapes which are present in a given string vibraiton. The figure at left shows the mode number spectrum for the string struck at (plucked at $x = 1/3L$). Notice that all multiples of 3 are missing.

Back to the Vibrations and Waves: Demos and Animations Page



(This is the first frame of a 1.2 kB mpg movie. Click on the graph to download the movie)

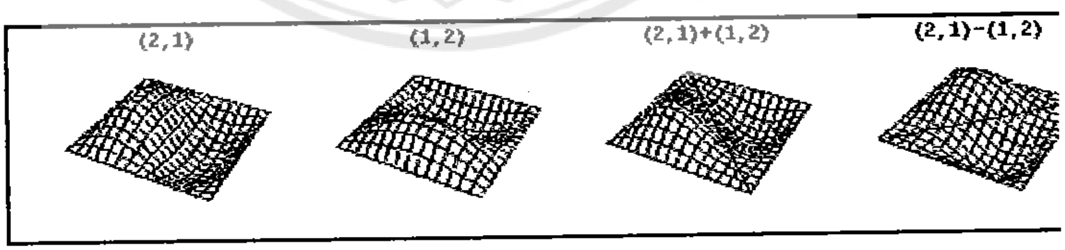
The (2,2) Mode



(This is the first frame of a 1.2 kB mpg movie. Click on the graph to download the movie)

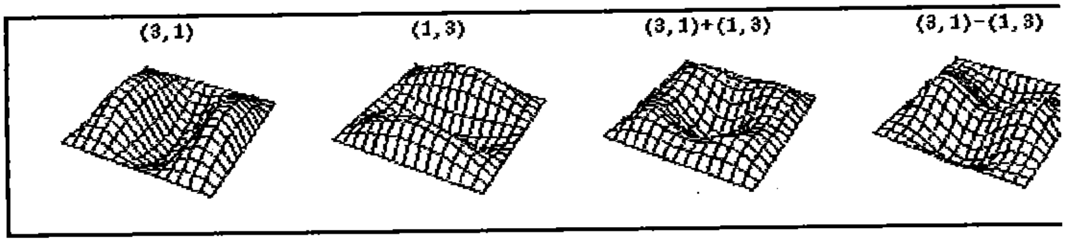
Degenerate Modes for a Square Membrane

The (2,1) and (1,2) Modes



(This is the first frame of a 9026 byte mpg movie. Click on the graph to download the movie)

The (3,1) and (1,3) Modes



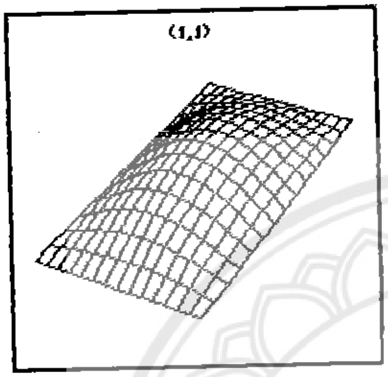
(This is the first frame of a 9000 byte mpg movie. Click on the graph to download the movie)

Back to the Vibration and Waves Demos Page

Vibrational Modes of a Rectangular Membrane

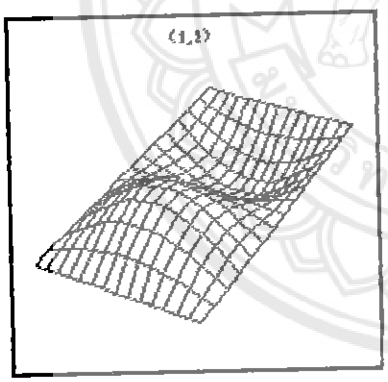
Rectangular Membrane

The (1,1) Mode



(This is the first frame of a 1.2 kB mpg movie. Click on the graph to download the movie)

The (1,2) Mode



(This is the first frame of a 1.2 kB mpg movie. Click on the graph to download the movie)

The (2,1) Mode

Princeton University - Program in Materials, Mechanics and Structures

Recent publications related to research in

SOIL DYNAMICS AND GEOTECHNICAL EARTHQUAKE ENGINEERING

- "Spatial Variability of Soil Properties - Two Case Studies", R.Popescu, J.H.Prevost and G.Deodatis, *Proc. Geotechnical Earthquake Engineering and Soil Dynamics,* Seattle, Washington, August 1998, ASCE (submitted).

- "Characteristic Percentile of Soil Strength for Dynamic Analyses", R.Popescu, J.H.Prevost and G.Deodatis, *Proc. Geotechnical Earthquake Engineering and Soil Dynamics,* Seattle, Washington, August 1998, ASCE (submitted).

- "Effects of Spatial Variability on Soil Liquefaction: Some Design Recommendations", R.Popescu, J.H.Prevost and G.Deodatis, *G?otechnique,* 1997, (in press).

- "Digital Simulation of Non-Gaussian Vector Fields", R.Popescu, G.Deodatis and J.H.Prevost, *Probabilistic Engineering Mechanics,* Vol. 13, No. 1, 1998, pp.1-13.

- "Integrated Procedure for Dynamic Analysis of Fault-Soil-Structure Systems", J.H.Prevost, G.Deodatis, R. Popescu, Y. Nojiri and N.Ohbo, *Proc.* 14^{th} *Int. Conf. Soil Mech. Found. Engnrg.*, Hamburg, Germany, Sept.1997 (accepted for publication).

- "Constitutive Relations for Soil Materials", J.H. Prevost and R. Popescu, *Electronic Journal of Geotechnical Engnrg., ASCE,* December, 1996, http://geotech.civen.okstate.edu/ejge/ppr9609/index.htm.

- "Influence of Spatial Variability of Soil Properties on Seismically Induced Soil Liquefaction", R.Popescu, J.H.Prevost and G.Deodatis, *Proc. Uncertainty in the Geologic Environment: From*

Theory to Practice, Madison, Wisconsin, August1996, ASCE, pp1098-1112.

- "Comparison between VELACS Numerical ``Class A" Predictions and Centrifuge Experimental Soil Test Results", R.Popescu and J.H.Prevost, *Soil Dynamics and Earthquake Eng.*, Vol.14, No.2, 1995, pp.79-92.

- "Reliability Assessment of Centrifuge Soil Test Results", R.Popescu and J.H.Prevost, *Soil Dynamics and Earthquake Eng.*, Vol.14, No.2, 1995, pp.93-101.

- "Centrifuge Validation of a Numerical Model for Dynamic Soil Liquefaction", R.Popescu and J.H.Prevost, *Soil Dynamics and Earthquake Eng.*, Vol.12, No.2, 1993, pp.73-90.

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Geotechnical Earthquake Engineering and Soil Dynamics
Seattle, Washington, August 1998, ASCE (submitted)

Spatial Variability of Soil Properties - Two Case Studies

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Princeton University, Princeton, New Jersey 08544

Abstract:

Many physical systems in general and soil materials in particular exhibit relatively large variability in their properties, even within so called homogeneous zones. Deterministic descriptions of this spatial variability are not feasible due to prohibitive cost of sampling and to uncertainties induced by measurement errors. A more rational approach to geotechnical design is made possible by use of stochastic field based techniques of data analysis, which rely more on analytical methods when dealing with various uncertainties related to soil properties.

The probabilistic characteristics of spatial variability of soil properties are studied based on two sets of in-situ measurement results. The first case study uses the results of a two dimensional measurement array consisting of 24 standard penetration test profiles, performed in a natural soil deposit in the Tokyo Bay area, Japan. The soil deposit is formed of three distinct layers (fine sand with silt inclusions, silty clay, and dense clean sand), and large spatial variations of recorded penetration resistance are observed in both vertical and horizontal directions within each soil layer. The second case is based on the results of a series of cone penetration tests performed at an artificial island in the Canadian Beaufort Sea. Though measured in a supposedly homogeneous man-made soil deposit, the recorded cone tip resistance shows significant spatial variations.

The soil properties are modeled as the components of a multi-dimensional, multi-variate, non-Gaussian stochastic field, and the probabilistic characteristics of the stochastic field are estimated

based on the in-situ soil test results, using the method of moments and a nonlinear regression procedure. The probability distributions, coefficients of variation, and correlation distances exhibited by the soil properties in the two cases analyzed (a natural and a man-made soil deposit), can be used as guidelines for stochastic analysis of similar soil deposits.

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Comments? mail to: RADU POPESCU

Geotechnical Earthquake Engineering and Soil Dynamics
Seattle, Washington, August 1998, ASCE (submitted)

Characteristic Percentile of Soil Strength for Dynamic Analyses

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Abstract:

Experimental evidence shows that there is significant spatial variability of material properties within so called ``homogeneous" soil layers, in both natural and artificial soil deposits. It has been proved using Monte Carlo simulations of soil liquefaction that the soil system response is strongly affected by this variability, and therefore it is important to account for it in analysis and design. For the same average values of soil parameters, more pore water pressure build-up was predicted by Monte Carlo simulations, accounting for spatial variability of the soil properties than by deterministic analyses using the average values of in-situ recorded soil properties. A possible explanation is that soil liquefaction is triggered by the presence of loose pockets in the soil deposit. Deterministic design cannot account for such variability, and therefore, to avoid non-conservative results, geotechnical engineering practice relies on sometimes large factors of safety.

The objective of this study is to provide the geotechnical design with a characteristic value of soil strength (expressed as a percentile exceedence criterion) which, when used in deterministic soil liquefaction assessment, will provide an equivalent response (in terms of predicted excess pore pressure build-up and horizontal displacements) with that predicted by more expensive Monte Carlo simulations. For convenience, the soil strength is expressed in terms of the stress normalized cone tip resistance, for which several correlations with observed field behavior have been developed. The soil properties over the analysis domain are modeled as the components of a non-Gaussian stochastic field. Parametric studies are

performed, involving various probability characteristics of this stochastic field, which are most likely to influence the dynamic behavior: probability distribution, degree of variability, correlation distances. A conservative characteristic value of soil strength is estimated by comparing the the results of a series of deterministic analyses using various percentiles of soil strength with the upper bound of Monte Carlo simulation predictions, resulted from a large number of generated sample functions. The dynamic analyses are performed using a multi-yield plasticity soil constitutive model implemented in the finite element code DYNAFLOW, which has been repeatedly validated in the past for soil liquefaction potential assessment.

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Comments? mail to: RADU POPESCU

G?otechnique, 1997 (in press)

Effects of Spatial Variability on Soil Liquefaction: Some Design Recommendations

Radu Popescu - Jean H. Prevost - George Deodatis
Department of Civil Engineering and Operations Research
Princeton University, Princeton, New Jersey 08544

May 1996

Abstract:

The effects of spatial variability of soil properties on the behavior of saturated soil deposits subjected to seismic excitation are analyzed, and their implications on geotechnical design are discussed. A Monte Carlo simulation methodology, combining digital generation of non-Gaussian stochastic vector fields with dynamic, nonlinear finite element analyses is used for that purpose. The proposed procedure is applied to assess the soil liquefaction potential, which is found to be considerably affected by the inherent spatial variability of soil properties. Parametric studies, involving the degree of soil liquefaction and the frequency content of the seismic input are performed. Finally, a characteristic percentile value of soil strength, which will predict a response equivalent to that provided by the more expensive Monte Carlo simulations, is proposed for use in deterministic design.

Keywords

Statistical analysis, Liquefaction, Shear strength, Sands, Numerical modeling and analysis, In situ testing.

Acknowledgements

The work reported in this study was supported in part by a collaborative research agreement between Kajima Corporation, Japan and Princeton University. This support is gratefully acknowledged. The authors are also indebted to Dr. Michael G. Jefferies for providing the field data, reviewing the paper and offering many valuable suggestions. This work was also supported by the National Science Foundation under Grant \#~BCS--9257900 with Dr. Clifford J. Astill as Program Director.

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Comments? mail to: RADU POPESCU

Probabilistic Engineering Mechanics, Vol. 13, No. 1, 1998, pp. 1-13.

Simulation of Non-Gaussian Stochastic Vector Fields

Radu Popescu - George Deodatis - Jean H. Prevost
Department of Civil Engineering and Operations Research
Princeton University, Princeton, New Jersey 08544

February, 1996

Abstract:

A spectral representation-based simulation methodology is proposed to generate sample functions of a multi-variate, multi-dimensional, non-Gaussian stochastic vector field, according to a prescribed cross-spectral density matrix and prescribed (non-Gaussian) probability distribution functions. The proposed methodology starts by generating a Gaussian vector field that is then transformed into the desired non-Gaussian one using a memoryless nonlinear transformation in conjunction with an iterative scheme. The generation of the Gaussian vector field is performed taking advantage of the Fast Fourier Transform technique for great computational efficiency. The special case of simulation of non-Gaussian vector fields modeling material properties is examined, mainly from the point of view of certain simplifying assumptions that can be made for such random media. Finally, a numerical example involving a tri-variate, two-dimensional, non-Gaussian stochastic vector field is presented in order to demonstrate the capabilities and the efficiency of the proposed methodology.

Keywords

Non-Gaussian stochastic vector field, multi-variate stochastic field, multi-dimensional stochastic field, Monte Carlo simulation, spectral representation, Fast Fourier Transform, memoryless nonlinear transformation, iterative scheme, stochastic variability of material properties

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INTEGRATED PROCEDURE FOR DYNAMIC ANALYSIS OF FAULT-SOIL-STRUCTURE SYSTEMS

Jean H. Prevost - George Deodatis - Radu Popescu
Department of Civil Engineering and Operations Research
Princeton University, Princeton, New Jersey 08544

Yoichi Nojiri - Naoto Ohbo
Kajima Corporation, Tokyo, Japan

July 1996

Abstract:

An analysis procedure for fault-soil-structure systems based on the Monte Carlo simulation method is presented. Both ground motion (near field and far field) and spatial distribution of soil properties are first generated using various spectral representation-based procedures. Next, dynamic nonlinear finite element simulations with stochastic input are performed. The procedure is used for assessment of soil liquefaction potential and for predicting the seismic response of large scale structures.

Next Next: INTRODUCTION

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Comments? mail to: RADU POPESCU

Constitutive Relations for Soil Materials

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and
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Princeton University, Princeton, New Jersey 08544

"Everything should be made as simple as possible, but not simpler."
(Albert Einstein)

Table of Contents

KEYWORDS: Constitutive theory, Elastic-plastic, Strain localization, Parameter calibration, In-situ soil tests, Soil liquefaction, Stochastic finite elements

INTRODUCTION

Recent advances in digital computer technology and in numerical techniques such as the finite difference or the finite element methods, have rendered possible, at least in principle, the solution of any properly posed boundary value problems in soil mechanics. Further progress in expanding analytical capabilities in geomechanics depends upon consistent mathematical formulations of generally valid and realistic material constitutive relations. An increasing effort has thus been devoted since the 1960's to a more comprehensive description of soil behavior. Numerous formulations have been proposed in the soil mechanics literature. All rely on a better knowledge and understanding of mechanics in general, and continuum mechanics in particular, than has been common in traditional soil mechanics training. The results and progress in the field of constitutive relations have thus until recently been mostly ignored by the mainstream of soil engineering. However, recent progress and honest validation exercises have instilled confidence and finally attracted the attention of the practice. We should therefore see in the future more impact on the practice of this area of soil mechanics.

It is the purpose of this paper to provide an overview of soil constitutive models and related issues. The review is brief and makes no attempt to be exhaustive. In recent years, the growing interest in constitutive relations has led to a number of conferences devoted exclusively to theoretical, experimental, numerical implementations and application problems associated with this field. It would have been impossible to record all the papers and discuss all the models that have been proposed. Also, the reader is referred to the extensive review paper by Scott (1985) for a historical review and discussion of constitutive theories.

PREAMBLE

Soils consist of an assemblage of particles with different sizes and shapes which form a skeleton whose voids are filled with water and air or gas. The word ``soil" therefore implies a mixture of assorted mineral grains with various fluids. Hence, soil in general must be looked at as a one (dry soil) or two (saturated soil) or multiphase (partially saturated soil) material whose state is to be described by the stresses and displacements (velocities) within each phase. There are still great uncertainties on how to deal analytically with partly saturated soils. The stresses carried by the soil skeleton are conventionally called ``effective stresses" in the soil mechanics literature (see e.g., Terzaghi (1943)), and those in the fluid phase are called the ``pore fluid pressures."

In a saturated soil, when free drainage conditions prevail, the steady state pore-fluid pressures depend only on the hydraulic conditions and are independent of the soil skeleton response to external loads. Therefore, in that case, a single phase continuum description of soil behavior is certainly adequate. Similarly, a single phase description is also adequate when no drainage (e.g., no flow) conditions prevail. However, in intermediate cases in which some flow can take place, there is an interaction between the skeleton strains and the pore-fluid flow. The solution of these problems requires that soil behavior be analyzed by incorporating the effects of the transient flow of the pore-fluid through the voids, and therefore requires that a two phase continuum formulation be available for porous media. Such a theory was first developed by Biot (1955, 1956, 1957, 1972, 1977, 1978) for an elastic porous medium. An extension of Biot's theory into the non-linear inelastic range (see e.g., Prevost (1980)) is necessary in order to analyze the transient response of soil deposits. This extension has acquired considerable importance in recent years due to the increased concern with the dynamic behavior of saturated soil deposits and associated liquefaction of saturated sand deposits under seismic loading conditions. For that purpose, soil is viewed as a multi-phase medium and the modern theories of mixtures developed by Green and Naghdi (1965), and Eringen and Ingram (1967), are used. General mixture results can be shown through formal linearization of the field and constitutive equations, to reduce to Biot's linear porelastic model (see e.g., Bowen (1982)).

During deformations, the solid particles which form the soil skeleton undergo irreversible motions such as slips at grain boundaries, creations of voids by particles coming out of a packed configuration, and combinations of such irreversible motions. When the particulate nature and the microscopic origin on the phenomena involved are not sought, phenomenological equations are used to provide a description of the behavior of the various phases which form the soil medium. In multiphase theories, the conceptual model is thus one in which each phase (or constituent) enters through its averaged properties obtained as if the particles were smeared out in space. In other words, the particulate nature of the constituent is described in terms of phenomenological laws as the particles behave collectively as a continuum. Soil is thus viewed as consisting of a solid skeleton interacting with the pore fluids.

Microstructural Aspects

The particulate nature of soil materials is directly responsible for their complex overall behavior. Sands consists of an aggregate of particles with different sizes and shapes which interact with each other through contact forces (both normal and tangential) at the points of contact. Considering the particles essentially incompressible, deformation of the granular assembly occurs as the particles translate, slip and/or roll, and either form or break contacts with neighboring particles to define a new microstructure. The result is an uneven distribution of contact forces and particle densities that manifests in the form of complex overall material behavior such as permanent deformation, anisotropy and localized instabilities (Deresiewicz (1958), Oda (1972), Oda and Konishi (1974), Vardoulakis (1988)). Similarly, clays are composed of plate-shaped particles of clay mineral. Each plate is subject to gravity forces and electrostatic forces at the points of contact, which hold the particles together. Therefore, if one knew all about the particles' geometry (their shapes and contacts) and understood all the physics and mechanics of interparticle contacts, then in principle one should be able to predict the overall macroscopic response of the assembly. Such studies could lead to a rational explanation of the observed macroscopic behavior, and allow direct correlation between average macroscopic constitutive parameter values and microscopic entities (e.g., relate the overall friction angle to the individual particle-to-particle friction coefficient). A number of studies have been initiated along these lines. Several experimental (see e.g., Drescher and De Josselin de Jong (1972), Oda et al. (1982), Subhash et al (1991)), analytical (see e.g., Walton (1988), Goddard (1990)) and numerical models (see e.g., Cundall and Strack (1979), Scott and Craig (1980), Bashir and Goddard (1991), Chang et al. (1992), Ting et al. (1993), Thornton and Sun (1993, 1994), Hogue and Newland (1994), Zhuang et al. (1995), Wren and Borja (1995), Borja and Wren (1995)), have been proposed to study the effect of particle-to-particle interaction on the overall material response. Because of their oversimplifications, these studies have had, as yet, little or no impact on the relations used in current constitutive models. Eventually, this may change as the models are further defined.

The most popular numerical models, commonly called Distinct Element or Discrete Element Methods, derive from the pioneering work of P.A. Cundall (Cundall (1971), Cundall and Strack (1979)) or are adopted from the procedures used in numerical Molecular Dynamics for which the book by Allen and Tildesley (1987) is the standard reference. They consist in approximating the mechanical constraint of non inter-penetrability of particles (see e.g. Keller (1986)) by some close-range steep repulsion law. Every time interval for which two particles are close enough to be viewed as contacting (numerically, they usually are allowed to overlap a little), they are assumed to exert on each other some dissipative forces which mimic friction. Thus, the evolution problem is reduced to the integration of a system of second order differential equations, to which classical methods are applied. The steeper the approximate laws of interaction, the more realistic are the results, at the price of reducing the time-step length to ensure numerical stability. Some researchers (see e.g., Bashir and Goddard (1991), Borja and Wren (1995)) have recently advocated the use of semi-implicit procedures to avoid full integration of Newtonian dynamical equations when computing quasi-static responses of granular systems, at the price of having to approximate and/or neglect the complicated intermediate path-dependent phenomena involved when contact and friction occur between particles.

Uncertainty in the Geologic Environment: From Theory to Practice
Madison, Wisconsin, August 1996, ASCE, pp 1098-1112

Influence of Spatial Variability of Soil Properties on Seismically Induced Soil Liquefaction

Radu Popescu - Jean H. Prevost - George Deodatis
Department of Civil Engineering and Operations Research
Princeton University, Princeton, New Jersey 08544

Abstract:

One of the major problems in geotechnical engineering is estimating the geomechanical properties of soil materials, for use in modeling. Aside from the measurement induced bias and even within assumed homogeneous soil strata, natural soils are variable in their properties. The scarcity in field test results, characteristic to geotechnical engineering, and a sufficiently large degree of disorder exhibited by soil properties leads to the use of statistical methods in describing the distribution of those properties within a ``stochastically homogeneous" soil zone.

The study mainly deals with the stochastic variability of soil properties, but also addresses other uncertainties affecting the geotechnical design. Methods for (1) field data analysis for estimating the probabilistic characteristics of spatial variability, and (2) digital simulation of non-Gaussian random fields representing the stochastic distribution of various soil properties are proposed.

Monte Carlo simulations of soil liquefaction are performed for a saturated soil deposit subjected to seismic excitation, and the predicted excess pore pressures are compared with similar results obtained from deterministic analyses. It is concluded that a more realistic pattern of soil liquefaction occurrence, and higher pore water pressure build-up are predicted if the stochastic variability of soil properties is accounted for.

Soil Dynamics and Earthquake Engineering, Vol. 14, No. 2, 1995, pp. 79-92

Comparison between VELACS Numerical "Class A" Predictions and Centrifuge Experimental Soil Test Results

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- extended abstract -

Abstract:

The numerical "Class A" predictions performed within the framework of the VELACS Project are compared to the experimental results recorded in the centrifuge experiments. The comparison are made in terms of: (1) the root mean square error of the predictions with respect to the mean of the experimental results, referred as the ε_{rms} index; and (2) the size of a confidence interval centered at the predicted value which contains the estimated true value of the experimental results with a 75% probability, referred as the b_n^{av} index.

An assessment of the capability of various groups of constitutive soil models to predict excess pore pressures induced by dynamic loading is also presented.

Keywords

"Class A" predictions, centrifuge experiments, soil liquefaction, confidence intervals.

Acknowledgements

The work reported in this study was supported in part by a grant from Kajima Corporation, Japan to Princeton University. This support is most gratefully acknowledged. The authors are also indebted to the VELACS Project Steering Committee and experimenters, for providing the results of the "class Λ" predictions and centrifuge experiments discussed in the study. And last but not least, the authors would like to thank Professor Erik II. Vanmarcke for his valuable suggestions.

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CIVLIST

List of On-Line Civil Engineering Resources

This list of civil engineering resources is brought to you by The Shilstone Companies. We also have online a list of concrete-related design and construction associations.

Following is a summary of what I received so far in my search for civil engineering and construction related online resources. These have not all been verified, so let me know if I have something wrong.

This list has become pretty big, so I had to split it up. To go straight to a particular type of resouce, click on that category:

-

BBSs

-

Mailing lists

-

Univesity web pages

-

Non-university web pages

-

Telnet sites

-

FTP sites

-

gopher sites

-

Usenet newsgroups

If you have any other resources, please Email me and I will add them to the list. Also, please post any corrections.

The Shilstone Companies can help with your concrete technical needs. For more information, contact:

Jay Shilstone
Shilstone Companies
9400 N. Central Expy., #105
Dallas, TX, 75231
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jay.shilstone@shilstone.com
(214) 361-9681
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BBS: (214) 361-8873
(Concrete Consultant)

We make the pieces fit

The Shilstone Companies

Materials Technology for Design and Construction

CIVLIST - WWW PAGES

List of On-Line Civil Engineering Resources

If you have not already done so, please fill in your name

[ ] and press [Submit Query] to sign our guest log.

If you would like more information about The Shilstone Companies, make your entry at our extended guest register.

This list of civil engineering resources is brought to you by The Shilstone Companies. We also have online a list of concrete-related design and construction associations.

This list will probably become stagnant, as it is getting too hard to manage and covers such a broad range. Instead, be on the lookout for *Concrete Online*, focusing more closely on the concrete industry, which is our specialty.

Following is a summary of what I received so far (as of 6/3/97) in my search for civil engineering and construction related online resources. These have not all been verified, so let me know if I have something wrong.

To go straight to a particular type of resouce, click on that category:

BBSs

Mailing lists

Telnet sites

FTP sites

gopher sites

Usenet newsgroups

WWW

====

This list is getting pretty big and I have had to split it. All of the university listings are on this page. Another page has been set up for the other categories:

Concrete Sites on the Internet (This is a new category. Soon I hope to have the whole thing searchable.)
CIV-LIST Sites that have changed in the last 7 days.

North American Universities
Other Universities (by country)
Government sites
Trade and Professional Associations
Commercial sites and "Internet malls" for engineering and construction
Search sites and engineering lists
Other neat stuff on the Web

North American University sites

Most of these references are only announcements about the presence of the location online. The universities may include course info. Where I have found something really interesting I have placed a:

- Arizona State Univ - Center for Professional Development offers classes on SuperPave
- *Auburn University* - College of Engineering
- *Brigham Young University* - Civil and Environmental Engineering. Has a GREAT link to the Thomas Register where you can find the name and address of almost any manufacturing firm.
- *Bucknell University*
- *California Institute of Technology* - Southern California Earthquake Center contains a map of seismic activity
- *California State University* - Civil Engineering Information

- California State University, Sacramento
- *Carleton University* - Civil and Environmental Engineering -
  - Multimedia 4th Yr reports done for Civil & Environmental Engr classes
  - Carleton Univ. Civil Engineering software list
  - Movie of Tacoma Narrows Bridge failure
- *Carnegie Mellon University* - Civil and Environmental Engineering
- *Case Western Reserve University* Ohio
- Clemson Univ., South Carolina
- *Columbia University* Civil Engineering Dept.
- *Cornell University* - College of Engineering
  - *Cornell University* - Engineering Library
  - *Cornell University*CFD, Math and Related Software - free downloads!!
- *Dartmouth College* Thayer School of Engineering
- Environmental Research Institute of Michigan (ERIM)
- *Georgia Institute of Technology* - Civil and Environmental Engineering has a link to School of Civil and Environmental Engineering - EPITOME Project
- *Indiana University*
- Institute for Research in Construction Home Page
- *Kansas State University*- College of Engineering
- *Lehigh University*, with the The Center for Advanced Technology for Large Structural Systems (ATLASS)
- *Michigan Technological University* - Civil and Environmental Engineering
- NEW Mississippi State Civil Engineering Dept.
- New Jersey Inst. of Technology - Civil Engineering
- *North Carolina State University at Raleigh* - College of Engineering
- North Carolina State - VIMS project
- *Northwestern Univ*
  - Infrastructure Technology Institute Library Services Program at Northwestern University
  - Advanced Cement Based Materials
- *Notre Dame* - Civil Engineering and Geological Sciences
- *Ohio Northern University* - Engineering Dept.
- *Princeton University*
- *Princeton University* - Directory of Transportation Resources
- *Purdue University* School of Engineering and home of the ASCE Journal of Infrastructure Systems
- *Rutgers University* Civil Engineering Dept., also check out the Rutgers ASCE homepage
- Southern Illinois University at Carbondale
- Southern Illinouis Univ. at Edwardsville - Engineering educational software
- *Southwest Texas State Univ.* - Edwards Aquifer Research and Data Center
- *Stanford University* - School of Engineering - includes *Stanford University* - Center for Integrated Facility Engineering
- *Texas A&M University (College Station)*
- *University of Alberta, Canada* Water Resources Engineering
- *University of California at Berkeley*

- *University of California at Berkeley* - Partners for Advanced Transit and Highways (PATH)
- *University of California at Berkeley* - Northern California Earthquake Center
- Consortium on Green Design and Manufacturing
- UC Berkeley ASCE Student Chapter Home Page

- Univesity of California at Irvine SEP - Physical Science has links to K-12 teaching tools on the 'Net
- *University of Cincinnati* - College of Engineering
- Univ. of Cincinnati - College of Engineering
- *University of Colorado at Boulder*
- *University of Florida at Gainesville* - Civil Engineering
- *University of Hawaii* - College of Engineering
- *University of Illinois* - Civil Engineering Has links to the Center for Cement Composites and Advanced Construction Technology
- *University of Manitoba* - Dept of Civil and Geological Engineering
- *University of Miami* - Engineering Dept.
- *University of Michigan* - Materials Engineering Univ. Mississippi Civil Engineering Dept.
- University of Nevada at Las Vegas Architecture and Building: Net Resources
- *University of New Brunswick, Canada* - Fire Science Centre
- *University of Buffalo* Department of Civil Engineering and the *University of New York at Buffalo* - National Center for Earthquake Engineering Research (NCEER)
- *University of North Carolina* - Institute for Transportation Research and Education has a map of construction sites. You can click on a site and get information about the project.
- *Univ. North Carolina, Charlotte* - College of Engineering - Contains a GREAT link to Document Center, where you can order on-line a large number of codes and standards. It costs money to order, but where else can you one-stop-shop for international codes and standards?
- *University of Oregon* - Architectronics Homepage
- *University of Portland* - Multnomah School of Engineering
- NEW Univ. of Sherbrook CSCE Conference
- *University of Southern California* - Structural Control
- *University of Tennessee at Knoxville* - Engineering Short Course Information
- *University of Texas*
- *University of Victoria* - Faculty of Engineering
- *University of Washington, Seattle* - College of Engineering and *University of Washington* Dept. of Civil Engineering
- University of Waterloo - Dept. of Civil Engineerin, Canada
- *Univ. Wisconsin- Madison*
- *Virginia Tech*
  - *Virginia Tech* geotechnical division
  - *Virginia Tech* Multimedia Statics program
  - SUCCEED Project - GREAT!! Graphical presentation of standard concrete and aggregate test techniques.
  - Scholarship listing

- *Wash University at St. Louis* - Department of Civil Engineering
- Worchester Polytechnic Institute
- W. Virginia Univ. Constructed Facilities Center

Universities outside North America

Australia

- *Div of Building Construction and Engineering* - in Melbourne, contains a link to some shareware engineering software.
- High Performance Concrete in Australia
- *Curtin University of Technology* - School of Civil Engineering
- *Deakin University* - Engineering and Technology
- *Monash Univ.* Australia
- *University of Sydney* - Dept. of Architectural & Design Science, Key Centre of Design Computing
- *University of Tasmania* Department of Civil and Mechanical Engineering

Belgium

- *Catholic Univ. of Leuven* - Civil Engineering Department

Chile

- Engineering - *Pontificia Universidad Catolica de Chile*

France

- Center for Advanced Engineering Education (ESIEE)

Italy

- *Univ ersity of Parma* - Civil Engineering

Japan

- *The University of Tokyo* - Concrete Laboratory, Tokyo, Japan.

Korea

- *Korea Advanced Institute of Science & Technology* ***I haven't been able to connect to this in a while. It may be a dead link.***

Netherlands

- *Delft Univ.* - Concrete Structures. Also check out the Dept. of Civil Engineering
- University of Twente - Dept. of Technology and Management

New Zealand

- University of Canterbury, Christchurch, New Zealand

Norway

- Civil Engineering - *University of Trondheim - NorwegianTechnical University* or try here or the Institutt for Geoteknikk

Poland

- *Warsaw Agricultural Univ.* -Department of Structural Mechanics

Slovenia

- *University of Ljubljana*

South Africa

- *Univ. of Natal* - Computing Center for Water Research

Spain

- Univ. of Bienal, Zaragoza- Architecture & University Foundation Project, Spain

Sweden

- *Chalmers University of Technology* - School of Civil Engineering, Goteburg, Sweden.
- Lund University, Sweden, School of Structural Engineering, including a list of Nordic links for engineers
- Royal Institute of Technology, Dept. of Structural Engineering, Sweden

Switzerland

- Laboratory of Building Materials

United Kingdom

- British Geological Survey (couldn't access)
- *Cambridge Univ.* - Engrg Dept contains a link to Project Interact
- Imperial College Dept. of Civil Engineering
- *Leeds Univ* - Civil Engineering
- *Napier University* - Building & Surveying

- *Newcastle University*, Dept. of Civil Engineering
- Queen Mary and Westfield College - Software for Engineering Education
- *South Bank University* or check out the School of Construction
- Surry University - Dept. of Civil Engineering
- *University of Bradford* - West Yorkshire
- *University of Bristol*
- *University of Durham* Geotechnical and Geological Engineering
- *University of Edinburgh* - Civil Engineering
- *University of Portsmouth* - Civil Engineering
- *University of Reading* - Construction Management
- *University of Strathclyde*. They are developing a Virtual Reality Construction Site
- UK Building Research Establishment
- *University of Wales at Swansea* Masonry research

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- Other neat stuff on the Web

Government sites

- Argonne National Laboratory
- Alberta Research Council
- California Department of Transportation has some pretty neat links to Caltrans-developed software and up-to-the-minute lists of San Diego traffic tie-ups.
- Library of Congress
- National Institute of Standards & Technology has interesting model of cement hydration process
- NIST - High Performance Constructions Materials and Systems
- National Science Foundation includes a listing of all grants done by NSF.
- U.S. Army Corps of Engineers
  - Civil Engrng Research Lab
  - Construction EngineeringResearch Laboratories
  - Waterways Experiment Station

- WES - Structures Laboratory (couldn't access)
- U.S. Department of Transportation
- U.S. Geological Survey
- USGS Geological Data
- Washington State DOT Home Page includes links to projects underway, ferry schedules and all kinds of neat stuff
- Oak Ridge National Laboratory Review - The Lab's Research and Development Magazine
- BUREAU OF RECLAMATION Draft Home Page has many great links including a concrete statistics program you can download for free. PCQAS Program (Just a note - ours isn't free but it is a great program with lots of users. Save our demo disk to a disk file, then extract it from DOS and type DEMO to run.)
- US Bureau of Reclamation Aggregate database
- US Bureau of Reclamation - Test of the month
- Arizona DOT
- Dept. of Energy grant list
- International Road Federation, European road organization
- Strategic Highway Research Program, SHRP
- National Highway Traffiic Safety Administraton
- NEW Transportation Research Board
- NEW AASHTO
- NEW NTIS listing of new research
- NEW New York State DOT
- NEW NIST report on Federal R&D efforts in Materials & Engineering
- SHRP
  - FHWA
  - Office of Technology Applications - Back issues of SHRP *Focus* newsletter
  - Turner-Fairbank Highway Research Center
  - NEW SHRP Clearinghouse
  - SHRP Clearinghouse has a BBS - contact 202-682-3739 and ask for Kimeerly Moody

Trade & Professional Associations

- ACI International (The American Concrete Institute) Homepage Not much here yet, but there is a promise of a lot more to come. Check out the link to the seminars on the newly revised ACI 318 Building Code.
- American Society of Civil Engineers (ASCE) Homepage
- ASCE COM site - metrication
- Mississippi State ASCE Student Chapter
- Environmental Services Assn. of Alberta
- International Standards Organization
- Student chapter ASCE at Berkeley
- American Society of Civil Engineers - Engineering Mechanics Division
- ANSI Catalog of Acronyms

- ASEE Clearinghouse for Engineering Education
- Inst. for Research in Construction (Can.)
- Inst. of Transportaion Engineers, Vancouver Island Section
- Association of Consulting Engineers of Manitoba
- Struct. Engrs. Assn of California
- Aberdeen Group's World of Concrete home page. Big concrete trade show. They have them in the U.S., South America, Europe and the Orient.
- Professional Engineers Assn. of New Zealand
- American Institute of Architects
- TQM documents
- Building Industry Exchange Foundation
- Virginia Society of Professional Engineers, Tidewater Chapter
- National Society of Professional Engineers
- ASQC, American Society for Quality Control
- Institution of Civil Engineers, UK
- ASCE geotechnical Div.
- CIMA, Construction Industry Manufacturer's Association
- Concrete & Cement Assn. of Australia
- Concrete Paver Institute
- ASCE
- Civil Engineering Research Foundation
- Civil Engineering Research Foundation CENet
- Fly Ash Resource Center
- National Center for Asphalt Technology
- National Technology Transfer Center
- SHRP information
- Building Industry Exchange Foundation
- American Society for Nondestructive Testing
- National Information Service for Earthquake Engineering
- NEW RILEM site
- US Committee on Large Dams (USCOLD)
- Association of Consulting Engineers, London, England
- ASCE New Orleans branch
- Concrete Reinforcing Steel Institute
- American Society of Civil Engineers - Computing in Construction Committee
- San Antonio Builders Assn
- Precast Concrete Assn of New York
- Tubecon - Quebec Concrete Pipe Assn.
- Indiana Ready Mixed Concrete Association
- NEW Portland Cement Assn. (USA)
- NEW American Concrete Pavement Assn.
- NEW ASCE Journal Tables of Contents
- NEW RILEM
- NEW Tilt-Up Concrete Assn.
- NEW Construction Estimating Institute of American
- NEW ASCE San Francisco Branch

- NEW European Group on Structural Engineering Applications of Artificial Intelligence
- NEW Canadian Association for Earthquake Engineering
- NEW CSIR- South African Engineering research center

Commercial sites

THE SHILSTONE COMPANIES

Home of CIVLIST and the Construction Trade Association list.

Architects

- Callison Architecture Inc.
- Celli-Flynn Assocs Home page -Architectural firms on the Web
- Architect database
- Architecture of Historic Montreal
- Mining, Minerals & Materials Engineering - Queensland
- Architecture by Frederick Clifford Gibson - portfolio
- NEW National Standards Systems Network, comprehensive source for codes and standards
- NEW Specs-Online
- NEW Architect's First Source - online specs

Contractors

- Raytheon Engineers & Constructors
- Black & Veatch
- Idorn Web site
- Decorative Concrete Paving
- Allan Block - retaining walls
- Masonry site, Fireplaces
- Guide to Home Building Products
- Home Depot
- NEW Atkinson Corporation, also try The Guy F. Atkinson homepage
- NEW Hakron- A Dutch company specializing in concrete construction and shuttering
- NEW Schnabel Foundation Co.
- NEW View daily construction progress of jail by Rotondo Precast
- NEW Bomanite Corp. concrete flatwork
- NEW XXsys Technology system for wrapping concrete columns with carbon fiber materials
- NEW Ice Block cast-in styrofoam forms
- NEW Concrete Repair Specialties

Cybermalls (collections of home pages)

- AECNet - Architecture, Engineering and Construction
- Global Construction Network Web mall specializing in construction
- InterPRO Construction Industry Mall
- McTrans
- McTrans Site 2
- PIRSOn-Line
- The Overlap - for architects
- Industry products database - New Zealand - product searcher
- InterPRO construction mall
- Pronet - International Real Estate Directory
- AECNet Architecture, Engineering and Construction. I have to give this one a good rating. They carry a column I write on concrete :-}
- The Construction Site
- NIST list of concrete servers
- Tahoenet homepage by Wally Marsh
- Links to civil engineering sites
- The Builder's Network
- AEC InfoCenter
- The Construction Site
- Builder Net Mall
- GeoSource, mall for geotechnical engineering
- GeoSource - resource pertaining to geosynthetics and geotechnical engineering
- UK Construction Directory
- Building Industry Exchange
- Pacific Building Industry
- Rebar Net (in Chinese)
- GETSET
- ARCH1 - Architecture website
- Northwest Buildnet - for the US Pacific Northwest
- Builders 411
- NEW BUILDdata - Australian building product listing
- NEW Construction Materials product listing. When I checked, they didn't have anything on it yet.
- NEW Construction Equipment site
- NEW Engineering links

Engineers

- ABAM Engineers
- NORUT Technology
- Pildysh & Associates
- SF255/SF254 processing software for governement forms for architects and engineers
- C E Ball & Partners - Surveyors and Construction Cost Managers
- NEW VEMAX- Canadian transportation consultant
- NEW Robert Conroys web page about geodesic domes
- NEW Enviro-Development Company
- NEW Listing of Expert Witnesses
- NEW Stone Products Consultants
- NEW China Engineering Consultants Inc. in Taiwan
- NEW On-line Engineering Test
- NEW TMM Consulting Engineers
- NEW Job openings for engineers
- NEW DC Jackson personal page describing his book "Building the Ultimate Dam"
- NEW John Davidson and Assocs. website for engineering professional placement service

Equipment

- Mobile Concrete Dispensers and Wastewater Sludge processing equipment
- Equipment World, construction equipment publication
- IMAGEnet, online graphical equipment database
- NEW Information on equipment for cement and concrete production
- NEW Campbell Scientific Process Control equipment
- NEW Target equipment for concrete cutting
- NEW Deninson Hydraulics makes hydraulic equipment
- NEW MPAQ Automation batch plants
- NEW Sciquest search engine for lab supplies
- NEW SDS Non-Destructive Testing Equipment
- NEW Besser Appco concrete and aggregate plant equipment
- NEW Versa-Lok Retaining Wall Systems
- NEW Rockwell Intl Heavy Vehicle Div.
- NEW Command Data batch plants

Laboratories

- Bowser- Morner Labs
- Virginia Geotechnical Services
- Geotechnical Testing Services - Pittsburgh, PA

- NEW Paradigm Consultants - testing lab in Houston, TX

Manufacturers

- Admiral Steel Building Products
- F&F Concrete Co.
- Fibermesh Synthetic fibers for concrete
- Gilson test equipment, makers of sieving apparatus
- GlobalSource, info on admix for concrete (?)
- Protovale, makes metal detection equipment used in non-destructive testing of concrete
- Handy Store Fixtures - fixtures for retail sales (don't ask what this has to do with construction - they wanted to be here)
- Construction Market Research - has links for the aggregate industry
- Precise Forms Inc. - makes aluminum forming systems for concrete
- Texas Industries (TXI) - makes cement, concrete, aggregate, bagged products, specialty cements
- Aiken Ford Lumber - lumber wholesaler in Eugene, OR
- Rapid Set Cement Products
- Frey Concrete
- Davis Colors
- T&S Concrete Systems & Bomanite, Inc.
- Deborah Berger precast
- Consumers Concrete
- NEW Lafarge CorporationCement, concrete and aggregates
- NEW Bedford Aggregates aggregate
- NEW Blue Circle Enterprises concrete, cement and aggregate
- NEW Chaney Enterprises concrete and aggregate
- NEW Granite Rock aggregates
- NEW London Aggregates aggregates
- NEW Morse Brothers aggregate
- NEW Sanger Sand & Gravel
- NEW Teichert Aggregates
- NEW Vegas Rock
- NEW Vulcan Materials aggregate
- Concrete Concepts
- NEW CustomCrete of Southwest Florida
- NEW Lightweight concrete in Norway
- NEW Global Recycling Network
- NEW Breton Precast

Misc

- Hydrology articles & simulation
- Prince Edward Island Bridge Project
- Prime Materials and Supply - Asphalt emulsion
- New method for measuring prestressing forces
- Ki-Net, New Engineering Techologies, Scotland - discussing virtual corporations
- Info on Cable-Stayed Bridges
- Strong motion database LDEO/NCEER
- Value Link value engineering site
- Bill Hayden's site for construction quality, ASQC
- Construction quality site
- Construction quality site
- Construction quality site
- Used Heavy Truck sales
- Miles Abernathy homepage - sewers and septic tanks
- Edinburgh Engineering Virtual Library -
- Engineering Newsgroup Archive - Edinburgh Engineering Virtual Library
- Herbert Whitman homepage - has some engineering software
- Jeremy Benn Hydraulics engineers
- Construction Industry Foundation for Research and Development - Taiwan
- NEW Infratech Polymers for Asphalt. Has an asphalt discussion group
- NEW Concrete Solutions concrete consulting company
- NEW Natl. Institute of Health - Building 50 is documenting the design and construction process of this building as an educational resource.
- NEW SteelForge Newsletter
- NEW Global Network for Safety Training list of safety videos
- NEW Water Online Water, Wastewater, Pollution info
- NEW National Academy Press reading room of online engineering books

Publications

- Seattle Daily Journal of Commerce
- New Civil Engineer Today - UK publication
- New Civil Engineer magazine
- Construction Monthly
- Engineering News-Record, the premier construction magazine in the U.S.
- Science & Engineering Network News
- McGraw Hill publishers
- The Construction Reporter - construction news in Southern California
- *Roads and Bridges* Online
- InfastructureNET
- Aberdeen Group

- NEW Aggregates Manager publication
- NEW World Road Statistics publication
- NEW List of engineering publications. Also see this site, both at Lund University, Sweden
- NEW Renovations On-Line Internet Magazine
- Concrete Construction Publications
- NEW NDTnet Ultrasonic Testing Online

Software

- Engineering Software Exchange
- Bridge Engineering home page
- BEST ESTIMATE Software Home Page - estimating software
- Computational Mechanics Corporation INFORMATION PAGE - software company that has finite element analysis software
- Computational Mechanics Home Page - not the same as CMC above. Engineering software comapny.
- CivilServe Software - Germany
- Finite element analysis homepage
- FElt homepage
- Pavenet - Pavement Engineering Site - they make software for pavement design and analysis
- ROAD/SITE Designer software, with demos
- Architectural Animations & Models
- FirstMix homepage
- Engineering Software Exchange Newsletter
- Finite Elements homepage
- Hydrology software
- Neoscape - visualization services for architects and builders
- Database of manufacturer's CAD details
- Engineering Software Center
- Scientific Engineering Software
- *University of Toronto* Rock Engineering group, has **FREE** software on rock engineering
- NEW RockWare Software for soils
- NEW Univ. of Sheffield computer program for specifying shear reinforcment
- NEW Aquarian Software simulation software for hydrology
- NEW Material Science and Technology Teachers Workshop- has outstanding education software for engineers
- NEW IFAS - "Integrated Frame Analysis system"- free download of software
- NEW Concrete condition evaluation software
- NEW List of civil design shareware
- NEW Calc95 sci/eng calculator shareware
- NEW List of engineering shareware
- NEW Alladin matrix and finite element software
- NEW Bestech Systems structural analysis software

- NEW Flexible Intelligence Group info on fuzzy/neuro systems
- NEW Advanced Software Designs makes Road/Site Designer software
- NEW Comprehensive list of hydrologic & environmental software
- NEW Engineering Training software
- NEW List of engineering shareware
- NEW CR Engineering Analysis free download of Dynatool, for time series analysis
- NEW Geopak

Lists of other Civil Engrg. sites and Search Tools

- Lycos search
- The TechExpo on World Wide Web has references to all kinds of technical areas, not just civil engineering.
- ArchiWeb : PLAZA conatins a list of architecture-related web sites and other info
- Yahoo list for Civil Engineering
- CMU SCS White Pages Queries
- Yellowwweb Pages - directory of commercial sites
- Internet Search
- RiceInfo: Internet Navigation Tools
- SUSI II - A WWW Search Engine
- World Wide Web Worm
- EINET Civil and Construction Engineering WAIS Server
- University of Texas search site
- Directory of Professional Services, UK
- NEW MapQuest map source
- NEW Lookup USA online Yellow Pages
- NEW SINTEF engineering search engine
- NEW List of engineering links

Other Interesting Sites on the Web

- Commerce Business Daily (CBD)
- CALTRANS Traffic Reports (real-time!)
- Patent Search Service: U.S. Patents 1972-present
- VRML Repository, hot new Virtual Reality Markup Language home page area. With this system you can do virtual walk-thrus, etc. You can also download extensions that let you view VRML pages online. The Windows 3.1 version is WorldView for Windows
- TradeNet, links to Italian industry

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Web pages

-

Telnet sites

-

FTP sites

-

gopher sites

-

Usenet newsgroups

Misc
====

The Transportation Research Information Service maintains a bibliographi
database available as File 63 on DIALOG & available through gateways on
Compuserve, Internet, etc. This is a database search facility that usua
costs money, but selected abstracts can be found on the FHWA BBS for fre

Telnet
=====

Construction on the Toronto Freenet

    login:guest then "go construction" (or go biz)

FTP sites =========

- Anonymous ftp for Roman Kaminski, login as mwod/anonymous, password=X@

- Tasmanian State Public Service FTP Archive
- ftp: archive.afit.af.mil/pub/ - Air Force Wavelets Archives
- ftp: casper.cs.yale.edu/mgnet/ - MGNET - MultiGrid Net
- ftp: clark.eng.buffalo.edu/pub/ - NCEER/Earthquake - related
- ftp://dla.ucop.edu/pub/irl/1987/87-3-13
- ftp://ftp-pubs.lcs.mit.edu/pub/lcs-pubs/listings/abstracts/TR-202.htı
- Corps Engineers, Construction Engrg Research Lab (cd\ASCE)
- ftp://ftp.cis.ohio-state.edu/pub/hcibib/IJMMS12.bib
- ftp: ftp.csn.net/COGS - Computer-Oriented-GeoSciences
- ftp://ftp.t.u-tokyo.ac.jp/pub/net/doc/infoServers.html
- University of Tasmania FTP Archive
- ftp://fwux.fedworld.gov/pub/w-house/0127-3.txt
- ftp://iclnet93.iclnet.org/pub/resources/text/taize/jh-current.txt
- ftp: interval.usl.edu/pub/interval_math - Interval Computations
- ftp: lamont.columbia.edu/nceer/ - NCEER
- ftp: lib.stat.cmu.edu/ - Statlib
- ftp: mailbase.ac.uk/pub/ - Miscellaneous engineering related lists
- Archie.au - Simtel Mirror
- Archie.au - Garbo Mirror

- Struc. Engrs. Assn of S. California
- ftp://stis.nsf.gov/awards91/awd9122/a9122704.txt
- ftp: venus.eng.buffalo.edu/pub/EMD/ - EMD News

Gopher ======

- gopher://159.148.108.8:70/00%5cNEWS%20of%20Latvia%5cLETA%
- gopher://agate.lut.ac.uk:4077/1
- U.S. Department of Energy, Office of Scientific & Technical Information
- USAE Waterways Experiment Station
- Civil Gopher Server - *Texas A&M University*
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- gopher://gopher.msu.edu:3441/0threaded%20soc.culture.bosna-herzg
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- gopher://gopher1.cit.cornell.edu:70/00/.files/CH030493/CH0304931
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FTP sites

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gopher sites

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- ftp: archive.afit.af.mil/pub/ - Air Force Wavelets Archives
- ftp: casper.cs.yale.edu/mgnet/ - MGNET - MultiGrid Net
- ftp: clark.eng.buffalo.edu/pub/ - NCEER/Earthquake - related
- ftp://dla.ucop.edu/pub/irl/1987/87-3-13
- ftp://ftp-pubs.lcs.mit.edu/pub/lcs-pubs/listings/abstracts/TR-202.htı
- Corps Engineers, Construction Engrg Research Lab (cd\ASCE)
- ftp://ftp.cis.ohio-state.edu/pub/hcibib/IJMMS12.bib
- ftp: ftp.csn.net/COGS - Computer-Oriented-GeoSciences
- ftp://ftp.t.u-tokyo.ac.jp/pub/net/doc/infoServers.html
- University of Tasmania FTP Archive
- ftp://fwux.fedworld.gov/pub/w-house/0127-3.txt
- ftp://iclnet93.iclnet.org/pub/resources/text/taize/jh-current.txt
- ftp: interval.usl.edu/pub/interval_math - Interval Computations
- ftp: lamont.columbia.edu/nceer/ - NCEER
- ftp: lib.stat.cmu.edu/ - Statlib
- ftp: mailbase.ac.uk/pub/ - Miscellaneous engineering related lists
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- Struc. Engrs. Assn of S. California
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- Corps Engineers, Construction Engrg Research Lab (cd\ASCE)
- ftp://ftp.cis.ohio-state.edu/pub/hcibib/IJMMS12.bib
- ftp: ftp.csn.net/COGS - Computer-Oriented-GeoSciences
- ftp://ftp.t.u-tokyo.ac.jp/pub/net/doc/infoServers.html
- University of Tasmania FTP Archive
- ftp://fwux.fedworld.gov/pub/w-house/0127-3.txt
- ftp://iclnet93.iclnet.org/pub/resources/text/taize/jh-current.txt
- ftp: interval.usl.edu/pub/interval_math - Interval Computations
- ftp: lamont.columbia.edu/nceer/ - NCEER
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