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Utility Cut Consortium Project Implementation Plan

IRC-IR-804

ElHussein H. Mohamed, Khogali, W.E.I., Martin-Perez, B.; Zeghal, M.; Geagea, Z.; Janoo, V.; Eaton, R.; Barna, L.

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Utility Cut Consortium: Implementation Plan

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IRC Internal Report 804 (IRC-Proposal: NP – C500)

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PREFACE

This document outlines activities that will be implemented under various project tasks. It provides details of field experiments, laboratory investigations, information gathering and full-scale accelerated loading to be conducted in the FERF facility of CRREL. The implementation plan links activities to the objectives of the research project. Although most project activities are interdependent, the intention is to identify those activities in the *critical path* whose timely completion is necessary for delivering the research products according to the announced schedule. The implementation plan also acknowledges the fact that some of the investigative tools (analytical model and resilient test) used in the research will continue to evolve during the project life. In using these tools to support early activities of the project, it is important to consider their limitations and take the necessary precautions when implementing their results.

While it is important to follow the implementation plan, project members are encouraged to propose new and more effective techniques that will improve the quality of the project deliverables or result in a shorter implementation period. Since additional details will emerge, either because of new findings or as a result of consultation with clients and experts in the field, an updated implementation plan will be issued semiannually. This updated implementation plan will be used to prepare briefings for the Steering Committee to secure their approval for activities that will be carried out in the following six months.

INTRODUCTION

The objective of this R&D project is to develop effective utility cut restoration technology based on sound engineering practice. The proposed project deliverables are:

- Guidelines of best reinstatement practices that include technical specifications and quality control measures suitable for real-life construction activities.
- A structural analysis procedure software for the utility cut/pavement system that considers the available technical expertise of municipal and consulting engineers and that permits the incorporation of data related to prevailing traffic and environmental conditions.
- An easy-to-use, performance prediction software tool to support decision-makers in conducting life cycle cost analysis based on evaluation of alternative reinstatement options.

Components of the R&D project incorporated in the statement of work (Proposal), to facilitate the development of the restoration guide and the software for structural design and in support of management activities, include:

- Information gathering tasks
- Laboratory investigations
- Fields tests
- Analytical modelling
- Full-scale accelerated loading tests

The National Research Council Canada's Institute for Research in Construction (NRCC/IRC) and the U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory (CRREL) have joined forces to build a collaborative research and development project that will produce practical, cost-effective solutions to extend the expected service life of urban roads that experience extensive road cuts. This document provides details of the R&D activities and the manner in which the various investigations will contribute to the development of effective restoration practices.

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INFORMATION GATHERING

Task Manager: Morched Zeghal

Literature Search

The literature search task is designed to review previous utility cut studies carried out by municipalities, utilities and others throughout the last fifty years. The review will extend beyond work done in North America to include studies from all over the world. This task consists of the following activities:

- Identify and contact groups with expertise in utility cut restoration.
- Collect and analyze restoration standards.
- Analyze critical elements investigated in earlier studies and review standards developed based on them to determine the reason(s) behind their success/effectiveness or lack of it, and identify knowledge gaps to be addressed in this project (all team members will contribute to this activity).
- Carry out objective critique of approaches, analyses and conclusions of previous studies. If needed, the research team will take advantage of outside expertise to objectively evaluate certain aspects or components of some studies.
- Design and maintain a database (typical format below) to record relevant information such as authors, sponsoring agency, date and location of the investigation. It will also include a brief summary of each study pointing to its main focus and the major investigative tool(s) used (field, analytical, etc). A feature in the database that allows research members identify latest additions will also be incorporated. A separate database will be assigned for housing restoration standards.

Study ID	Title	Author	Date published	Focus	Standard produced
1	*The mechanics of small utility cuts in urban streets pavements*	Humphrey, M. H. and Parker, N. A.	1998	Analytical	No
2					.
3					.
.					.
.					.
.					.
.					.
.					.
.					.
.					.

N.B. For each record (study) the database will have a form that contains a summary of the study (see example below). Every team member will have the responsibility of updating the database after reviewing a study.

Study ID	1
Title	*The mechanics of small utility cuts in urban streets pavements*
Author	Humphrey, M. H. and Parker, N. A.
Date published	1998
Summary	The investigators made use of three-dimensional finite element analysis to study the magnitude and extent of distress associated with cuts in urban roads. The structural components, of the pavement studied, consisted of 4 inches of asphalt concrete, 8 inches of granular base and 8 feet of granular fill/subgrade. Assuming the process is done in steps and using ANSYS solid 45 version 5.2, excavation was simulated by introducing a stress relief approach. The research concluded that when utility cut is made, a stretching zone is created behind the unsupported face of the utility cut, extending up to 3.5 feet into the pavement structure. The fill/subgrade layer seems to be the subject of the worst distress. Based on the results of the analysis the following procedure was recommended for further experimental investigations: 1. Restore the utility cut up to the top of base elevation; 2. Remove the asphalt surface from around the cut to have a cutback equal to the maximum distance of disturbance in the fill material; 3. Vibro-compact the cutback area to develop initial stresses in the depths of the pavement structure; and 4. Resurface the whole area.

- Following completion of the review, a state-of-the-art report of the practice of utility cut restorations will be produced, which will serve the following purposes:
  - Guide the development/refinement of all other tasks of the project to avoid duplication of effort and prevent errors committed in previous studies.
  - The report will be submitted to the project steering committee before the end of the first year as a confirmation the subject task is completed.
  - To be used by research team members in responding to inquiries from the public, project participants and potential clients to demonstrate awareness about current achievements and confirm the originality of the activities of this project.

Literature review is a very effective tool for defending and justifying the research team choices pertaining to different phases of the project. Accordingly, participation of all team members with expertise in different areas of the subject is critical for the success of this task. In order to prepare the material for the first meeting of the steering committee, every member of the research team will need to address the items mentioned above and clearly identify gaps in the knowledge base and propose how they will be tackled in this project.

Survey Questionnaire

Purpose

The survey questionnaire is intended to collect important information regarding utility cut practices in North America and to gain from this experience to develop effective solutions considering realistic field conditions and available technical expertise. The collected information should accurately reflect the prospects and concerns of all participants and that of people with expertise in the subject matter. The survey questionnaire will be distributed not only to project participants but also to organizations or persons that possesses an experience in the subject. The questionnaire will acquire general information about the composition of typical roads and the problems encountered with utility cut restoration. It will mainly collect information regarding construction related issues such as cutting and excavation specifications, restoration procedures including the type of backfill used, equipment used, quality control procedures and their degree of enforcement and the experience available at different localities with engineered materials such as flowable fill and soil stabilizers. The survey will also touch on the management schemes prevailing in North America. In general the response should reflect to the research team which scheme(s) (construction and management) is (are) producing good results and others that are less successful.

Approach

This task will follow the sequence of activities listed below:

1. Based on existing information, identify knowledge gaps, which require collection of additional data and probably further research.
2. Develop general plans and ideas with respect to:
    - expected uses of the data
    - reports required.
3. Review information regarding existing restoration standards, including those for design and construction, and their effectiveness as reported by the specifying agencies.
4. Consult users (team members) to clarify:
    - major/minor objectives
    - content of areas of inquiry
    - minimum quality
    - mode of production of results (reports, tables)
    - sample size
    - respondent nature and characteristics
    - language
    - field method

- data capturing method

5. Draft questions, test them, record the results and report back to the users.
6. Arrange questions into logical groupings.
7. Develop the first draft of the questionnaire.
8. Conduct a pilot test, noting particularly what presents difficulties. The test questionnaire should be subjected to all coding, editing, data capturing and processing routines and reports are prepared on the quality of data.
9. Make final modifications to the questionnaire and supporting documentation and present to steering committee for approval.
10. Conduct the full-scale survey: the survey questionnaire will be circulated to targeted groups and will be added to the project Web Page.
11. Use the designed database for recording responses.
12. Analyze results and record observations related to problems and solutions and prepare reports.

Action

Timely collection and analysis of the data is necessary to provide critical information needed by the researchers. Therefore is a first draft covering the research team needs will be made ready prior to the first steering committee meeting scheduled to take place in February 1999. To meet this deadline, it is critical that the research team addresses the concerns and points in the first 4 steps described above.

The following is a tentative questionnaire identifying some of the needed information in logical grouping format. Final layout, format and wording of questions need to be developed prior to the first steering committee meeting. It is intended that team members address their needs/concerns by clearly defining:

- major/minor objectives (the information needed with priority)
- expected use of data (the form in which reports are needed, i.e. tables, figures, statistics, etc.)
- language (English, French , etc.)
- documentation of field method (hard copy, web page, etc.)

Suggested Survey Questionnaire Format

Part I: General

- **Composition of a typical road structure**

1. Please specify the composition of a typical road structure encountered in your locality and the design procedure followed (fill in the appropriate columns below).

	Material	Thickness (inch, mm)	Design procedure (AASHTO, Asphalt Institute…)
Subgrade			
Sub-base			
Base			
Cement-treated Base			
Portland cement layer			
Asphalt concrete layer			

- **Frequency of utility cuts**

2. How frequent are utility cuts in your region? ------------------------------------cuts/year
------% deep -----% shallow (a cut is deep if it is deeper than 1.2 m (4.0 ft)

3. How are the cuts distributed in your locality?
------% water and sewer -----% gas
------% electric -----% telecommunication
------% cable -----% other, please specify-------------------

Part II: Standards and procedures

- **Studies sponsored**

4. Have any studies, related to cuts, been done by or for your agency?
❍ no ❍ yes, Please specify ---

- **Reinstatement procedure**

5. Are you following a standard procedure for reinstatement?
❍ yes, please specify--
❍ no, do you have your own procedure then? ❍ no ❍ yes, please attach a copy

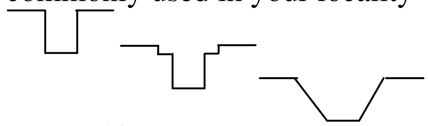
6. Do you have different specifications for seasonal repairs and emergencies?
❍ no ❍ yes, please attach a copy

- **Cut geometry and type**

7. What cut geometry is commonly used in your locality?
❍ -----% rectangle

❍ -----% square
❍ -----% other, please specify ------------------------------------

8. What type of cut is commonly used in your locality
❍ -----% standard
❍ -----%T-shaped
❍ -----% tapered,
❍ -----% Other, please specify ---



- **Cutting method**

9. What are your specifications concerning breaking the pavement?
❍ jack hammer ❍ saw to ------% of the asphalt depth
❍ none ❍ other, please specify -------------------------------

- **Excavation method**

10. What are your specifications concerning excavation tool and method?
❍ manual ❍ backhoe
❍ vacuum ❍ other, please specify --

- **Backfill material**

11. Do you have any specifications as of the kind of materials to be used as backfill?
❍ no
❍ yes, please attach a copy of your specifications

12. Do you have any experience with slurry mixes (unshrinkable fill, controlled low strength)
❍ no
❍ yes, please attach specifications and state for how long?-------------------------years

13. Do you have any problems with it?
❍ no
❍ yes, please specify--

14. Do you have any experience with soil stabilizers?
❍ no ❍ yes, please specify what kind and for how long?------------ years

15. Do you have any problems with it?
❍ no ❍ yes, please specify--

16. Do you have any experience using geogrids in cut reinstatement?
❍ no ❍ yes, please specify type----------------------. For how long?---------years

17. Do you have any problems with using geogrids?
❍ no ❍ yes, please specify---

- **Compaction equipment**

18. What are your specifications concerning compaction equipment?

❍ vibrating plate, specify type -------- ❍ tamper, specify type ----------------
❍ none ❍ other, please specify ----------------

19. Is the equipment used assures the required degree of compaction?
❍ yes ❍ no, please specify if any corrective measures are taken------------

- **QA/QC and inspection**

20. Do you have any quality assurance program?
❍ no ❍ yes, please specify---

21. In what percentage are the inspection, testing and inspection plus testing Done? Please specify the quality control measures used at each level (if any).

	Subgrade		Subbase		Base		Wearing Surface	
	%	Test	%	Test	%	Test	%	Test
Inspection								
Testing								
Inspection + Testing								

22. Are the quality control measures specified above effective?
❍ yes
❍ no, what do you think will be a better measure?--

23. What measures are you using for density control?
❍ dynamic cone penetrometer ❍ compaction meter
❍ none ❍ nuclear device
❍ other, please specify--------------------------

24. What measures are you using for moisture control?
❍ nuclear device ❍ squeezing soil in the hand
❍ plant moisture meter ❍ none
❍ other, please specify----------------------------

Part III: Performance

- **Criteria**

25. What are the criteria used to judge the performance of cuts?
❍ maximum allowable settlement--------inch/mm
❍ maximum crack opening--------inch/mm
❍ cracking intensity around the cut
❍ public complaints
❍ other, please specify ---

26. What are the methods used for performance evaluation?
❍ visual inspection
❍ direct measurements, please specify-------------------------
❍ non-destructive test, please specify -------------------------

❍ other, please specify--

- **Problems encountered**

27. Please indicate the time frame of any problems encountered and the frequency of occurrence.

Problem	0-1 year	1-2 years	2-3 years	3-4 years	After 4 years
Settlement	-----%	-----%	-----%	-----%	-----%
Cracking	-----%	-----%	-----%	-----%	-----%
Other (specify):	-----%	-----%	-----%	-----%	-----%
i) -----------------	-----%	-----%	-----%	-----%	-----%
ii) ----------------	-----%	-----%	-----%	-----%	-----%
iii) ---------------	-----%	-----%	-----%	-----%	-----%

28. Please specify the percentage of cuts that are not performing well.
------% of the deep cuts ------% of the shallow cuts

29. Specify the type/distribution of traffic that non-well performing cuts are subjected to.
-------AADT, distributed in the following percentage:
------% light vehicles -------% buses -------% heavy trucks

30. The cuts that are not performing well are located:
-------% at traffic lights ------% middle of streets
-------% other location, please specify---

- **Cut position and orientation**

31. Did you notice a difference between the performance of cuts made in the wheel path and others made outside of it?
❍ no
❍ yes, please specify how the location seems to affect the performance----------------

32. Did you notice a difference between the performance of longitudinal and transversal cuts?
❍ no
❍ yes, please specify how the orientation seems to affect the performance-------------

- **Seasonal variation**

33. Please specify the season during which most cut distresses seem to appear.
❍ fall ❍ winter ❍ spring ❍ summer

Part IV: opinion

34. Do you think that the procedure you currently follow effective?
❍ yes
❍ no, please specify what you think should be improved----------------------------------

35. In your opinion what is behind the cut problems (major factors)?
❍ malpractice ❍ lack of inspection and testing
❍ lack of effective procedures ❍ other, please specify ---------------------------------

36. Any additional information or comments regarding the utility cut reinstatements would be highly appreciated? ---
----

Part V: Management

37. What scheme is commonly used to manage utility cuts in your locality?
❍ enforcing technical specifications ❍ construction control specifications
❍ permitting-fees scheme ❍ other, please attach a copy

38. Are you satisfied with your management scheme?
❍ yes
❍ no, please specify what need to be improved or what will be an alternative scheme
----

ANALYTICAL MODEL

Task Manager: Beatriz Martin-Perez

Preamble

Current procedures for design and analysis of pavements were designed specifically for new highway construction, and, thus, prevalent analysis tools do not account for urban roads and their operating conditions. In particular, existing pavement models do not address the local conditions that affect the performance of restored utility cuts in city streets. For example, current analytical models do not consider the lateral boundaries of the urban roads that result from the presence of buildings and their foundations. Neither do they account for the traffic patterns specific to urban conditions or for the extensive network of pipes and cables underneath the roads. Because of the localised nature of the problem posed by the reinstatement of utility cuts, current methods of pavement design and analysis are not applicable, and the need for a new approach of analysis exists.

Furthermore, there has been a trend in recent years to adopt performance-based specifications to guarantee effective restoration of utility cuts. The performance criteria imposed in these specifications are usually based on limiting the structural damage of reinstated cuts that is induced as a result of external loading over a specified period of time (e.g., limiting the cracking intensity inside and around the cut or limiting settlement of the restored cut). A problem with following this type of specifications is that there is no established and widely acceptable procedure of analysis that links the structural response of pavement structures to their performance through the prediction of incurred damage. For this approach to be viable, there is a need for sound analytical models that not only are capable of predicting performance through damage evaluation, but also provide a means for a performance-based design of the restored cut under in situ conditions.

It is the objective of the analytical component of this project to work towards the development of structural analysis procedures tailored to the unique nature of the problems posed by utility cuts in urban roads. This objective has as its focus the attainment of two of the project deliverables: (1) a structural design procedure for restoration of utility cuts, and (2) a performance-prediction tool to support decision-makers in conducting life-cycle cost analysis based on the evaluation of alternative reinstatement options.

IRC Analytical Model

The proposed structural analysis procedure will be built on IRC's finite element program of pavement analysis, which is based on the theory of continuum damage mechanics. This theory recognises the heterogeneous nature of pavement materials and combines a process micro-mechanics damage model with the theories of elasticity, plasticity and fracture mechanics to accommodate the majority of the energy dissipation mechanisms associated with the evolution of various distresses (e.g., cracking and rutting). The IRC analytical model provides capabilities to represent in a realistic manner existing (in-service) conditions such as construction joints, cracks, and permanent deformations. It is also capable of handling the non-linear response of pavement materials as well as complex geometries and loading conditions (not limited to axysimmetric representations). The model in its current format can predict damage in various forms, enabling the use of the micro-mechanics approach to predict the performance of roads as influenced by in-service and boundary conditions of a pavement structure. Although initially developed for research purposes, the IRC analytical model will be tailored to the analysis of utility cuts during the project life. Potential developments include refinements aimed at incorporating the impact of variables related to materials, design and construction. Validation of the model will be based on the use of data obtained from field experiments and accelerated loading tests, which will result in an effective analysis tool for engineering the restoration of utility cuts.

Scope

Tailoring the IRC analytical model to the restoration of utility cuts will be achieved by jointly considering in the analysis the impact of material types, structural design features and construction quality on the performance of reinstated cuts. Some of the material parameters for the different pavement materials needed for the analysis are summarised in Table 1. Design features include inputs such as layer thickness, cut geometry, boundary conditions, and traffic and environmental loading. Construction-related variables include excavations, presence of joints, field density, etc.

Materials

Results from the material characterisation component will provide the analysis with the necessary information needed to define the mechanistic response of the different restoration materials in the form of constitutive relations. These constitutive relationships will be based on the resilient modulus, which accounts for the elastic response of unbound aggregate materials, cohesive sub-grades and engineered materials to traffic loading, and on the classical theory of plasticity. The implementation of the resilient modulus relationships into the IRC analytical is possible because the model is already capable of simulating the response of non-linear elastic materials under the action of external loading. Theoretical developments of the existing model will also benefit from the material characterization task, which targets the development of laboratory capabilities to measure the permanent deformation of these materials under the action of mechanical loading. In addition, the implementation of constitutive relations to assess the viscous deformation of asphalt concrete based on the theory of visco-plasticity is currently under way. The asphalt concrete characterisation implemented in the model follows a scheme developed by the Strategic Highway Research Program (SHRP).

The impact of the different restoration materials on the performance of reinstated cuts will be assessed through a parametric analysis using IRC analytical model. This exercise will enable the evaluation of various reinstatement techniques, giving the research team the opportunity to find out what materials are appropriate to particular conditions/situations and to identify further research needs that are not supported by the field and accelerated loading tests.

Design

It is the intention of this project to engineer the restoration of utility cuts similar to the style used in other structures, with the objective of producing a design procedure as one of the deliverables. Although the IRC analytical model is capable of handling complex geometries and boundary conditions (see Figure 1), and it is not limited to the traditional axisymmetric representation of pavement structures, it will be further developed to make it more responsive to needs pertaining to the design of utility cuts restoration (i.e., materials, geometry, boundary conditions, loading).

The existing model uses a loading technique that simulates closely the repetitive nature of traffic loading. However, the difference between an existing pavement and a restored cut introduces a dynamic impact associated with the transition from the existing road surface to that of the cut, i.e., travelling over a joint and probably different surface levels quality. To address this condition, dynamic loading capability will be built into the current IRC analytical model during the project life. This step will provide the research team with an opportunity to study the impact of vehicle/pavement interaction on the performance of restored cuts.

The effect of environmental loading on the mechanical response of pavement materials is indirectly taken into account into the model through the use of appropriate material parameters. A simplified model of thermal analysis and moisture transfer will be incorporated into the existing program to account for seasonal variations on the reinstated cuts performance; however, a literature review of previously developed analytical models that simulate frost heave and settlement due to environmental loading will be conducted to improve current analytical capabilities. The expertise of the research team at CRREL will be utilised in this respect to address frost actions.

The influence of design details on the performance of reinstated cuts will be also assessed through a parametric analysis of design-related parameters. The outcome of this exercise will provide input in the design of both the experimental field studies and accelerated loading tests and the results of these experiments will be used to refine the model. The refined model will then be used by the research team to explore situations not covered by the tests.

Construction

The impact of construction-related variables (e.g., excavation, joints, compaction quality) will be investigated in the study to incorporate into the model the specific needs associated with problems encountered in restoring utility cuts. Implementation of analytical procedures to simulate the stress relief in soil layers due to the excavation process will be carried out. This feature will allow the research team to determine the extension of the disturbance zone introduced by the cut, if such a zone exists. Furthermore, recovered data and performance records from the field studies and accelerated loading tests will be analysed and the results will be used to carryout further model developments and refinements related to such a disturbance zone.

The current capabilities of the IRC analytical model as well as those to be implemented in the future are summarised in Table 2.

Research Activities

In order to achieve the stated objective, the following tasks will be carried out during the project life:

Parametric Analysis

The purpose of this task is to study the influence of variables as related to materials, design, and construction on the performance of reinstated cuts through a parametric analysis using the existing analytical model. The objectives of this task are twofold:

(a) support the design of the field experiments, by identifying critical locations where sensors, monitoring seasonal changes in temperature and moisture conditions and accumulated damage (deformations), may be installed;

(b) support the development of a preliminary plan for the accelerated loading tests to be conducted at FERF by establishing the spectrum of variables to be investigated.

The task consists of the following activities:

- Determine the impact of critical variables related to materials, design and construction practices known to influence the performance of reinstated cuts. These variables will be identified through the two information gathering mechanisms (literature review and survey questionnaire) described early in this document. All team members are expected to provide input regarding relevant parameters to be included in the investigation.
- Design a plan for the parametric study. Once critical parameters are identified, the number of simulations associated with the variables and relevant ranges of values will be established.
- The actual parametric analysis will entail the following:
  - An analysis of the impact of geometric details: depth, width, slope of cut, layer thickness, boundary conditions (e.g., presence of buildings and layers of buried utility pipes), cut location and orientation, …
  - An analysis of the impact of different restoration materials.
  - An analysis of the impact of changes in the environment and traffic loading. Environmental loading is implicitly considered in the model by the influence that environmental factors (moisture and temperature) have on the mechanical response of pavement materials. The impact of vehicle/pavement interaction on the performance of the restored cut will be possible once dynamic analysis capabilities are established.
  - An analysis of the impact of various parameters on the extent of the potential disturbance zone around the pavement cut. This activity will be possible once capabilities to simulate stress relief due to excavation are incorporated in the analytical model.
  - An analysis of the impact of the slippage/settlement at the cut interface. The existing model has capabilities to simulate discontinuities in a general form; however, the role these interfaces (construction joints) play in the performance of reinstated cuts has not yet been established. An interdependent link between the

data retrieved from the field and the accelerated loading tests and the results obtained from the analytical model will provide the research team with the necessary information to establish the significance of the cut interfaces on the overall performance of the restored cut.

Design of Field Experiments

IRC analytical model will be used to analyse restored cuts in the selected field sites in order to identify the critical locations where sensors need to be installed. Output from this exercise will help the design of the field experiments and ensure collection of data that is of relevance to the performance of the restored cuts. The design will be incorporated in the construction contract plans prepared for the field experiments.

Design of FERF Experiments

The intent of this task is to support the design of the pavement sections to be built at the FERF facility for the purpose of performing accelerated loading tests. IRC analytical model will be used to test different restoration options, which will be a combination of materials, design features and construction techniques. These solutions will be proposed after completion of the two information gathering exercises, the parametric analysis, material characterisation and the experimental field studies.

Field and FERF Data Reduction and Analysis

The analytical model will be used to analyze the field sites and FERF sections according to as-built plans, so that the associated performance of the investigated restoration solutions can be predicted over time. This task will facilitate future comparison of calculated responses with observed performance.

Support for Material Characterisation

The mechanical response of native soils and granular materials in the model is currently being characterised through the use of resilient modulus, whose range of values are highly susceptible to testing conditions (e.g., confining pressure, moisture content, loading cycles). The material characterisation task with support from the discrete element modelling activity has as its objective the development of testing procedures and material specifications to obtain a universal resilient modulus relation. The micro-mechanics features of the IRC analytical model will be employed to further investigate the mechanical behaviour of granular materials and support the above mentioned activities.

Model Refinement and Validation

Data provided from the field experiments and accelerated loading tests will be critical to test the model's ability to accurately predict performance, by comparing predicted values to sensor recorded ones. In the case of discrepancies, these data will be used to further refine the model's prediction capabilities after identifying the causes for such discrepancies. Non-destructive testing (NDT) results obtained at the field sites and the FERF facility will be also used for validation purposes by comparing them to results obtained from the analytical model. Final input from the material characterisation task will be also critical to refine material relationships in the analytical model. Once confidence on the analytical model's ability to predict performance is established, the model will be used to expand the analysis beyond the ranges of the variables studied during the field experiments and accelerated loading tests, giving the research team the opportunity to explore options not previously covered.

Analysis of NDT Results

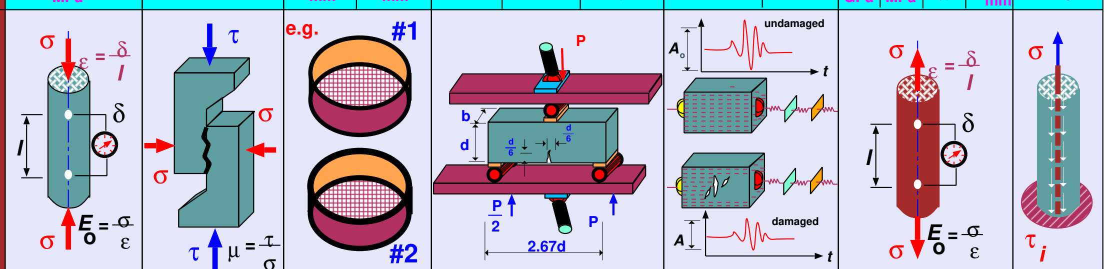
NDT results present a potential to provide with information that can be used to determine the impact of utility cuts on the performance of roads. One of the intended uses of NDT will be for benchmarking performance by conducting tests before and after restoration. However, current uses of the data to predict such an impact is not well established. The ability of IRC analytical model to account for in-service conditions such as construction joints, cracks and other deformations will facilitate analysis of data obtained through NDT. The support of the analytical model in the analysis of NDT results will enhance NDT data interpretation and will make NDT more effective in providing the required information including the structural integrity of the road after restoration of the cut. This information may be used by cities or utilities to propose remedial measure(s) if analysis indicates a pronounced drop in the serviceability of the road.

Performance Prediction

One of the deliverables of this project is a performance prediction tool for utility cuts restoration to support design and management decisions. In order to develop this performance prediction scheme, damage prediction facilitated by structural analysis conducted on a number of proposed restoration options will be used to quantify the performance of a road with a restored cut. Performance prediction will be carried out by directly quantifying the intensity of cracking in and around the cut, including their widths and lengths, as well as the extent of settlement, ruts, etc. This task will be completed after recovering performance data from the field studies and accelerated loading tests followed by establishing a correlation between the model predictions and actual performance. The proposed tool will be developed in a format capable of addressing cities and utilities planning and management requirements. These requirements will be established through gathered information and consultation with project participants. The software developed to employ the analytical model performance prediction capabilities will be compatible with existing pavement management (or assess management) programs.

Implementation of a Friendly User Interface

Intended program developments will target ease input requirements, which include variables related to road and backfill materials, design, cut geometry and construction specifications. Analysis will then facilitate the processing and interpretation of results which users can use directly to make necessary design and management decisions. The details of this task will be developed once the prospects and concerns of project participants are fully understood, and the full capabilities of the model in terms of design and performance prediction of utility cut reinstatements are in place. Project participants will have the opportunity to evaluate the software package and suggest modifications prior to its final delivery.

#	1	2	3		4			5		6				7
Material properties	Elastic moduli of granular materials and binder-matrix	Coefficient of dry friction of asphalt concrete	Aggregate size		Fracture toughness			Void percentage		Fibres				Interface shear strength
			Maximum	Minimum	Cement paste	Interface		Initial de-bonded interfaces	Initial damage	Modulus	Yield stress	Dimension		
					Mode-I	Mode-I	Mode-II					Volume	Length/Radius	
Symbol	E_o MPa	μ	D_M mm	D_{Min} mm	K_I^{b} ! MN/m$^{3/2}$	K_I^{if} ! MN/m$^{3/2}$	K_{II}^{if} MN/m$^{3/2}$	ρ	ω_o	E_f GPa	σ_f MPa	V_f %	l_f/r_f mm/mm	τ_i MPa
Testing methods														
Test name	Uniaxial test!!	Push test!!	Sieve analysis		Notched beam test!!			Ultrasonic test+		Uniaxial test				Pull-out test

! *b* and *if*, correspond to the binder-matrix and interface, respectively

!! non-destructive test is sufficient

\+ other tests can be used such as: [1] Micrography analysis
[2] Radioactive analysis
[3] Acoustic emission

TABLE 1 Material Parameters for the IRC Analytical Model

TABLE 2 Capabilities of the IRC Analytical Model

Model features	Existing	In progress	Future implementation
Linear elasticity	x		
Non-linear elasticity	x		
Continuum damage mechanics	x		
Fracture mechanics	x		
Plasticity	x		
Visco-plasticity		x	
Stress-relief due to excavation			x
Dynamic loading			x
Heat and moisture transfer			x

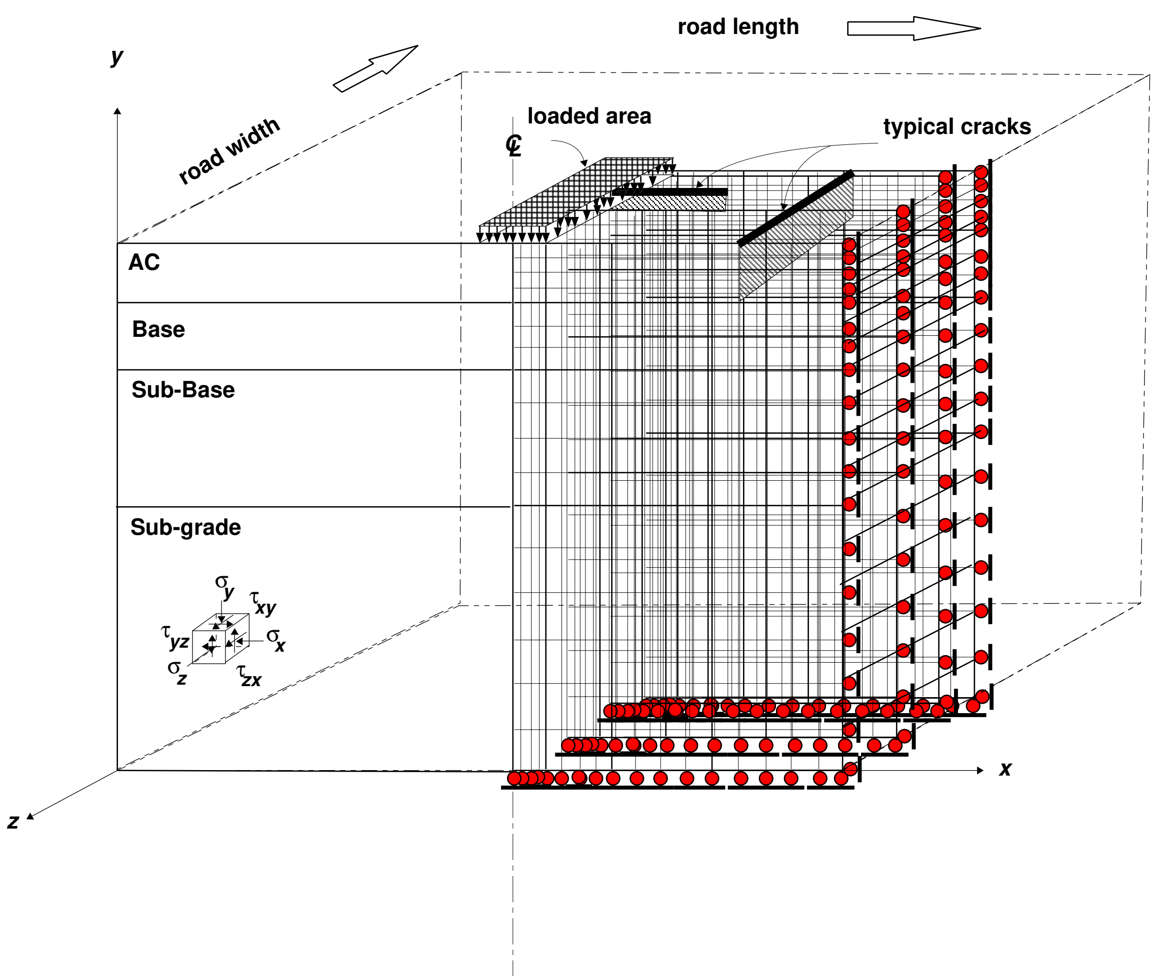


FIGURE 1: Finite Element Representation of a Pavement Structure.

MATERIAL CHARACTERIZATION

Task Manager: Walaa Khogali

Preamble

Characterization of pavement materials, in general, poses a great challenge to pavement engineers and practitioners due to some significant gaps in the knowledge base associated with the quantification of the mechanical response of these materials. The mechanical properties of these materials are not constant and tend to change appreciably under varying loading and physical conditions. This may be attributed to the fact that all pavement materials have inherent heterogeneity due to its particulate nature, which renders the identification and quantification of a representative material parameter to describe the behaviour under load, a difficult task. In the past, a partial solution to the problem was achieved through the introduction of numerous assumptions and the use of analytical approximations when dealing with the characterization of pavement materials. Such approximations served well in dealing with continuous pavements, as assumed in the case for highways and airfields. However, in dealing with conditions like those encountered in urban roads such as utility cuts, discontinuities (cracks and joints) and buried facilities introduce unique conditions that require a more elaborate and fundamentally sound approach for characterizing road materials to support effective analysis of some problems and to develop the required solutions.

Currently there are a number of materials being used in the reinstatement of utility cuts. Prior to the adoption of any of these materials for regular use, there are a number of questions that need be answered. To list a few:

- Which material is the best to use, and based on what criteria?
- How much of it should we use (thickness)?
- What performance should we expect form this material (or combinations of materials)? i.e. how can we quantify performance (criteria)?
- Can the material under consideration be used universally, or only in some localities and under certain climatic conditions?
- How are we going to control the quality of the work done in the field (QC/QA measures) to guarantee effective implementation of the design?
- What about non-conventional materials (engineered materials)? Can we use them successfully and justify the high cost?
- Is there any specific method that is currently available for effectively characterizing backfill and other materials used to restore utility cuts? If no, can we modify any available procedure(s)/equipment or should we develop new one(s) that can accomplish our objective?

The answers to these questions are the subject of the material characterization task.

Scope

Current approach to material characterization, which uses a number of physical properties (e.g. Proctor density, gradation, etc.), can not alone guarantee the choice of an adequate restoration material nor can it be used to effectively control the quality of construction. This is demonstrated in Figure 2, which combines the commonly used density – moisture relationship with the mechanical response of the material as described by the resilient modulus parameter. The resilient modulus, which closely simulates in-situ material conditions and externally applied loading, suggests that the current approach can not capture the impact of a parameter such as seasonal changes in moisture content. A slight increase in moisture content at the same dry density, resulted in a significant drop in the material's strength, and consequently its ability to sustain external loading. Therefore, this project will employ the resilient modulus testing approach toward improving material characterization. The resilient modulus is a mechanical property of the material that describes its stress - strain relationship under dynamic loading and specified physical conditions. It will be used to close the knowledge gap in material behaviour and to develop the targeted material characterization technique tailored to the requirements of utility cut restoration.

Inputs from other project activities together with results from the resilient modulus investigation will be used to establish a link between the material mechanical/physical properties and observed performance patterns.

The scope of the material investigation comprises the following activities:

- Conduct resilient modulus, M_r, tests to characterize the mechanical response of road/backfill materials. Tailoring the conventional test method to project needs will be part of this activity.
- Study the effects of seasonal variations in temperature and soil suction on the resilient response.
- Develop M_r constitutive models for various restoration materials that describe both their resilient and permanent deformation behaviour under dynamic loading (cyclic σ_3 & σ_d). These models will be subjected to continuous refinement through support from Discrete Element Modelling (DEM) and IRC pavement analysis model.
- Develop QC - M_r relationships to support the evaluation of currently available QC measures and tailor their application to the utility cut restoration problem.
- Use DEM to support the development of QC - M_r relations.

The objective of the material investigation is to provide the following outputs/deliverables:

- Guidelines for material selection based on performance requirements through the determination of its mechanical response and physical properties. The guidelines will use the selected criteria to choose acceptable materials considering their availability and cost.
- Material constitutive relations as inputs to support tailoring IRC analytical model capabilities toward analyzing utility cut restorations based on evaluation of alternative solutions including different restoration materials.

- QC/QA measures that will produce effective restoration with known and acceptable performance.

The intended characterization would involve unbound aggregate materials, cohesive subgrades and engineered materials. For asphalt concrete materials, the results of recent developments in characterizing the behaviour of asphalt materials will be implemented (–SHRP).

Activities within the material characterization phase will involve both laboratory and construction-related material investigations. The laboratory study will involve the development of the M_r models for the various restoration materials. The construction-related material investigation will involve provision of the constitutive relations as inputs for the design of the FERF experiment and the development of QC/QA guidelines for field restoration. In addition, NDT tests conducted during field experiments and in the FERF will be used in conjunction with IRC analytical model to refine the developed materials' relations. The refined format of the constitutive relationships will be one of the inputs that will be used to develop analytical performance prediction capabilities. An outline describing the various activities of the material investigation is given below.

Laboratory Investigation

The laboratory investigation primarily involves the determination of resilience characteristics (M_r & ν_r) of a number of base, sub-base and backfill materials. Both conventional (e.g. unbound aggregates, cohesive materials) and engineered materials (e.g. RAP, chemically or physically stabilized materials) will be evaluated. In addition, a number of physical and mechanical tests will be performed on these materials to aid in the interpretation of the resilient modulus test results and to help develop the required M_r constitutive models. A partial list of some of the prospectus tests and their intended use is given below:

- *Resilient modulus tests* to provide mechanistic parameters for the characterization (non-conventional M_r to adapt to utility cut restoration problem).
- *Tests to determine the composition and microstructure features of materials* to be used in discrete element modeling and in the interpretation of resilient modulus results (sieve analysis: dry and wet determinations, X-ray diffraction, digital image analysis).
- *Tests to obtain some material intrinsic properties* to be used in DEM (Los Angeles abrasion test to determine aggregate toughness and resistance to crushing, angularity and soundness tests for aggregates to determine aggregate resistance to environmental degradation, percent elongated particles content to quantify the deformability of the material internal structure under external loading).
- *Tests to provide data on the effects of seasonal variations on material properties* (Atterberg limits, determination of soil water retention characteristics, moisture content-density relationship)
- *SHRP tests to provide inputs pertaining to binders and asphalt characteristics* ($G^*\sin\delta$, fracture toughness obtained from notched-beam tests, etc.)
- *Laboratory CBR tests* (to correlate with resilient modulus results and QC measures)

The laboratory investigations are grouped under four main activities. Following is a description of each activity, its interactions with other project activities and its anticipated outputs and/or deliverables.

Factorial Experiment Design

This activity involves the development of a plan for a factorial experiment to study pertinent factors that influence the resilient modulus parameters (both M_r and ν). The design of the factorial experiment will be performed by Dr. Khogali and supported by Dr. Janoo. This task, which is expected to span a period of two months from the project starting date, consists of two activities. The first activity will benefit from data collected during the information gathering phase to identify candidate parameters that affect resilient responses. The second activity will involve the utilization of factorial and fractional factorial design techniques to plan the full laboratory investigation. Upon completion of this task, a testing schedule will be set wherein laboratory facilities at both IRC and CRREL will be engaged in performing the M_r tests on selected materials that will be studied in this project.

M_r Tests and Data Analyses at IRC

Out of the total number of M_r tests to be performed in the laboratory study, 200 soil specimens will be handled at IRC. This represents six material types (3 backfill materials, 2 conventional aggregate bases/sub-bases and 1 engineered material). The remaining materials will be tested at CRREL laboratories.

The tests that will be conducted at IRC include materials from the field experimental sites. Parallel testing on replicate samples of the same materials will be conducted concurrently at CRREL laboratories. Test results from IRC and CRREL will be jointly used to verify the consistency / reliability of obtained M_r data and to provide an abundant source of information to develop material constitutive relations.

Early inputs in terms of material constitutive models obtained from this task will be fed into the IRC analytical model to support the design of the first section in the FERF experiment. The preliminary material models will be ready August 2000. Similar inputs from this activity will be available for use by IRC analytical model to support further the development and refinement of the model.

Resilient modulus testing at IRC is expected to continue for a period of eight months following the completion of the factorial design task.

Analyses of M_r Tests done at CRREL

This activity involves refinement of the developed constitutive relations from the previous activity and it will utilize all M_r results obtained from both IRC and CRREL laboratories. Discrete element modelling to incorporate the effect of material microstructure features on the resilient behaviour will support analyses of M_r results. This activity is planned to span a period of one year and will provide several interim material inputs to IRC analytical model to support the design of the remaining two sections at FERF. Inputs will also be utilized to further develop and tailor the use of the IRC model to the utility cut restoration problem.

Material Selection Guidelines Manual

This activity involves compilation of material information gathered during the laboratory investigation in a form of a manual that can be used as a basis for selection of suitable materials for utility cut restoration. The manual will contain specifications pertaining to acceptable physical and mechanical properties of materials that are considered appropriate for restoration purposes. Examples of such properties may include percent original material finer than 0.076μm, percent crushed material finer than 0.076μm after compaction at a specified field dry density and moisture content, Atterberg limits, CBR of material obtained at designated compaction and moisture content level, percent asphalt present in RAP material and so forth. It is planned that the developed material selection criteria be based on the results of M_r tests conducted at IRC and CRREL.

The Manual for Material Selection Guidelines constitutes the first deliverable of the project and is planned to be available one year from the starting date of the project.

Construction-Related Material Investigation

Details of the construction-related material investigation phase are given below.

QC/QA Measures

The use of QC tests is an effective tool to ensure that the completed construction work meets the specified design requirements. Assuring quality requires the identification of three elements:

- elements that affect quality,
- criteria or specification(s) to obtain the desired quality, and
- test(s) to quantify the obtained quality.

Within the framework of the project implementation plan, a QC measure is defined as a criterion (e.g. a material property; physical and/or mechanical, an output based on a specified lab and/or field test) that should be controlled during design and construction associated with restoration of a utility cut to produce a well defined performance. On the other hand, a QA test is a field test(s) that when carried out by the crew restoring the road cut, during construction, will ensure that the QC criterion specified is met.

This task involves the development of guidelines for QC measures to be used in the lab and the field to ensure proper restoration of utility cuts. Test results from the laboratory material investigation together with discrete element modelling will be used to evaluate the effectiveness of potential QC candidates in satisfying performance requirements.

Activities within the QC/QA activity include the following:

- ***Evaluate existing QC/QA measures***: This involves using the information gathered from the literature review and survey questionnaire tasks to identify available QC/QA measures (tests) that are currently used in utility cut restorations and the degree of success associated with their use as reported by the different agencies. The next step in the evaluation process will be to find out if any of the planned field experiments involves the use of the identified QC/QA measures. If this turn to be the case, then the research team will observe and document, during the field experiment in question, how the QC/QA measure is being used and the degree of success achieved with its use to control the quality of the completed construction work. .

- ***Establish Performance Requirements***: The rationale behind the use of any of the identified QC/QA measures from the previous activity will be examined here to ensure that the use of the particular QC/QA measure in question is adequate to provide the anticipated performance. This activity will also involve rigorous use of laboratory obtained M_r data and DEM to establish quantitative relationships of the investigated QC/QA measures with the M_r parameter. The output from this analysis will be QC – M_r relations that can be utilized to ensure optimum field performance of the restored cut.

- ***Develop, Test and Validate QC/QA System at FERF:*** The developed QC/QA guidelines and the QC – M_r relationships will be tested during the construction of the second and third sections of the FERF experiment to validate the ability of the system to produce the required construction quality. Additional tests and validation of this system will be carried out by a select group of participating municipalities/utilities in different regions in North America. These final tests will enable the research team to modify/upgrade the system as needed to produce the final version of the QC/QA system to be included in the project second deliverable, a Guide for Best Restoration Practices.

A schematic representation of the QC/QA measures task is shown in Figure 3.

FIGURE 2: Typical Resilient Moduli for a Cohesive Soil Material
(*Effect of Seasonal Variations*)

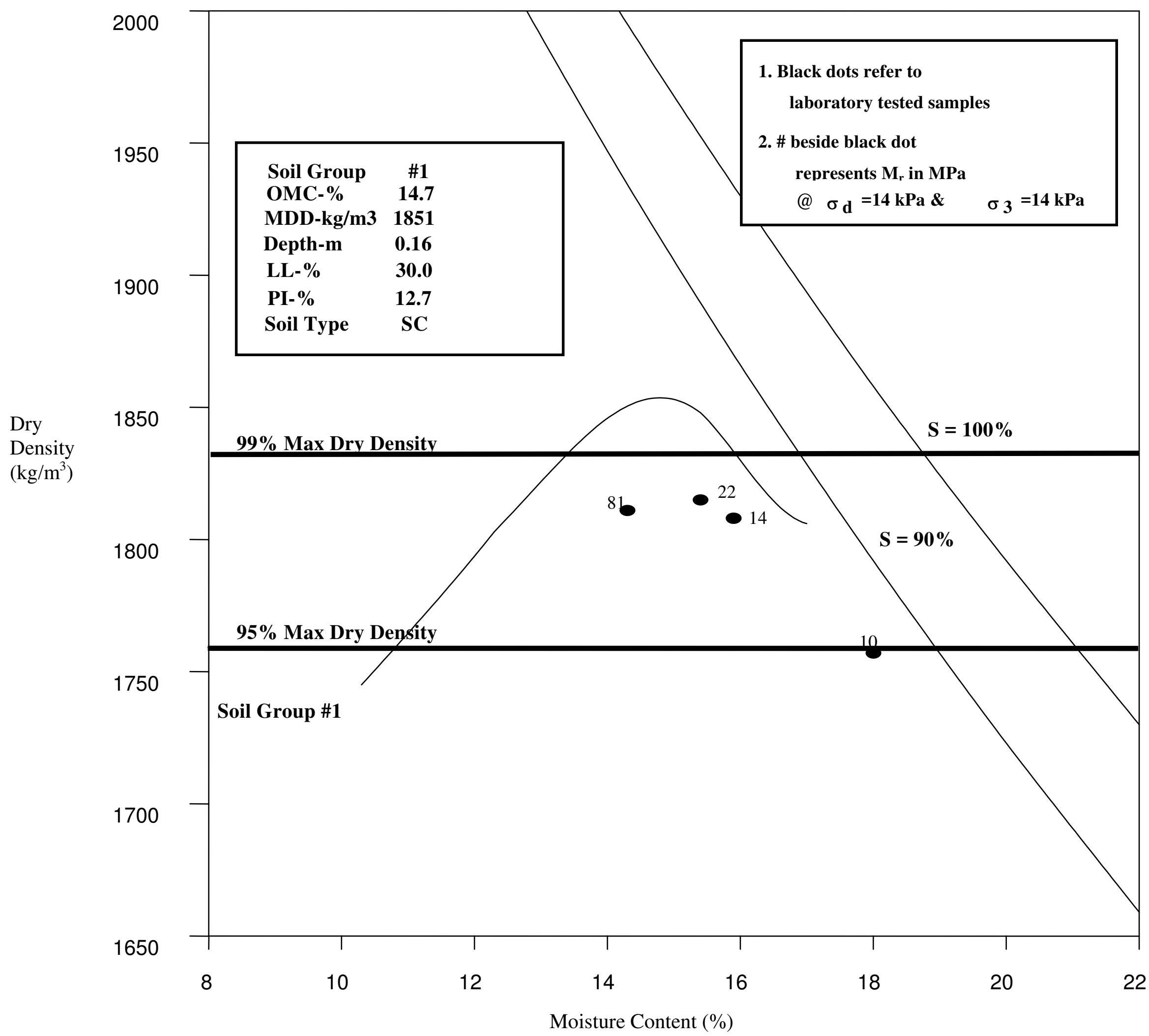
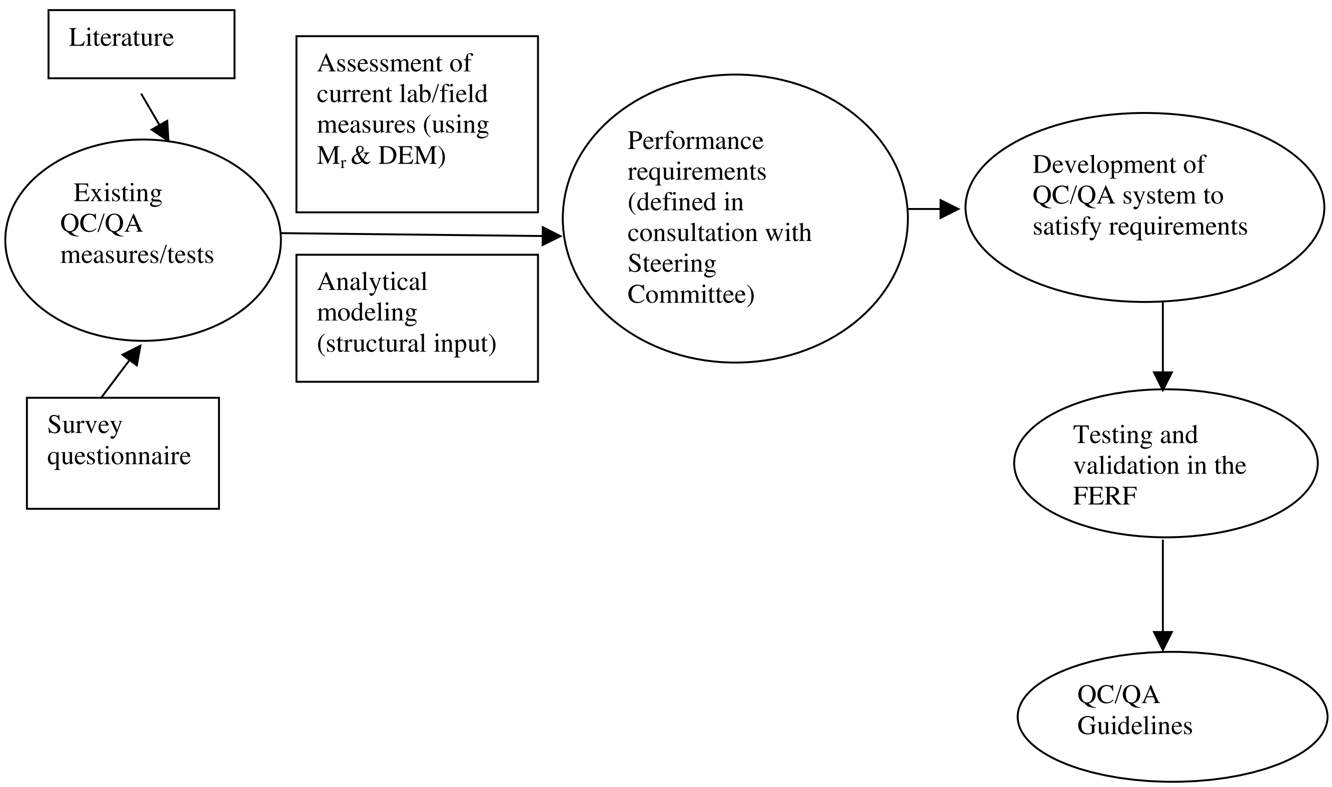


FIGURE 3: Schematic Representation of the QC/QA Task Activities



FIELD EXPERIMENTS

Task Manager: Ziad Geagea

The purpose of these field experiments is to investigate construction-related variables and evaluate the potential for using NDT techniques for designing utility cut reinstatements and predicting their performance. The field experiments will also serve in identifying and evaluating good practices that may benefit clients of the project in other locations. A number of sources of information collected through the literature search, survey questionnaire and other developed using tools (Analytical Model) available to the project, are being used to plan the field experiments. Complemented with instrumentation, valuable data related to the impact of the environment, traffic and construction quality on the performance of the restored cut structure may be collected, which will aid the research team in identifying the critical elements that influence performance. Other than satisfying the research needs outlined in the proposal, it is important to incorporate other factors that are motivating a number of the project clients to request field experimental sites beyond those included in the original initial estimate (5 sites).

The success of this task in satisfying the project objectives depends on the quality of planing and design of the field experiments and the effectiveness of its implementation.

Communication Plan

The fact that the research team at the site includes members from CRREL and IRC with involvement from city officials, utilities and a construction contractor, necessitates good co-ordination of all activities. The success of the instrumentation plans depends on the effective incorporation of its requirements in the construction plans. Early contacts with city officials and utilities, which will be maintained throughout the life of the experiment, will be used to secure city support to these experiments. Since the contractor is usually in charge of the construction site, it will be beneficial to establish a contact with the construction contractor. The Co-ordinator, with the support of CRREL (Mr Robert Eaton), will be pursuing with city officials, Utility Company representatives and possibly the contractor agent, the following activities:

- Request construction plans before the bidding process to incorporate research needs so that the contractor will accommodate the presence of IRC and CRREL personnel and instrumentation activities carried out by the research team at the construction site.
- Ensure that the instrumentation task and the time required to complete the job are incorporated in the contract.
- Ensure that the necessary tools, sensors and other supplies (survey equipment) are ready for all planned activities.
- Hire sub-contractors (possibly through the principal contractor) to conduct NDT tests and to recover undisturbed material samples before and after reinstatement.
- Confirm with city officials that a traffic control plan will be implemented at the construction site to accommodate the work schedule of the research team and provide for their safety. Ensure that the city would cover all the costs associated with traffic control.

- Implement changes on site in the reinstatement plan, if such a need arises, to enable the research team to install the sensors when faced with unpredicted circumstances (presence of pipes or other obstacles).
- Request a frost-free Benchmark at the site to use as a reference for establishing the location (depth) of sensors during construction and to monitor the performance of reinstated pavement (changes in road profile at the surface).
- Request a location (traffic lights box, a close by structure, a post, etc.) close to the construction site where the data acquisition system connected to the sensors may be secured.
- Provide a power line to the data acquisition system and a telephone line for data retrieval using a modem. Support from the city (providing and paying for the cost of the power and telephone lines) will be requested.
- Convince city officials to play a positive role in the experiment and support performance monitoring by conducting frequent damage survey using a format proposed by the project's research team.

It is important that the co-ordinator receive input and advice from all project members regarding the nature of the information that needs to be collected. The budget for this task is limited and any last changes or requests that may add cost may not be granted.

Planning the Field Experiments

Planning of the field experiments will require input from a number of sources and will be influenced by many factors:

- Input from CRREL related to instrumentation and laboratory testing of samples that will be collected from the field.
- Preliminary analysis (in progress) to capture critical locations where sensors may be placed.
- Incorporate research elements, identified through literature search and survey questionnaire, in the experimental plan.
- Further refinement of the analysis following model developments (tailoring the model structure to satisfy utility cut needs and incorporate relevant construction related variables such as the impact of joints), which will then be used to test the draft plan and introduce necessary changes. In order to assess the impact of discontinuities on the performance of the restored cut with the analytical model, it is desirable to obtain information of deformation patterns at the joint under actual field conditions, e.g., opening/closing of the joint and load transfer at the interface. Because of potential difficulties associated with obtaining such type of measurements in the field, an alternative will also be considered. The alternative plan will involve measuring moisture gradient at the interface to record changes occurring at the contact plane. Further investigation of this factor will be carried out by installing sensors across the construction joint in the accelerated loading tests at FERF.
- Site specifics learned through communications with cities (these are elements, such as different backfill types that may require unique types of sensors).

- Construction plans for each site prepared by utilities and/or cities. This will include nature of cut (deep vs. shallow), which will guide instrumentation planning.
- Results and experience gained from the first field experiment, which will be conducted in Ottawa Canada (April 2000).

The preliminary drawings (Figures 4 to 7) will be updated to expand the planning and design of the field experiments by incorporating details relevant to the various activities, for example:

- Locations for NDT tests to produce deflection basins that will capture the impact of the joint at the end of the cut and cover other locations known to deteriorate following the restoration process.
- Locations of accelerometers to measure the triaxial acceleration of the pavement due to traffic.
- Locations for collecting undisturbed (plan view) and disturbed samples (x-section) before and after the reinstatement. Further more, samples from outside the will be collected if cities approved. The extraction of undisturbed granular materials samples (6”) is desirable and the possibility of such activity will be verified with city officials.
- Locations of asphalt concrete samples from *before* and *after* reinstatement. Asphalt samples will be shipped to IRC laboratories.
- Route for extending cables connected to sensors,
- Protective measures around sensors (pipes, fine materials, enclosures, etc.)
- Construction specifications, to be added to the city/utility construction drawings, to accommodate placement of sensors.

Support for the tasks targeting the development of a material selection criteria based on improving the characterisation techniques, refinement of the analytical model and analytical modelling to be carried afterwards to explain the performance of the restored cuts, all require the results of tests conducted on samples recovered from the field. Undisturbed and undisturbed samples (71 mm (2.8”) & 152 mm (6”) dia.) will be collected and later used to perform Resilient Modulus tests. Disturbed samples will also be collected from the existing road structure and from materials intended for used as backfill for restoring the cut and later compacted (various levels of effort and moisture content) to establish relationships covering the variables considered in the investigation. Accordingly, material samples from all structural layers will be collected and shipped to CRREL laboratory to conduct the scheduled tests (some samples will be shipped to IRC laboratories). Effective sampling necessitates that the research team arrives at the site prepared with containers suitable for collecting samples satisfying the different purposes:

- Samples for sieve analysis (guard against loss of fines)
- Moisture (there is a plan to drive a mobile lab with an oven, balance, and other simple devices and equipped with a generator to supply necessary power).
- Steel tubes for extracting undisturbed samples in case the contractor does not provide such a service.

Documentation of Construction Activities

Although the intent is to closely follow the developed plans, as with construction everywhere, deviations from the plan is expected to occur influencing outcomes of the field experiment. Therefore, development of *as-built-plans* will be given adequate attention by the research team through close follow-up and documentation of construction activities. Another element of construction that requires attention is quality control. All tests conducted by the city/utility/contractor will be monitored and documented and the results acquired will be used to satisfy the task dedicated to the evaluation of current quality control measures. All effort will be made to encourage city/utility officials to engage in discussions regarding these practices and their opinion about the improvement that they anticipate from the project.

Instrumentation Plan

The proposal describes the field experiment as the task that will enable the research team to learn more about construction related variables. Accordingly, a wide array of sensors will be installed in the reinstated cuts to capture the influence of environmental and traffic loading effects. In addition, Non Destructive Testing (NDT) will be conducted prior to and after construction.

Instrumentation for Seasonal Parameters

The monitoring of seasonal variations, in the parameters described below, will help in establishing fundamental understanding of the magnitude and impact of these variations in the pavement response to external loading conditions.

The following table lists the seasonal parameters to be monitored and the sensors (proposed) to be used:

Temperature	**Thermocouple Probes**
Volumetric Water Content	CS615 Water Content Reflectometer probes
Frost Depth	CRREL Resistivity Probes
Frost Heave	Anchor, Coil Gauges, Surveying
Soil Suction	Tensiometers

For budgeting purposes, the current instrumentation plan was developed based on a 2.5m deep cut. Further, all sensors dedicated to capturing seasonal variables will be positioned along the inner wheel path.

Temperature:

Copper-Constantan (Type T) thermocouple probes will be used to determine the temperature profile of each layer and the entire pavement structure. Type T thermocouples have proven to be very successful for measuring temperatures in harsh environments with a moderate accuracy of $\pm 0.5^{o}C$.

Depending on the thickness of the asphalt layer, temperature will be measured at 3 or 4 different depths in the surface layer. Temperature will be measured every 100 mm in the other layers starting at 25 mm (1”) below the AC layer. An additional probe will be installed at a different location (at the centreline) as a control measure.

Volumetric Water Content:

Twelve Water Content Reflectometers CS615 will be used to record volumetric water content. The water content information is derived from the effect of changes in the dielectric constant on electromagnetic waves propagating along a wave guide. The reflectometers can be used with a Campbell Scientific CR10X (and a AM416 relay multiplexer). The measured period of wave propagation can be converted to volumetric water content using standard calibration values. Performance specifications are provided by Campbell Scientific.

Installation Procedure:

If the thickness of the top granular base layer is greater than 300 mm (12"), the first TDR probe (from top to bottom) will be installed 150 mm (6”) below the bottom of the lowest stabilized layer. Otherwise, the first probe will be placed at mid-depth of the top granular base layer. The next seven probes will be installed at 150 mm (6 inch) intervals. The two bottom TDR probes will be placed at 300 mm (12 inch) intervals.

Frost Depth:

The newly developed CRREL frost probe will be used to measure frost depth at the cut location in cold regions. The tubes replace their conventional probe, which provided less reliable results when used in granular materials. Further information about the CRREL frost tubes will be provided by CRREL in the final plan.

CRREL frost tubes are compatible with the datalogger used for the seasonal sensors (Campbell Scientific CR10X).

Soil Suction:

Negative pore-water pressure will be measured using tensiometers to establish a relationship between water contents and soil pore pressures in the subgrade. Two tensiometers will be installed at different locations in the subgrade layer, and two additional sensors will be placed in the backfill if a native soil is used.

Frost Heave

Frost heave will be measured using the results of coil gauges and field survey data which will be collected by collaborators (participating city or utility personnel) during the first winter season.

Structural Response Sensors

The following table lists the structural parameters to be measured and the sensors to be installed on the outer wheel path.

Parameter	Sensor	Range	Accuracy
Strain (AC)	Dynatest Past-II AC	Up to 1500µst	
Deflection	Slope Indicator Rod Extensometer	100 mm (4")	0.025% F.S.
	εmu coil gauges	150 mm (6")	0.635 mm (0.025")
Vertical acceleration	Kistler 8628B50?	Up to 1500µst	
Pressure	RST TP-101	50 - 250 psi	0.1% F.S.
	Kulite 0234	0 – 100 psi	

Strain:

Dynatest PAST II-AC strain gauges will be used for measuring strain in the asphalt concrete layer along the outer wheel path. The PAST II-AC strain gauge is an "H" shaped precision transducer specifically manufactured for strain measurements in AC. The gauges will be installed in longitudinal (3 per layer) and transverse (2 per layer) directions, and will be placed at the bottom of each AC layer. Depending on the AC thickness, there will be 2 to 3 layers of instrumentation. The maximum number of strain gauges installed will be 15gauges per field site.

Pressure:

Earth pressure cells will be used to determine the magnitude, distribution and direction of total stress within the reinstated cut. Pressure will be measured in the x-, y- and z-directions at the bottom of the base, and in the z- direction only, at the bottom of the sub base and the backfill layers. RST Instruments TP-101-S will be used to measure the vertical (z-direction) pressure distribution. As for the x-direction and y-direction, installing the RST cell will be difficult due to its large diameter (225). Therefore, Kulite (type 0234 – 50.8 mm dia) will be installed in the x- and y-directions.

Pressure cells will be installed following compaction of the layer under consideration. To measure the pressure at the bottom of the base for example, a circular hole roughly the same diameter as the pressure cell and sufficiently deep for placing the sensor at the required location, will be excavated in the sub base layer. The surface at the bottom of the excavation should be smooth. A thin layer of sand can be placed at the bottom of the prepared hole and compacted (with a tamper) to provide the smooth surface. The cell is then placed on top with its surface even with the surface of the base layer in this case. The cell is then covered with lightly tamped sand. The sand eliminates the stress concentration around the instruments. Before placing the next layer, the readings from the pressure cell are checked, as well as its location and serial number.

Deformation:

Soil deformation in the x-, y- and z- direction will be measured using CRREL εmu Strain Measurement system. The system is capable of recording dynamic and permanent (static) displacements based on the spacing between two adjacent coils.

The εmu system as used in CRREL facilities, consists of an electronic box containing a power supply, an oscillator, and the electronics to match the output signal from the coil pairs, as well as a multiplexer and a PC system.

For the purpose of evaluating an alternative, commercially available sensor, a parallel system will be installed at the first site (Ottawa). If the results prove to be satisfactory, the εmu system will be used throughout the rest of sites.

Coils will be placed at the bottom of each layer. When the layer thickness exceeds 150 mm, additional coils will be placed at a spacing of 150 mm.

Extensometers will be used the pilot study to be carried out in Ottawa. Rod extensometer monitors changes in the distance between one or more downhole anchors and a reference head. More information about the extensometer and its installation procedure are provided by the manufacturer.

Vertical Acceleration:

Piezo-accelerometers will be used to measure vertical acceleration of the pavement surface under the influence of moving traffic. It will also allow for the calculation of vertical deformation by double integration. IRC/CRREL are currently experimenting different models to determine the best that suit this project needs.

Construction Joints:

Further search is underway to find a sensor that will enable us to monitor the behaviour of construction joints between the reinstated cut and the road.

Design

The instrumentation plan will be customized to the features of each site, to effectively capture the effect of different parameters related to the environment, traffic, foundation materials and borrowed backfill materials. The initial plan was developed for a general case and will be tailored to each specific site later.

Sensors will be installed at the outer lane if the road consists of two lanes or more. The instruments for seasonal parameters will be installed at the inner wheel path while the instruments for the structural response will be installed at the outer wheel path. The backfill will be constructed in layers of approximately 150mm each to allow for the installation of the different sensors.

Due to the variety of transducer types, a flexible data logger will be used to accommodate requirements of different sensor types used in the study. Campbell Scientific CR10X, a battery-operated programmable device that operates over a wide temperature range, is proven to be a durable system. The CR10X is equipped with a 3 or 4 AM416 multiplexer to accommodate all of the sensors. The rate of sampling of the CR10X is ideal to monitor thermocouples, full bridge strain gauges, and water content reflectometers. As for monitoring stress and strain (εmu coil gauges), a faster datalogger is required to collect data for recording structural dynamic responses. The Campbell Scientific CR9000 is a fast, durable, battery-operated, stand-alone and programmable datalogger that operates over a wide temperature range. It can measure up to 100,000 samples per second and accommodate up to nine I/O modules.

Construction Plan

Before installation of instruments can be started, a monitoring program will be planned and instruments will be procured.

- Planning for installation of instruments will include preparation of detailed written installation procedures. The procedures must include a detailed listing of required materials and tools, and installation record sheets must be prepared for documenting factors that may influence the data.
- Installation plans will be coordinated with the construction contractor and arrangements made for access and for protection of installed instruments against potential damage.
- An installation schedule will be prepared, consistent with the construction schedule.
- The location of instruments will be shown on the contract plans, and the exact location of each sensor will be verified using surveying.

Depending on the distance between each sensor and the data logger, which varies with each site, the length of cables will be determined.

Non-Destructive Testing (NDT)

(This task will be managed by: Walaa Khogali)

The project proposal identified the potential for using non-destructive tests (NDT) as a tool for evaluating the structural adequacy of an existing pavement as a step that may precede design of utility cut restoration. One specific application of the NDT techniques that will be pursued is in-response to what seems to be contradicting conclusions in earlier studies conducted by cities and utilities. Studies conducted by utilities concluded that a well-designed and constructed restoration will perform effectively and will not affect road performance. On the other hand, Cities are convinced that a road cut will negatively influence road performance regardless of the measures followed in restoring the cut. These conflicting results may be attributed to varying conditions (native soil, road structure, construction practice, environment, etc) where these studies had been conducted in the past. Different results suggest that there are conditions, not accounted for in the design and construction of these restorations that may have influenced the response of the reinstated roads. The project will investigate the validity of the assumption that there are problematic sites with conditions where conventional restoration is not effective and will consider the use of NDT to identify these problematic locations to support the development of effective solution(s).

In lieu of the material investigation, the Falling Weight Deflectometer equipment will be used to collect deflection data during field experiments and in the FERF controlled experiment. This data will be used to backcalculate material layer moduli before and after restoration. Backcalculated moduli will be compared with laboratory determined resilient moduli to develop field relationships that can be utilized as QC criteria to aid in the selection of suitable materials with adequate mechanical strength and acceptable field performance. It is planned to use IRC model capabilities to streamline the backcalculation procedure to suit utility cut applications.

Other non-conventional uses of NDT technology may involve the development of equipment, test procedure, data analysis, etc. to arrive at the appropriate technique(s) that will satisfy the project objectives.

The following implementation plan describes the details of the different activities linked to the NDT investigation.

NDT Activities:

Activity I: Explore the potential of using Falling Weight Deflectometer (FWD) data to evaluate the structural integrity of an existing road prior to cutting.

Using results and inputs from the material characterization, the field experiments and the analytical model components, a limiting criterion or a set thereof, quantifying the structural adequacy of the road structure will be set. This criterion will be used as a check prior to cutting to make sure that the original road structure is in good condition to permit the process of cutting and restoring a buried utility. This task will include the following activities:

- Develop a FWD test plan to be part of the field experiments. This plan will involve the selection of appropriate test locations and the placement of FWD sensors at desirable intervals.
- Obtain complete construction records and historical road performance data for the field experiment in question.
- Conduct FWD tests prior to cutting the road.
- Use the analytical model to analyze the road structure under simulated FWD loading conditions.
- Compare the results from analytical simulations with field FWD data collected from all field experiments and proceed to develop the targeted criterion.

Activity II: Use the results of NDT to predict the impact of excavation and restoration of utility cuts on the performance of roads

This task will involve the use of NDT techniques to quantify the effect of cutting and restoring a utility within the road structure. Tests will be conducted prior to cutting and after reinstatement. Data collected will then be used to develop a field criterion that quantifies damage induced in the original road structure. The field criterion may be a structural response or a material property. One such structural response criterion to be considered would be the deflection bowl while a material property might be the resilient modulus of constituent material(s) backcalculated from measured deflections. Results from this task will provide a means to:

- Identify problematic locations where road cuts can initiate/accelerate the deterioration of the road structure
- Conduct life cycle cost analysis that can be used as a tool for developing performance-based specifications for utility cut reinstatement.

This task will include the following activities:

- Make use of NDT tests results conducted prior to cutting and immediately after restoration as part of the activities of the field experiments.
- Conduct further NDT tests at predetermined regular intervals to span summer, spring and fall seasons following the reinstatement of the cut, within the field experiments, for a period of one year (this is intended to measure any deterioration in the road/cut structure due to seasonal variations.) With support from cities, these tests may be extended for a period of one more year following the first year.
- Modify the analytical model to include a module for backcalculating resilient moduli of constituent road/cut materials from measured deflection bowls.
- Backcalculate layer moduli for all materials used in the field experiments and compare values of the parameter before cutting and after restoration (results will be used to quantify the impact of the reinstatement.)
- Use the compiled results from this investigation in conjunction with other inputs from the analytical model, material characterization, field experiments and the FERF experiment to develop performance-based specifications for utility cut restoration.

FIGURE 4: Plan View

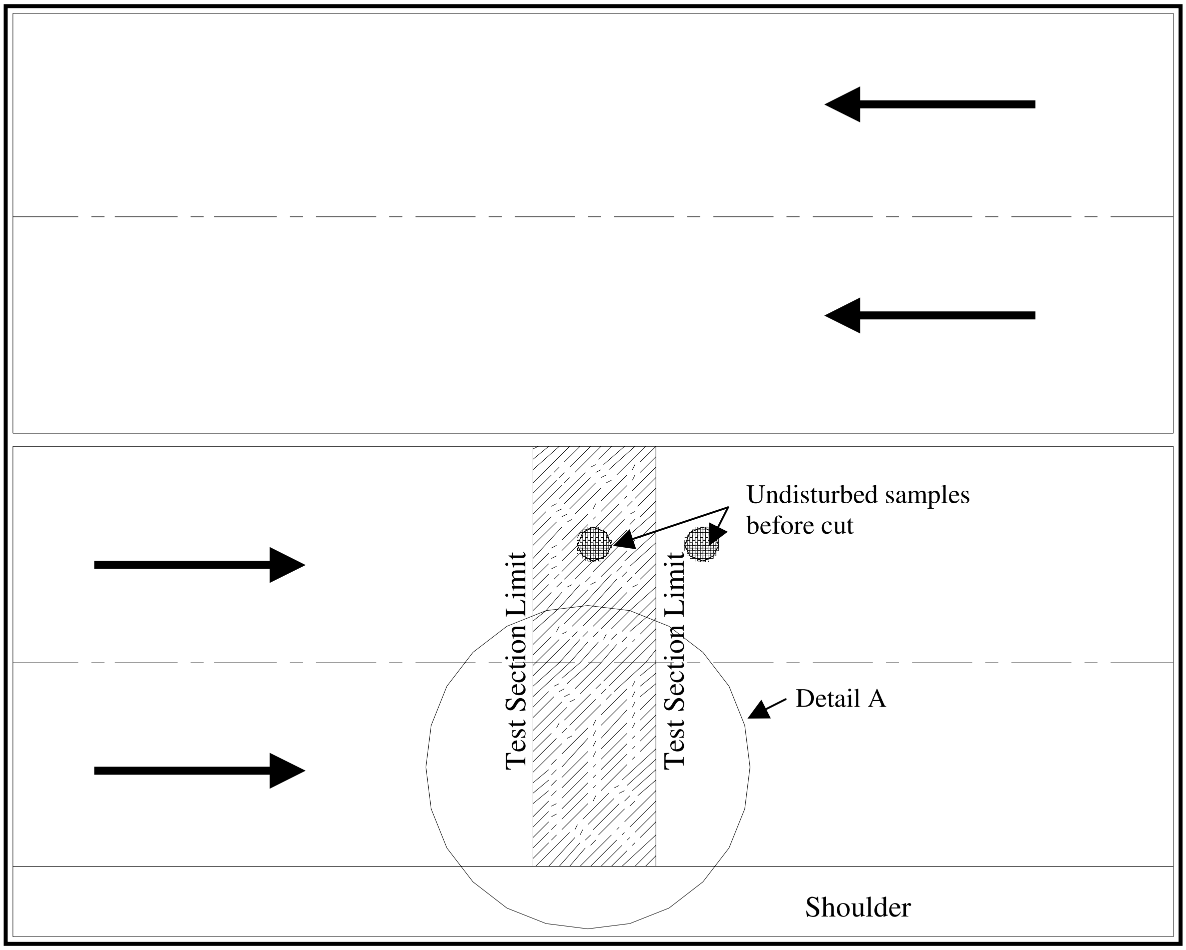


FIGURE 5: Detail A

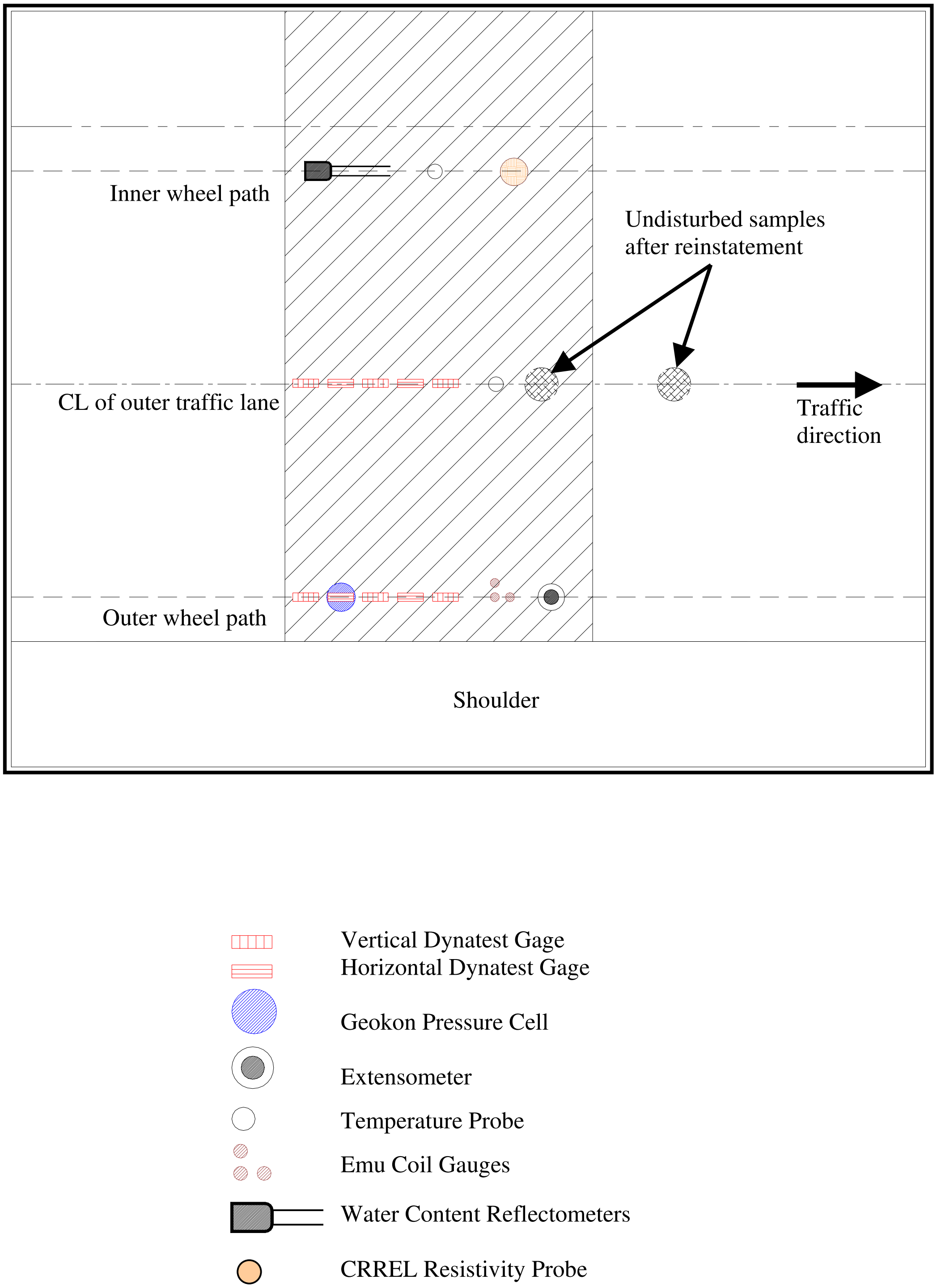
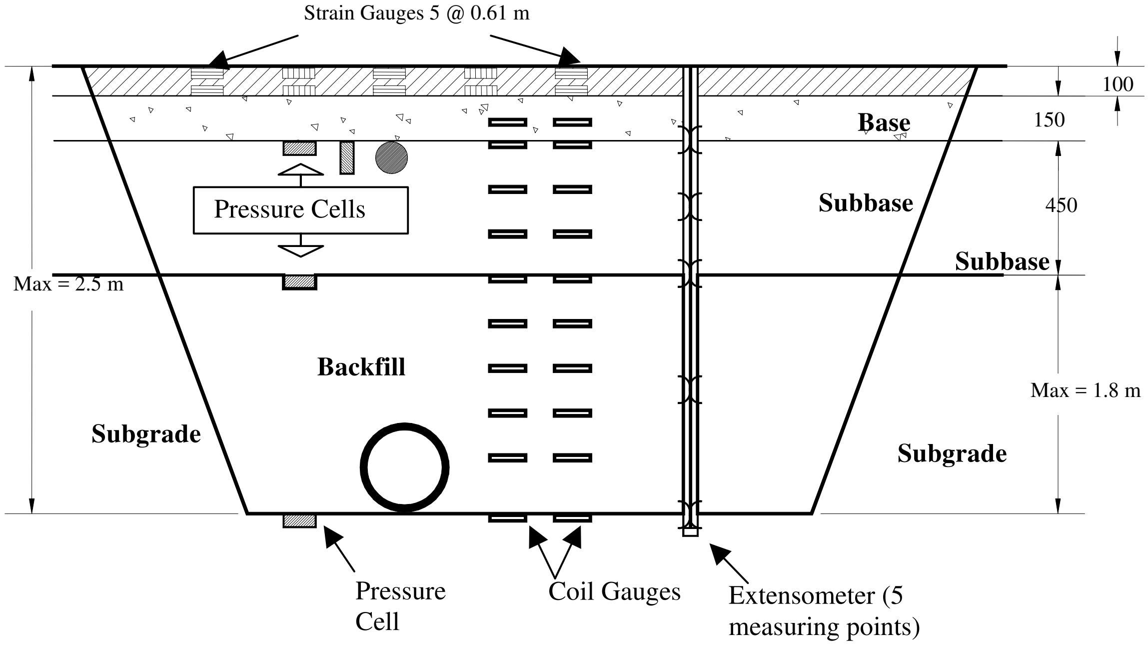


FIGURE 6: Structural Response
A: Profile View



B: Samples Locations

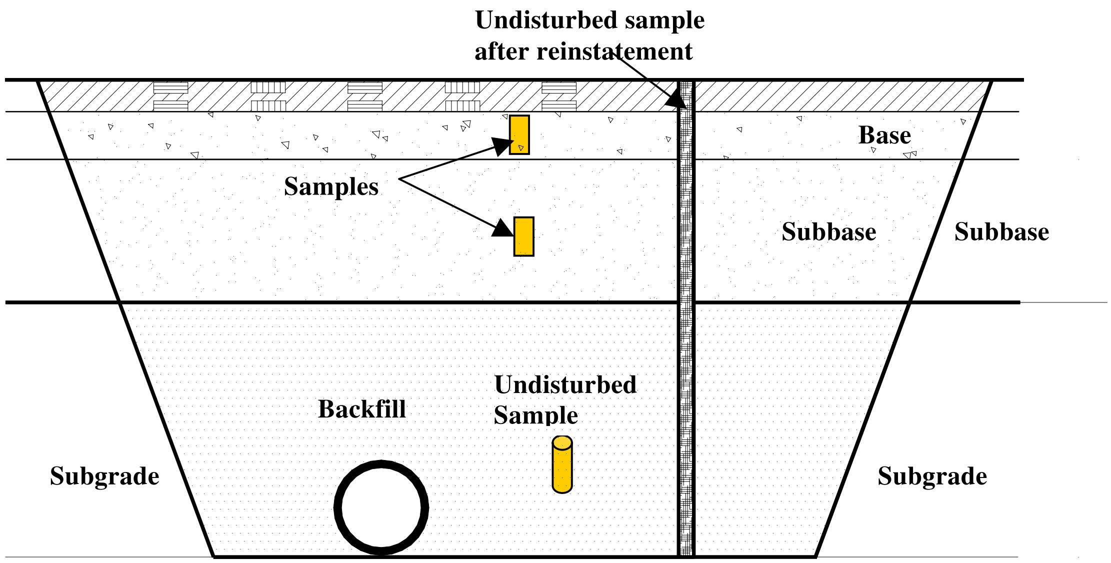
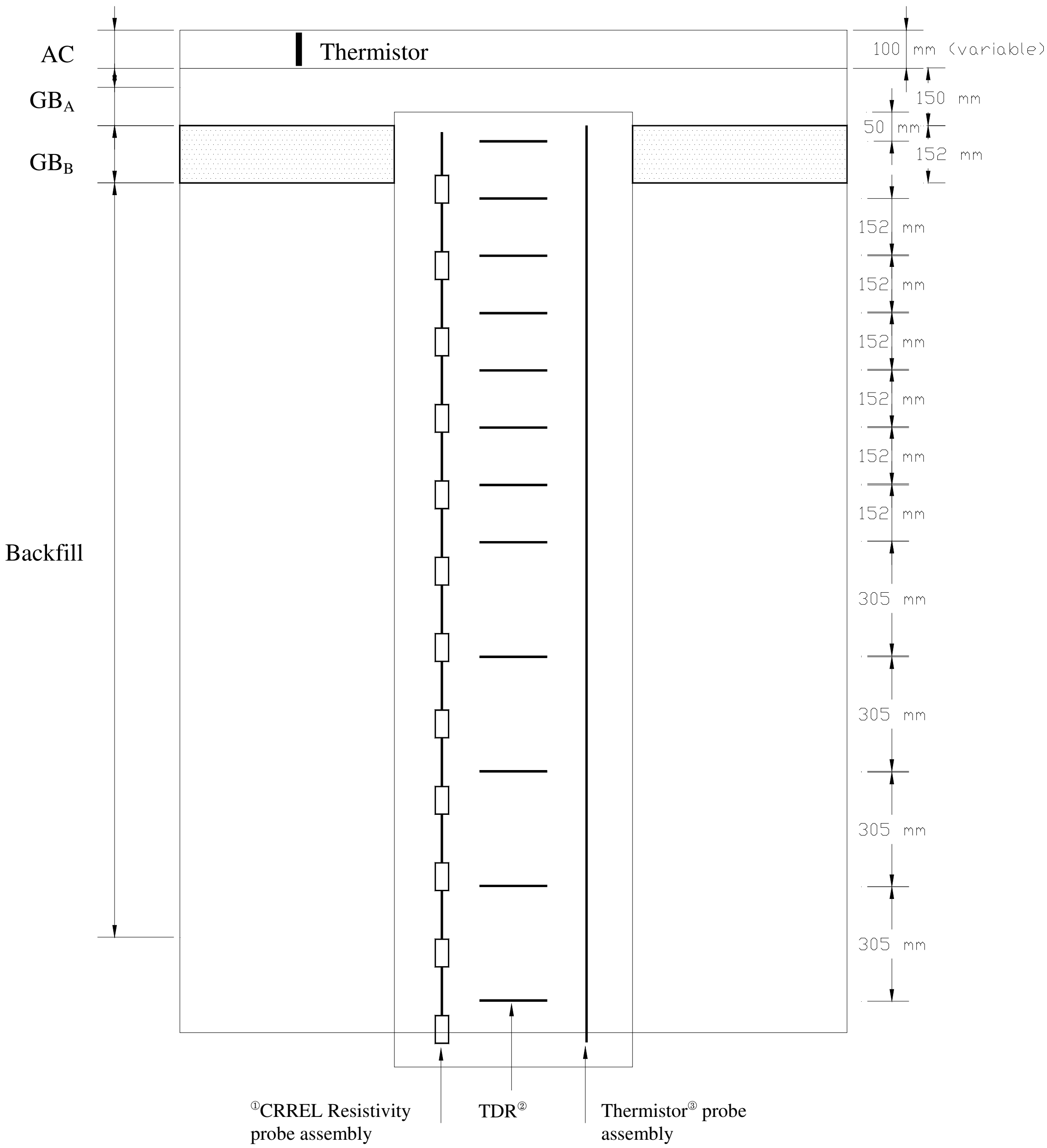


FIGURE 7: Seasonal Variations Instrumentation

Profile View



① 45 metal rings, spaced 51 mm & mounted on a solid PVC rod (~2.3m)

② 12 TDR spread @ 150 mm (or 300 mm) through GB and SG

③ 3-4 thermocouples per surface layer & 15-20 thermocouples through GB & SG (encased in 2.3 m PVC rod)

ACCELERATED LOAD TESTS

Task Managers: Vincent Janoo and Robert Eaton

Experimental sections with different road structures, cut geometry (width/depth/shape), backfill materials and construction specifications will be built and evaluated in the accelerated loading facility located at CRREL. The design of full-scale test sections will be based on preliminary findings obtained from the literature, initial results of structural analysis and other information from a selected number of field experiments conducted across North America. The test sections at CRREL will be constructed under controlled conditions to examine a number of variables known to influence the performance of reinstated utility cuts. Investigated variables will include a spectrum of structural, geometric, material and construction parameters. Major activities conducted at the FERF include:

- Construction of 3 experimental sections to fit space available within the FERF (Layout Plan shown in Figure 8). Each experimental section will be 30 m long and 6 m wide. A typical section will span the length of 4 cells, each cell being 7.5 m long. One section will be built using 4 m deep cells. In each section, typical layout shown in Figure 9, the length of one Cell (7.5 m) will be kept intact for control purposes and the rest to conduct road cut and restoration exercises.
- Material and structural details to be adopted will be prepared jointly by IRC and CRREL to cover typical construction material, road construction practices and prevailing North American subgrade soil types.
- Instrumentation of these sections, which will be discussed jointly by CRREL and IRC, is intended to be similar to that designed for implementation in the field experiments. Sensors for the field experiments are discussed in this document. Different functions and purposes are discussed throughout the implementation plans. Some of the intended uses of sensors are non-conventional and require in-depth investigation.
- Environmental conditions (moisture and temperature) simulating seasonal variations and regional differences will be controlled during the experiments. The specific categories will be determined after reviewing the final list of clients.
- Pre-cut conditioning, which involves operating the HVS on top of the experimental sections, to simulate service life before road excavation associated with utility cuts. Different loading levels will be implemented to study the impact road use history has on the performance of restored cuts.
- Cuts will then be made, using different techniques, across the built sections at predetermined locations and under specific conditions (to be determined after information gathering and parametric analysis). After laying the utility pipes within these excavations, cuts will be restored using the selected materials, reinstatement techniques, quality control and quality assurance procedures.
- Accelerated loading will then be resumed to the prescribed number of cycles, and a number of distress types will be monitored and recorded for analysis. Moisture and temperature conditions within the experimental sections will be controlled at pre-set

values selected to represent those prevailing in different climatic regions of North America. Recorded accumulated damage, complemented with sensor readings, will be used to evaluate the performance of the restored cut as influenced by pavement/cut design, material type, cutting procedure, restoration technique and external loading conditions (traffic and environmental). The evaluated techniques will include some representing currently used practices as well as other developed during this project.

- Performance determined in the accelerated loading facility will be compared with that predicted by the analytical model to validate the model. The validated model will then be used to expand the analysis beyond the ranges of the variables studied during accelerated loading tests.
- All materials, including that representative of native soils will be characterized using a resilient modulus test procedure, which will be discussed jointly by IRC and CRREL. The test will benefit from existing test equipment, but may follow a non-conventional test procedure (details discussed in the Material Characterization Task). Other conventional laboratory and field tests will be conducted to support activities dedicated to the evaluation of current practices related to design and quality control.
- Non destructive testing (NDT), using the CRREL FWD, will be conducted on the test sections. A separate activity dealing with the task of tailoring this testing technique to the requirements of utility cut restoration (assessment and design) is discussed in this document. CRREL will be provided with the proposed modifications to conventional NDT testing techniques to be implemented in conducting a series of tests aimed at determining the impact of various cuts and restoration techniques.

Since the outcome of accelerated loading will be required as input to many research components, the format of the collected data and observations made during the various experiments should be determined in advance to fully benefit from this important task. Members of the research team will meet regularly to discuss specific items and to develop components of the test regime after being familiarized with limitations associated with equipment capabilities, funding levels and available time.

Test Section Overview

The purpose of the full-scale accelerated testing in the FERF is to validate the model developed by IRC. These test sections will be designed based on the other components of the investigation: the information received from the survey and literature review, the results of the field test sites, the laboratory investigation and the structural analysis accomplished through the model. Test parameters will be determined following the review of current practices and after proposed solutions are developed, which will help in answering the following questions related to the details of the accelerated loading investigation.

- Where will the sections be located?
- What will the sections look like?
- What are the subgrade soil types?
- What are the base course materials?
- What laboratory analyses will be done on the soils?

- How will the section be built?
- What/whose QC/QA measures are used?
- What types and where will the instrumentation be located?
- How will the instrumentation be wired and the responses monitored?
- What level of pre-conditioning will be done?
- What type of utility cuts will be made?
- What types of backfill materials will be used?
- What type of data will be transferred to IRC?

The 30 m by 6 m test section will be constructed in the FERF, using 4 continuous test cells. In order to accommodate the necessary depth of a utility cut trench, the test sections will have a maximum depth of 8 feet (Figure 8). A total of 3 test sections consisting of 3 different subgrade soils (one subgrade soil per 30m by 7m test section) are tentatively planned for this project. There will be four test cells within the full test section. One cell will be designated as a control cell, thereby allowing three cells to be used for utility cuts and restoration (Figure 9).

Should full funding not be achieved, the accelerated load test portion of this study will be re-designed to match available funding levels. Additionally, this test plan has been created based on currently available and existing pavement in FERF. The project schedule and budget do not include the cost of special construction techniques, construction equipment or quality control measures. If such special measures are necessary, the steering committee will be approached to request cost adjustment to accommodate such needs.

The pavement structure will consist of a 4-layer system, with a minimum 60 inches of subgrade material, 12 inches of sub base material, 12 inches of base course material, covered by 4 inches of asphalt concrete surface. The original test sections will not contain any utility equipment. The installation of utility equipment has specifically been reserved for the installation portion of the study.

The test basins consist of a concrete floor, which is no less than 12 inches thick and variable thickness concrete side walls, which are tapered to handle the effects of frost heaving (Figure 10). At the end of the test basin is a ramp allowing for access of full-sized equipment for test section construction (Figure 11). The ramp area is filled with identical test section cross section materials to the same level for the movement and placement of the accelerated load cart, or other equipment needed during testing. Adjacent to the test sections is a mobilization aisle where data acquisition systems which will be set up for data collection and monitoring.

Material Characterization

The pavement structure will consist of a flexible multi-layer system, consisting of a subgrade, base course and asphalt concrete. The soils recommended in this section are readily available at the FERF. Extensive laboratory testing has previously been conducted to characterize these materials. The following AASHTO standard laboratory tests were conducted to characterize the material (ref: subgrade study report). Other test, based on findings of the material characterization tasks, will be conducted on the all construction material used to build the three road structure and to reinstate utility cuts.

- Particle Size Analysis of Soils (T 88-90)
- Determining the Liquid Limit of Soils (T 89-90)
- Determining the Plastic Limit and Plasticity Index of Soils (T 90-87)
- Specific Gravity of Soils (T 100-90)
- Laboratory Determination of Moisture Content of Soils (T 265-86)
- The Moisture-Density Relations of Soils Using a 5.5 lb (2.5 kg) Rammer and a 12 in (305 mm) Drop (T 99-90)

Subgrade Soil

The material in the subgrade layer will be a fine-grained material, or a lean clay classified as ***CL*** under the unified soil classification system, or the A-4 category designation from AASHTO. This soil is predominant in the Northern Tier states. This soil *(describe a bit about the soil)*. Figure 12 shows the grain size distribution and Figure 13 shows the standard proctor results for the A-4 soil.

Sub-base Course Soil

The sub base course material: to be determined.

Same laboratory testing as the subgrade soil?

Base Course Material

The base course material: to be determined.

Same laboratory testing as the subgrade soil?

Asphalt Concrete

The asphalt concrete mix will follow State of New Hampshire specifications

Test Section Construction

CRREL personnel, who have extensive construction experience, will supervise all test sections constructed in the FERF. An outside agency will be used to pave the section with asphalt concrete. Subgrade soil will be placed in 6 inch lifts and compacted to a density of 95%. The optimum moisture content will be used for the subgrade soil. The base course material will be placed and compacted to a specific density of, which will be determined after reviewing common practices across North America.

Quality control and quality assurance tests will be conducted at the end of the placement of each lift of soil. Testing procedures will involve monitoring layer thickness, location of instrumentation, moisture, density, and material strength. The following list of tests accompanied by a brief description will be utilized for quality control:

Rod and level surveys

Commonly employed in road construction practices, this equipment will be used to determine the thickness of each lift, placement and location of instrumentation.

Soil density testing

The Troxler RoadReader™ Plus Nuclear Density Gauge, Model 3450 CE will be used to verify compaction control requirements.

Sand cone tests

In accordance with ASTM standards, sand cone tests will be performed in all experimental sections constructed in the FERF facility.

Dynamic cone penetrometer

The dual mass dynamic cone penetrometer (DCP) will be used to measure soil strength during construction. The values obtained from the DCP will then be used to determine the California Bearing Ratio (CBR) of the soil. This step will provide uniform soil strength while the lifts are being placed. Operation of the DCP and analysis of the data will be accomplished in accordance with Instruction Report GL-92-3 (Webster, et. al, 1992).

Clegg hammer

A companion test to the DCP is the Clegg impact soil tester. This non-destructive measuring device measures the compressive strength of soils. Advantages of using this testing device include ease of use, minimal cost and portability. The main elements of the device are a 10-lb compaction hammer within a guide tube, which is then connected to an electronic meter. Attached to the hammer is an accelerometer that is dropped four times. An electronic readout gives the average of the four drops (Okamoto and Nussbaum, *find the year*). Testing will be done in accordance with ASTM D 5874-95, *Standard Test Method for Determination of the Impact Value (IV) of a Soil.*

Instrumentation

Subsurface measurements of temperature, soil moisture, permanent deformation, stress and strain will be done using various instrumentation. Placement of the gages within the test section will be done upon completion of construction of that particular layer. In other words, the sensors are placed in each subgade layer after it has been placed. The same will be done with all instrumentation in the base layer. This minimizes the possibility of damage to the sensors during placement, as well as movement of the sensors prior to testing.

The location of instrumentation in the FERF test section will be similar to that used in the instrumented field experiments in order to isolate the variables for further study. The reader is referred to the "Field Experiments" section of this report for more detail on the proposed instrumentation.

Pre-cut Conditioning

Initial trafficking of the test section, using the Heavy Vehicle Simulator, will be done prior to the utility cut installation and reinstatement. This is to simulate an actual situation where a roadway undergoing a utility installation will have already experienced traffic loading. It is estimated that 1,000 uni-directional passes will provide the necessary conditioning level. A load level of 9,000 lbs. and maximum tire pressure of 100 psi will be used. Wheel wander within the traffic lane will be programmed to better simulate what actually occurs in an urban setting.

Environmental Conditions

Testing up to the pre-cut conditioning will be done holding the ambient air temperature inside the FERF between 60 to 85 degrees Fahrenheit. To simulate seasonal variations found in North America, surface freezing panels will be placed on one test cell (25 feet by 21 feet) at the conclusion of the pre-conditioning, to freeze that one test cell. The maximum depth of freeze will be up to 4 feet at a freeze rate of approximately 1 inch per day. It is estimated that approximately 2 months will be required to freeze the test section.

Utility Cut Simulation and Restoration

A total of 5 utility installations will be carried out in the test section. Three installations will be done in the unfrozen cells and two in the frozen cell. One cell will remain as a control. The research team will determine details on the type and depth of utility installation, as well as the quality control measures to use after consultation with the Project Steering Committee. It is currently planned that the utility installation and restoration will be completed using an outside agency.

Non-destructive Testing

Non-destructive testing will be used for quality control purposes during the construction of the test section, after the installation and restoration of the utility cuts, and at various increments of loading.

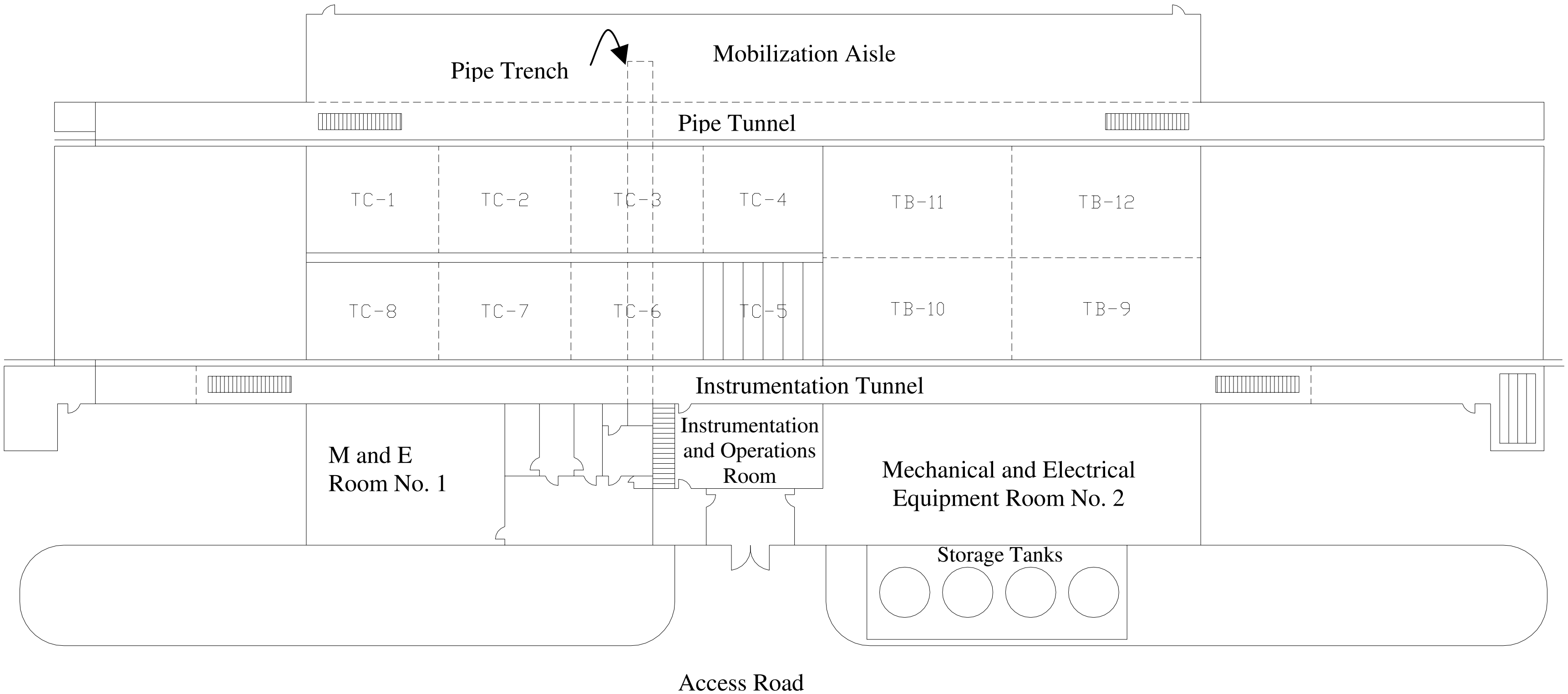


Figure 8: Plan View of Frost Effects Research Facility (FERF)

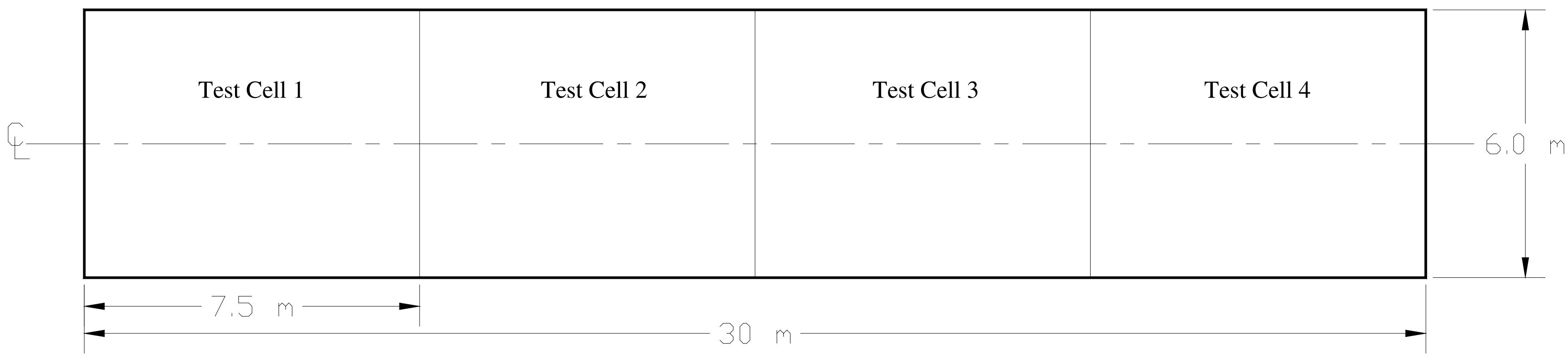


Figure 9: Typical Plan View for an Experimental Section

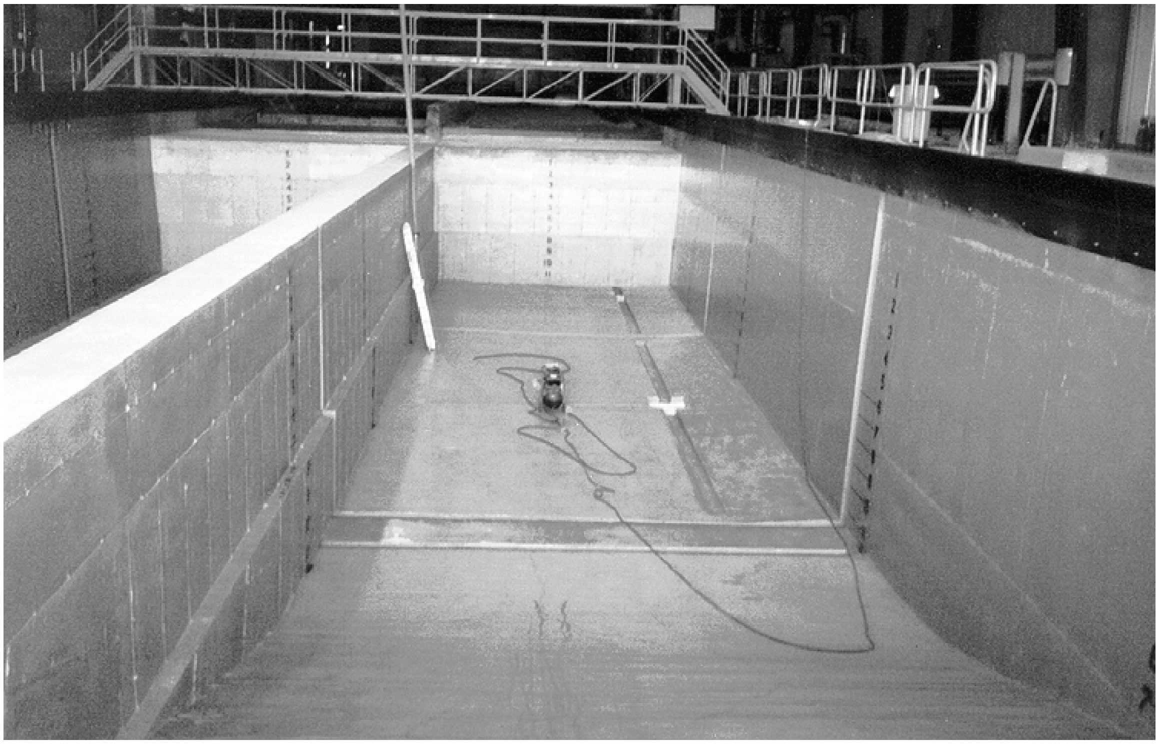


FIGURE 10: An Illustration of an Actual FERF Test Basin Prior to Construction.

FIGURE 11: Typical Full-size Construction Equipment for Test Section Construction.

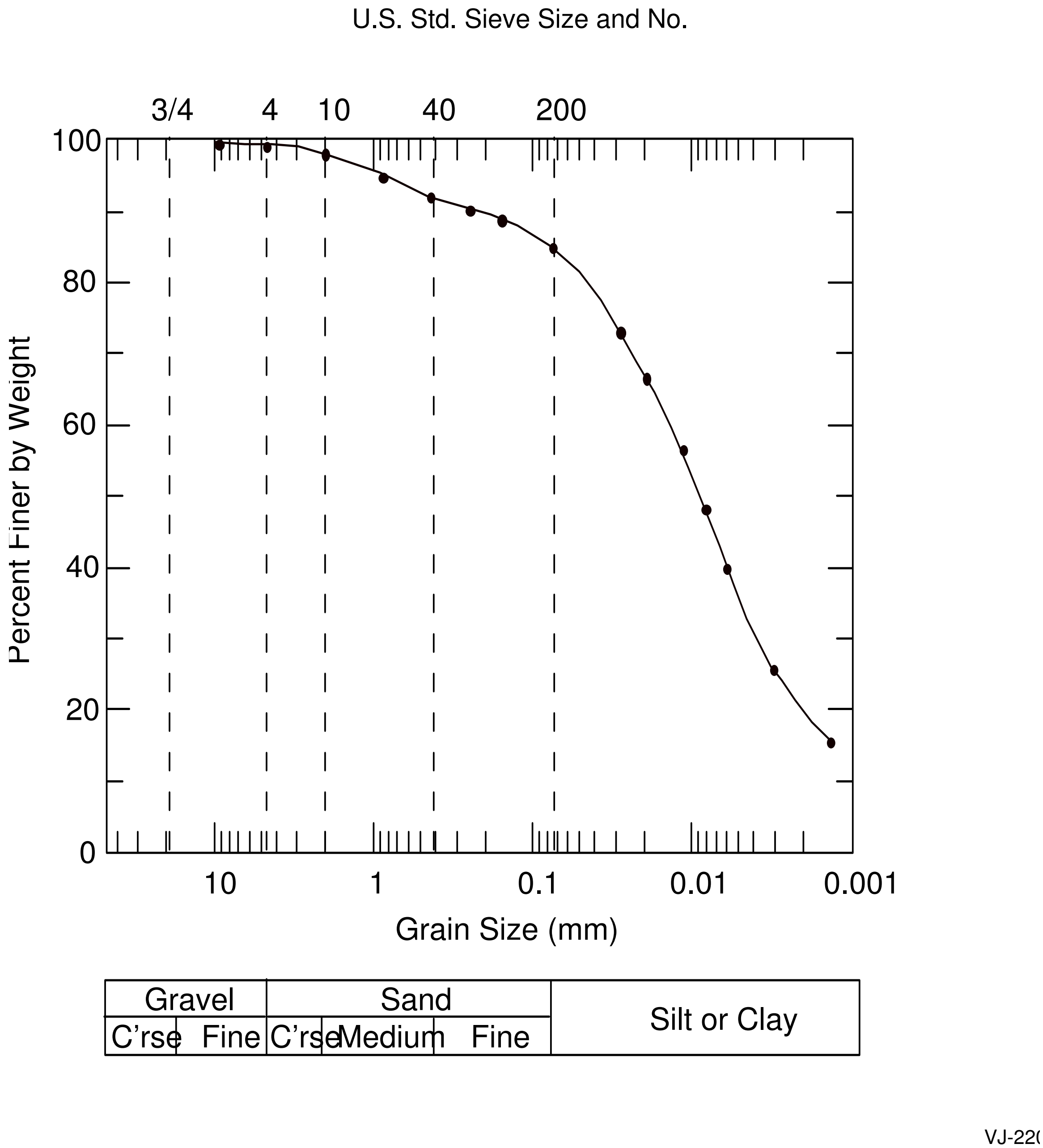


FIGURE 12: Grain Size Distribution for A-4 Soil.

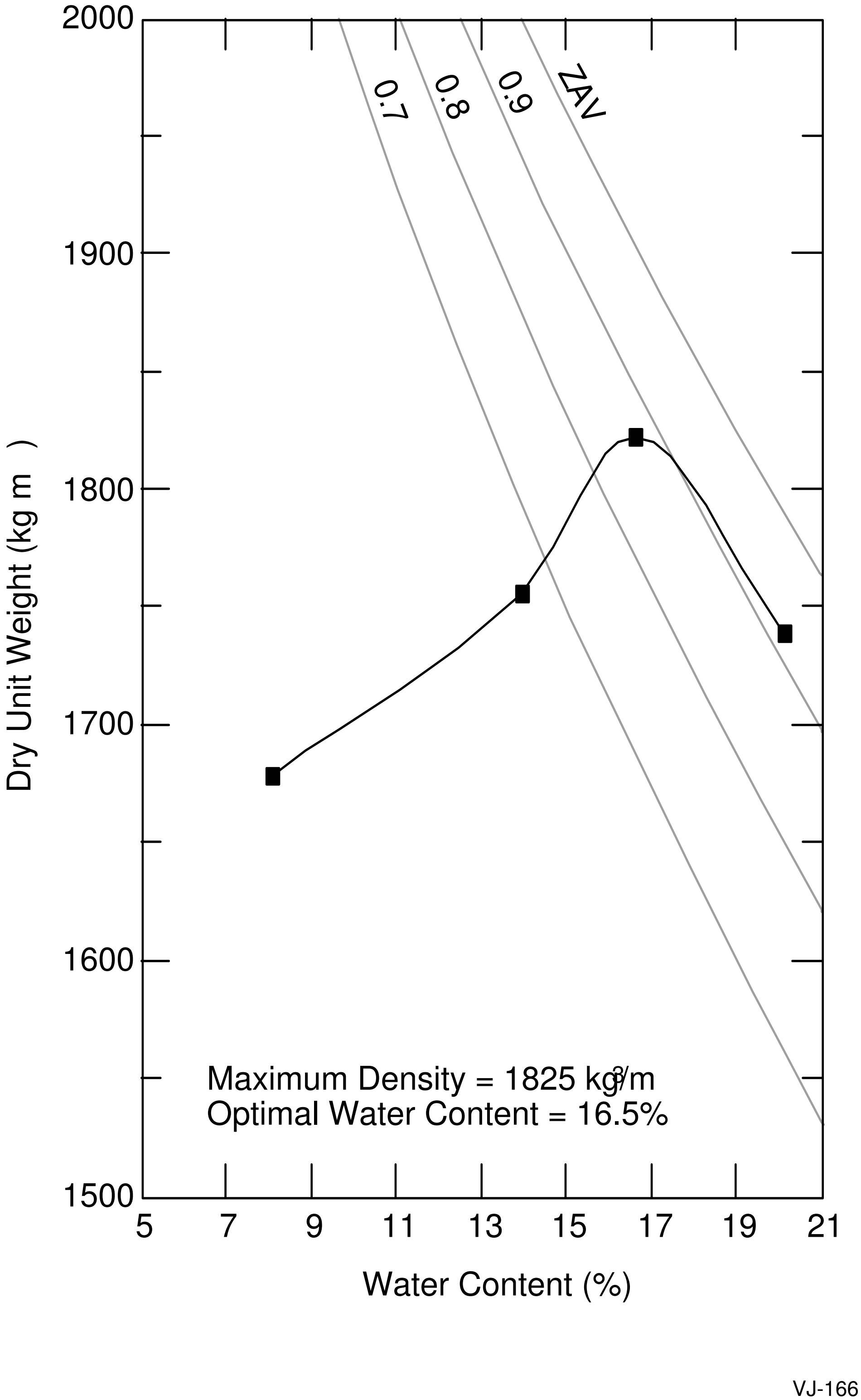


FIGURE 13: Results of Standard Proctor Test for A-4 Soil.

PROJECT MANAGEMENT

The project management scheme adopted in the project, details included in the proposal document, is a practical choice for a project with a large number of partners with opposing views regarding the causes of the problem and the format of the effective solution. The format proposed by the research team involves a flexible approach based on engineering the solution to satisfy local conditions, which include the nature of native soil, construction materials (used in road sub-base, base and asphalt concrete surface), environmental and traffic conditions, technical expertise, preferred management style and the prevailing bylaws. Accordingly, there are many ways in which the solutions may be engineered to produce an effective utility cut restoration practice. Therefore, it is critical that task leaders participate in the discussions that will take place during the steering committee meetings to capture the perspectives and concerns of the members. Follow-up meetings involving the research team should then analyze the outcome of discussion and agree on the best action plan to address points raised by clients. These semiannual meetings will be announced in advance and members should make all possible effort to attend.

A pilot IRC project management system (PMS), a component of SEGMA, will be employed to maintain close follow-up of progress made in various tasks using the schedule shown below in Figure 14. Detailed schedules for individual tasks will be included as sub modules in the PMS and task leaders may use them to inter data directly from their terminals. These task-related schedules are directly connected to the project schedule. Early notice about any potential delays or practical difficulties in completing an activity will enable the research team to jointly and timely resolve such issues. Completing time sheets, which the PMS translates into expenditure, is critical for maintaining control over the project budget. Potential deviation from the current procurement plan (mainly sensors for field experiments) as a result of changes in the construction plan or input from clients, should be discussed with the project manager prior to initiation of procurement actions.

Research team meetings will take place weekly at IRC and biweekly conference calls (telephone) for meetings with CRREL. Team members should benefit from these meetings to inform each other of research progress and upcoming events and to become informed about achievements in other tasks. E-mail messages should be used as a second means for communicating with other members of the team and to deliver messages related to required actions. MS Outlook system may be used to invite members for unscheduled meetings in the event that such a meeting is needed.

FIGURE 13: Time Schedule for Utility Cuts Consortium Project

Task Name	Duration
UTILITY CUTS CONSORTIUM	784d
1 Launching date of the project	0d
2 Literature Review	140d
3 Report for the steering committee (OUT 1)	0d
4 Survey Questionnaire	140d
5 State of the Art Report (OUT 2)	25d
6 Material Factorial Experiment	45d
7 Mr Tests @ IRC and Data Analysis	189d
8 Guidelines for Material Selection (D 1)	0d
9 Mr Tests @ CRREL and Data Analysis	265d
10 QC/QA Measures (OUT 3)	310d
11 Parametric Analysis (IRC Analytical Model	315d
12 Data Acquisition System	190d
13 Field Experiments (Coordin., design/cnst.)	230d
13.1 Field experiment 1 (Ottawa)	60d
13.2 Field experiment 2	60d
13.3 Field experiment 3	60d
13.4 Field experiment 4	60d
13.5 Field experiment 5	60d
14 Field data reduction and analysis	440d
15 Manual of Best Restoration Practice (D 2)	260d
16 Design of FERF experiments	148d
17 FERF Experiment Phase I	100d
18 FERF Experiment Phase II	100d
19 Model development and Refinement	470d
20 FERF data reduction and analysis	295d
21 Performance prediction	455d
22 Submission of program for evaluation	0d
23 Program evaluation by clients	125d
24 Implement clients' input	65d
25 Submission of final deliverables (D3 & 4)	0d