NDOT Research Report

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Evaluation of Rehabilitation Techniques for Flexible Pavements in Nevada

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NEVADA
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INTRODUCTION

For the past twenty years, state highway agencies (SHA) in the United States have been very busy maintaining and rehabilitating the current pavement network. The construction of brand new pavement represents a very small percentage of the pavement construction activities. Rehabilitating and maintaining an existing pavement is more complicated than designing and constructing a new pavement. In selecting a maintenance or a rehabilitation activity for a specific pavement section, the engineer must deal with the existing pavement while preparing an effective design which could optimize the benefits for both the owner agency and the road users.

Taking into consideration the existing pavement is not an easy task. Most pavements that are selected for rehabilitation would be experiencing a combination of distresses with various severity levels. In order for the design engineer to prepare a good design, he must identify the sources of these distresses and couple them with the appropriate repair strategy. The most common sources of pavement distresses are: traffic, materials, and environmental. Some pavements fail because they have served their intended service life while others fail because of severe climatic conditions which were not accounted for during the design stage. On the other hand other pavements may fail because of materials problems. Materials problem can be generated by either the selection of the wrong type of materials during the design stage or the delivery of substandard materials during the construction stage.

Any one individual or combinations of the above identified factors could lead to the cracking, rutting, raveling, bleeding, etc... distresses of flexible pavements. The job of the design engineer is to assess the degree of deterioration, evaluate the in situ conditions of the pavement, and recommend a rehabilitation alternative which can provide a good level of service for the anticipated design period. In an ideal situation, the design engineer will conduct all the necessary evaluations and prepare the final design recommendations. In reality, however, the engineer must also deal with budget constraints and the availability of materials. Under such circumstances the recycling of existing pavements prove to offer an effective alternative which has the potential of reducing the cost and waste generation of pavement rehabilitation. Recycling of the existing pavement offers an attractive approach for effectively dealing with the distressed pavement surface. A severely cracked pavement presents a challenge for the design engineer due to its potential of reflecting the cracks through the new overlay. Recycling of the existing surface, would delay the problem of reflective cracking in the meantime providing a strong base. Therefore, the combination of reduced reflective cracking potential and a strong base would result in the requirement of a thinner overlay.

The pavement engineering community's inclination to recycling started in 1975 where it was largely based on economics, with some interest in energy conservation. During the mid and late 1970s, the transportation industry in the United States faced the following problems:

- Reduced funding
- Shortage of materials
- Shortage of equipment
- Shortage of trained work force
- Energy awareness and availability

Recycling of existing pavement materials for rehabilitation and maintenance purposes offered a partial solution to these problems (1). Specifically, recycling offered potential benefits in reducing cost, conservation of materials, and conservation of energy. Early research efforts led to the categorization of three types of recycling for hot mixed asphalt (HMA) pavements: a) cold in place recycling (CIR), b) surface recycling, and c) hot recycling. The objective of this research project was to evaluate the potential of CIR for the rehabilitation of low volume roads in Nevada.

COLD IN PLACE RECYCLING (CIR)

Two forms of CIR of HMA mixtures have evolved in the U.S.: full Depth and partial depth. Full depth CIR is a rehabilitation technique in which the full HMA pavement layer and a predetermined portion of the base layer are uniformly crushed, pulverized and mixed with a bituminous binder, resulting in a stabilized base course. Additional aggregate may be transported to the site and incorporated into the construction process. This process is normally performed to a depth between 4 and 12 inches.

Partial depth CIR is a rehabilitation technique that reuses a portion of the existing HMA layer. Normal recycling depth is between 2 and 4 inches. The resulting bituminous-bound recycled material is normally used as a base course on low to medium traffic volume highways. This practice have resulted in a high quality durable pavement structure which provide a good level of service for a longer period of time.

Several research studies have evaluated the advantages of CIR which can be summarized as follow (2-5):

- Significant pavement structural improvements may be achieved without major changes in horizontal and vertical geometry and without shoulder reconstruction.
- Many types and degrees of pavement surface distresses can be treated.
- The potential of reflective cracking of the new HMA overlay is reduced.
- Pavement ride could be improved even with thin overlay or surface treatments.
- Normally only thin overlays or surface treatments are required.

- Existing pavement materials are conserved which reduced the potential cost and eliminate the waste management problem.

Some of the disadvantages of CIR have been identified as follow:

- Variations in the existing materials would generate variability in the recycled mixtures which may lead to differential in performance along the project.
- Appropriate curing is required for strength gain.
- Strength gain and construction practices are a function of climate conditions such as temperature and moisture.

Considering the above identified benefits and problems areas, CIR has been primarily used on medium to low traffic volume highways as a base course.

OBJECTIVES

The objectives of this research project were to develop and validate a mix design procedure for CIR mixtures in Nevada. CIR was selected due to its potential for cost savings and longer performing pavements. The objectives of the research were met through the conduct of two major tasks:

- Develop and implement a mix design procedure.
- Implement a field evaluation plan.

The mix design procedure would be used to determine the optimum combination of mix components, including; binder, lime, and moisture. The field evaluation plan would be used to assess the construction of the designed mixture and to refine the mix design process.

MIX DESIGN PROCEDURE

Designing CIR mixtures presents additional requirements which include the evaluation of the in-place materials and the identification of the optimum moisture content. Since the Nevada Department of Transportation (NDOT) uses the Hveem mix design procedure, it was necessary to develop a mix design based on the Hveem process. Therefore, the Hveem mix design procedure was used with three supplements. The mixing and compaction of the CIR mixtures follow the exact Hveem procedure. Also the measurement of the bulk specific gravity of the compacted mix and the theoretical maximum specific gravity of the loose mixtures follow the appropriate AASHTO test procedures. Finally, the resilient modulus property of the CIR mixtures is used in place of the Hveem stability. Prior to presenting the supplemental steps, it would be beneficial to present the objectives of a CIR mix design procedure.

The objective of a CIR mix design procedure is to accomplish the following goals:

1. *Reduce the brittleness of the aged existing mixtures:* it is anticipated that any pavement section selected for CIR treatment has an existing HMA layer which has been either cracked, rutted, moisture damaged or any combination thereof. In addition, it is expected that the HMA mixture has experienced a certain degree of aging due to exposure to various environmental conditions. The aging process results in a brittle pavement which must be made more flexible during the mix design process to avoid future problems with reflective cracking or rutting of the new surface layer. Therefore, the mix design process should identify a new binder which can provide the CIR mixtures with sufficient stability to resist traffic loads and yet maintain enough flexibility to eliminate the reflective cracking problem.

2. *Control the compactibility of the CIR mixtures*: CIR mixtures consist of pieces of an aged HMA mixture with various sizes and a certain percentage of an asphalt binder. It is almost impossible to control

the gradation of such mixture which presents a problem in the field compaction process. Therefore, the mix design process will to select a binder content which can result in a compactible CIR mixture producing ideal in-place air voids between 8 and 10 percent.

3. *Provide a mixture with enough stability for early traffic*: since CIR mixture use liquid asphalt and emulsions, the required curing time becomes a concern. Long curing times would create traffic delays and defeat the purpose of asphalt maintenance. It is very desirable to design a CIR mixture which can be open to traffic shortly after construction without rutting and raveling of the constructed layer. Therefore, it is highly critical that the design process evaluates the early stability of the designed CIR mixture.

4. *Improve the moisture sensitivity of mixtures*: as mentioned earlier, any HMA mixture selected for CIR is expected to have experienced moisture damage and/or aging. The combination of these two conditions result in a CIR mixture that is highly susceptible to moisture damage. Therefore, the mix design process should evaluate the moisture sensitivity of the designed CIR mixure.

In order to achieve the identified goals, the Hveem mix design procedure was supplemented and modified with several steps which are discussed in the following sections.

Supplemental Steps

The Hveem mix procedure was supplemented with four additional steps: a) evaluation of in-place materials, b) evaluation of optimum moisture content, c) evaluation of the stability of CIR mixtures at various stages, and d) evaluation of moisture sensitivity of the CIR mixtures.

a. *Evaluation of the in-place materials:* the evaluation of the in-place materials is necessary to assess the current state of the HMA mixtures to be recycled and to identify the various sections throughout the project. The process included the evaluation of the in-place mixtures or binder. This research concentrated more on the evaluation of the in-place mixtures because the CIR process does not separate the binder from the mixture. The resilient modulus (Mr) property of the in-place mixtures was evaluated to assess the degree of brittleness and used as a guideline in the design process. In addition, some binder properties were evaluated and provided to the contractor as supplemental information to assist in his field operations.

The Mr property was measured on cores obtained from various locations throughout the project. The initial intention was to evaluate the Mr property of the cores and then decide on the locations to obtain field mixtures to be used in the mix design process. However, for the projects presented in this report, this task was limited to only one location per project due to time limitation. The measured Mr property was therefore used only as a benchmark to measure the effectiveness of the newly added binder in reducing the brittleness of the in-place mixtures.

b. *Evaluation of the optimum moisture content*: the CIR mixtures consist of dry and brittle pieces of hot mix asphalt (HMA) mixtures. In order to achieve any compaction, moisture must be added to the mix. The standard moisture-density process was used where three levels of binder contents were mixed with four levels of moisture contents. The moisture-density curves were established for mixtures with lime and without lime independently. It was observed that mixtures with lime would require 1% additional moisture content.

c. *Evaluation of the stability of the CIR mixtures at various stages*: as mentioned earlier, the ability of the CIR mixture to provide early stability is highly critical to the success and long term performance of the project. The stability of the CIR mixtures was measured in terms of Hveem stability and Mr property. In order to monitor the rate of stability gain, the CIR mixtures were evaluated at three different curing stages: initial, final, and long term as described below:

- **Initial Curing**: compacted CIR samples are cured in the mold at 77°F for 15 hours. After curing, the samples were extruded from the molds and let cure at room temperature for 3 hours prior to conducting any tests.
- **Final Curing**: compacted CIR samples are extruded out of the mold and cured in an oven at 140°F for 3 days. After the oven curing, the samples were let cure at room temperature for 3 hours prior to conducting and tests.
- **Long term curing**: compacted CIR samples are extruded out of the mold and cured in an oven at 140°F for 30 days.

The initial and final curing stages were used to assess the mixtures ability in providing good level of stability throughout the life of the project. The long term aging was used to benchmark the performance of field cores cut from the project.

d. *Evaluation of moisture sensitivity of the CIR mixtures*: evaluating the moisture sensitivity of the CIR mixtures is the most critical step in the mix design process. As mentioned earlier, there is a high possibility that the in-place mixtures have experienced either moisture damage and/or severe aging. Both of these characteristics would result in a CIR mixture that is highly sensitive to moisture damage. NDOT has effectively used lime to reduce the moisture sensitivity of HMA mixtures for the past 15 years. It was assumed that lime would also be effective in reducing the moisture sensitivity of CIR mixtures. Therefore, all CIR mixtures designed in this research were evaluated with and without lime. The AASHTO T283 test method with one cycle of freeze/thaw was used to assess the moisture sensitivity of all CIR mixtures. The ratios of the Mr and tensile strength (TS) properties before and after moisture conditioning were used to assess the moisture sensitivity of all mixtures. The addition of lime (1-1.5%) improved both the early stability of the CIR mixtures and their moisture sensitivity.

In summary, the mix design process of CIR mixtures consists of the following steps:

1. Evaluate the Mr property of cores from various location throughout the project.
2. Evaluate the moisture-density curves to identify the optimum moisture content.
3. Mix and compact samples at the optimum moisture content with three binder contents with and without lime.
4. Cure three samples at each curing stage and conduct Mr and TS testing.
5. Cure six samples at the final curing stage and conduct moisture sensitivity testing.

Select the optimum binder content as the one that provides good level of early stability and good resistance to moisture damage. A good level of early stability is defined as a Mr value above 150 ksi and a good resistance to moisture damage is defined as a retained strength ratio above 70%. It should also be noted that most CIR mixtures will not achieve a 4% design air voids and any air voids level between 8 and 10% should be considered acceptable.

EXPERIMENTAL PROGRAM

The developed mix design strategy was implemented on three NDOT CIR projects which were constructed in 1997-1998. The objective of this experimental program was to implement the proposed mix design procedure on actual field projects and monitor the projects to further refine the mix design procedure. This implementation/refining process consisted of: a) preparing mix designs for the field projects, b) sample the field mixtures during construction, and c) sample cores from the constructed project. The sampled field mixtures are compacted and cured similar to the mix design mixtures and their corresponding properties are compared. The field cores are tested for their Mr and TS properties and compared to both the mix design and field mixtures. The data generated from the three projects are discussed below.

US 95 MERCURY PROJECT

This project was constructed in the summer of 1997 on US 95 between mileposts NY6.92 and NY14.37 with a total length of 7.45 miles. The objective of the project was to mill the existing hot mixed asphalt (HMA) layer and construct it back into 3" of CIR material, 3" of new HMAC materials, and 3/4" open graded material.

Evaluation of the In-Place Materials

The evaluation of the in-place materials includes measuring resilient modulus (Mr) and tensile strength (TS) on cores and measuring the properties of the extracted binder. A total of nine cores were obtained and used for the Mr, TS, and binder testing. Table 1 summarizes the Mr and TS properties of the cores. The objective of this evaluation is to assess the degree of aging and the variability of the in-place materials. The data in Table 1 show that the in-place materials have an average Mr of 1.4 million psi and an average TS of 282 psi which indicate that the in-place materials have experienced severe aging. On the other hand, the variability of the Mr and TS properties is relatively high as measured by the coefficient of variation which indicates that the in-place materials are not uniform throughout the length of the project.

Tables 1 also summarizes the properties of the extracted binder. The testing includes both conventional and rheological binder properties. Both the conventional and rheological properties indicate an aged binder with relatively high variability along the project.

This evaluation concluded that the in-place materials are significantly aged and exhibit high variability along the length of the project. Therefore, the mix design should include a well selected representative material and develops a mixture that is flexible to carry the traffic and environmental stresses.

Establish the Moisture-Density Curves

Cold-in-place recycling mixtures require a certain level of moisture content in order to achieve optimum compaction in the field. The optimum moisture content depends on the type of binder being used, the conditions of the in-place materials and whether lime is added to the recycled materials. In this project, lime was added to the CIR materials in a slurry form at a 1 percent rate. Therefore, it was decided to establish moisture-density curves for each of the binders that will be included in the mix design evaluation. Since the optimum binder content were not known at this stage, moisture density curves were established for three levels of binder contents of each binder type. The following presents a summary of the combinations of binder types and percentages and moisture contents used for this project:

Binder Type	Binder Percent	Moisture Content
ERA-25	0.7, 1.7, 2.7%	2, 3, 4, 5% without lime
		2.9, 3.9, 4.9, 5.9 % with lime

CMS-2S	0.7, 1.7, 2.7%	2, 3, 4, 5% without lime 2.9, 3.9, 4.9, 5.9 % with lime
ERA-75	0.7, 1.7, 2.7%	2, 3, 4, 5% without lime 2.9, 3.9, 4.9, 5.9 % with lime

All percentages are expressed in terms of percent by dry weight of recycled asphalt pavement (RAP) materials. A total of eighteen moisture-density curves were established for this project. Figure 1 shows typical moisture-density curves. All eighteen moisture density curves were inspected to identify the optimum moisture content for each combination of binder type and binder content. It was concluded that optimum moisture contents are 3.0 and 3.9 percent for the without lime and with lime mixtures, respectively. The selected optimum moisture contents will be used in the mix design process.

Selection of Optimum Binder Content

The mix design process followed a modified version of the Hveem mix design procedure as described in the previous sections. The objective of the mix design process is to select the most suitable binder type and the corresponding optimum binder content. As part of the mix design process, the Mr, Hveem stability, and TS properties were measured for the mixtures cured at all three stages (i.e. initial, final, and long term). However, only the properties of the final cured materials were used in the selection of the optimum binder type and content. The properties of the materials cured at the initial and long term stages will be used to correlate the properties of the laboratory mixtures with field mixtures and cores. The final cured mixtures are also evaluated through the moisture sensitivity test where the Mr and TS are measured before and after moisture conditioning using the AASHTO T283 procedure.

Tables 2, 3, and 4 summarize the mix design data for both the lime treated and untreated mixtures. The data presented in these tables are analyzed and decisions are made regarding the best binder type for the specific mixture, the corresponding optimum binder content, and whether or not lime treatment is necessary. The criteria used in the mix design process have been presented earlier and are summarized below.

a. reduce the brittleness of the aged existing mixtures

b. control the compactibility of the recycled mixtures in the field

c. provide a mixture with enough stability for early traffic

d. improve the moisture sensitivity of the recycled mixtures

Using the above criteria along with the data presented in Tables 2, 3, and 4, the following mix recommendations were made:

- The existing mixtures on US 95 are extremely brittle. The average resilient modulus at 77°F on cores obtained from US 95 is 1,400,000 psi which is considered extremely high for HMA mixtures.
- The ERA-25 and CMS-2S binders have significantly reduced the brittleness of the existing mixtures as indicated by the reduced values of the recycled mixtures shown in Tables 2 and 3.
- The addition of 1% lime (by wt of RAP) have improved the compactibility and the moisture sensitivity of the recycled mixtures as indicated by the reduction in the air voids and the increase of the retained strength ratios (Tables 3 and 4).
- The early stability issue is not of concern for this mixture due to its relatively high initial strength

values as indicated by the strength values at the initial curing stage (see Tables 3 and 4).

- In addition to the physical strength data presented in Tables 2, 3 and 4, laboratory experience indicates that the CMS-2S binder has a better coating ability than the other binders with this specific materials.

Based on the data analysis and observations presented above, the following mix design was recommended for this project:

Binder Type:	CMS-2S
Binder Content:	2.5% by wt of RAP
Moisture Content:	3.9% by wt of RAP
Lime Content:	1.0% by wt of RAP

If the 2.5% binder content causes some field problems, the binder content can be reduced to 2.0% by weight of RAP without significantly affecting the brittleness of the recycled mixtures.

Evaluate Field Mixed Materials

Field mixed materials were collected during construction from several locations throughout the project. The resilient modulus, tensile strength, Hveem stability, and air voids properties of the sampled mixtures were measured at the initial, final, and long term curing stages. Table 5 summarizes the data for the three curing stages. The data indicate that the mixtures continue to gain strength as they are subjected to longer curing periods with the most significant gain in strength occurring between the initial and final curing stages. The gain in strength is a good indicator that the mixture will exhibit good resistance to early traffic.

Evaluate Field Cores

The first set of cores were obtained during August, 1997 when the project was 3 month old and the second set of cores were obtained during August, 1998 when the project was fifteen month old. Table 6 summarizes the resilient modulus, tensile strength, and air voids data measured on the cores. The data showed that the variability of the cores properties along the project length is acceptable. The measured Mr values of the 1997 cores from stations 80+50/S and 111+00/S are significantly higher than the Mr values of cores cut form other locations. However, the 1998 cores from these same stations show a large reduction in Mr values which brought them closer to the rest of the project locations. It is recommended that the performance of these stations be closely monitored during the next 6-12 months period.

Comparison of Mix Design and Field Mixtures

The objective of this comparison is to assess the effectiveness of the mix design process in simulating the conditions of the actual field mixtures. The overall evaluation includes the following three studies:

- Compare the properties of the mix design mixtures with the properties of the field mixtures.
- Compare the properties of the mix design mixtures with the properties of the cores.
- Compare the properties of the field mixtures with the properties of the cores.

Figure 2 compares the Mr properties for the mix design and field mixtures. The construction activities log indicated that the field binder content ranged between 1.7 and 2.0%. Therefore, the properties of mix design mixtures corresponding to CMS-2S content of 1.7% are used for the comparison. The data presented in Figure 2 indicate that the mix design mixtures experience higher degree of curing when subjected to the final and long term curing conditions.

Figures 3 and 4 compare the Mr properties for the mix design mixtures and cores from the north and south directions, respectively. The data in these figures indicate that the field cores properties fall in between the initial and final curing of the mix design samples. The only alarming observation is that the resilient modulus of the south direction cores are decreasing with time. This section should be sampled in 1999 and the cores tested to see if this downward trend still exists.

Figures 5 and 6 compare the Mr properties for the field mixtures and cores from the north and south directions, respectively. The cores properties are compared with the properties of the field mixtures cured at the initial, final, and long term stages. The sampling of the field mixtures and cores coincides at some of the stations which provides excellent direct comparison of the field compacted and lab compacted mixtures. The data indicate that the properties of the cores are closer to the field mixtures at the final curing stage.

All three comparisons of the data indicate that laboratory mixing and curing can simulate field mixtures. However, it is not known at this stage what the laboratory curing conditions represent in term of number of years in the field. Continuous monitoring of this test section will provide valuable data toward this goal.

US 50 EUREKA PROJECT

This project was constructed in the summer of 1997 on US 50 between mileposts EU 38.00 and WP 3.00 with a total length of 12.38 miles. The objective of the project was to mill the existing hot mixed asphalt (HMA) layer and construct it back into 2" of CIR material and 2" of new HMAC materials.

Evaluation of the In-Place Materials

The evaluation of the in-place materials includes measuring resilient modulus (Mr) and tensile strength (TS) on cores and measuring the properties of the extracted binder. A total of fourteen cores were obtained and used for the Mr, TS, and binder testing. Table 7 summarizes the Mr and TS properties of the cores. The objective of this evaluation is to assess the degree of aging and the variability of the in-place materials. The data in Table 7 show that the in-place materials have an average Mr of 335 ksi and an average TS of 154 psi which indicate that the in-place materials have not experienced severe aging. On the other hand, the variability of the Mr and TS properties is relatively high as measured by the coefficient of variation which indicates that the in-place materials are not uniform throughout the length of the project.

Tables 7 also summarizes the properties of the extracted binder. The testing includes both conventional and rheological binder properties. Both the conventional and rheological properties indicate a moderately aged binder with relatively high variability along the project.

This evaluation concluded that the in-place materials are not significantly aged but exhibit high variability along the length of the project. Therefore, the mix design should include a well selected representative material and should consider a binder that could maintain the properties of the existing materials.

Establish the Moisture-Density Curves

In this project, lime was added to the CIR materials in a slurry form at a 1.5 percent rate. Therefore, it was decided to establish moisture-density curves for each of the binders that will be included in the mix design evaluation. Since the optimum binder content were not known at this stage, moisture density curves were established for three levels of binder contents of each binder type. The following presents a summary of the combinations of binder types and percentages and moisture contents used for this project:

Binder Type	Binder Percent	Moisture Content
ERA-25	0.3, 1.3, 2.3%	1, 2, 3, 4% without lime 2.9, 3.9, 4.9, 5.9 % with lime
CMS-2S	0.9, 1.9 %	1, 2, 3, 4% without lime 2.9, 3.9, 4.9, 5.9 % with lime
ERA-75	0.4, 1.4, 2.4%	1, 2, 3, 4% without lime 2.9, 3.9, 4.9, 5.9 % with lime

All percentages are expressed in terms of percent by dry weight of recycled asphalt pavement (RAP) materials. All moisture density curves were inspected to identify the optimum moisture content for each combination of binder type and binder content. It was concluded that optimum moisture contents are 2.0 and 3.9 percent for the without lime and with lime mixtures, respectively. The selected optimum moisture contents will be used in the mix design process.

Selection of Optimum Binder Content

The mix design process followed a modified version of the Hveem mix design procedure as described in the previous sections. The objectives of the mix design process were presented earlier. Tables 8, 9, and 10 summarize the mix design data for both the lime treated and untreated mixtures. The data presented in these tables are analyzed and decisions are made regarding the best binder type for the specific mixture, the corresponding optimum binder content, and whether or not lime treatment is necessary. The criteria used in the mix design process have been presented earlier and are summarized below.

a. reduce the brittleness of the aged existing mixtures

b. control the compactibility of the recycled mixtures in the field

c. provide a mixture with enough stability for early traffic

d. improve the moisture sensitivity of the recycled mixtures

Using the above criteria along with the data presented in Tables 8, 9, and 10, the following mix recommendations were made:

- The existing mixtures on US 50 are not severely aged. The average resilient modulus at 77°F on cores obtained from US 50 is 335,000 psi which is considered good for HMA mixtures.
- The ERA-25 and CMS-2S binders have significantly reduced the brittleness of the existing mixtures as indicated by the reduced values of the recycled mixtures shown in Tables 8 and 9.
- The addition of 1.5% lime (by wt of RAP) have improved the compactibility and the moisture sensitivity of the recycled mixtures as indicated by the reduction in the air voids and the increase of the retained strength ratios.

- The addition of 1.5% lime have significantly improved the early stability of the mixture. The strength of the initially cured mixtures with lime is twice the strength of the mixtures without lime.
- In addition to the physical strength data presented in Tables 8, 9 and 10, laboratory experience indicates that the CMS-2S binder has a better coating ability than the other binders with this specific materials.

Based on the data analysis and observations presented above, the following mix design was recommended for this project:

Binder Type:	CMS-2S
Binder Content:	1.0% by wt of RAP
Moisture Content:	3.9% by wt of RAP
Lime Content:	1.5% by wt of RAP

Evaluate Field Mixed Materials

Field mixed materials were collected during construction from several locations throughout the project. During construction, this project experienced more than usual variations in the percent binder used. In order to assess the impact of binder content variations on the performance of CIR mixtures, samples were obtained from locations with different binder contents and tested in the laboratory. Table 11 summarizes the properties of the field mixtures as a function of binder content. The resilient modulus, Hveem stability, and air voids properties of the sampled mixtures were measured at the initial, and final curing stages. The data indicate that the strength of the CIR mixtures peaks between binder contents of

0.75 and 1.20% which indicate that the 1.0% binder recommended by the mix design represents the optimum binder content for this mix.

Evaluate Field Cores

The first set of cores were obtained during August, 1998 when the project was 15 month old. Table 12 summarizes the resilient modulus, tensile strength, and air voids data measured on the cores.

Comparison of Mix Design and Field Mixtures

The objective of this comparison is to assess the effectiveness of the mix design process in simulating the conditions of the actual field mixtures. The overall evaluation includes the following three studies:

- Compare the properties of the mix design mixtures with the properties of the field mixtures.
- Compare the properties of the mix design mixtures with the properties of the cores.
- Compare the properties of the field mixtures with the properties of the cores.

Figure 7 compares the Mr properties for the mix design and field mixtures. The construction activities log indicated that the field binder content ranged between 0.45 and 1.20%. Therefore, the properties of mix design mixtures corresponding to CMS-2S content of 0.9% are compared with the properties of field mixtures at the 0.75 and 1.20% binder contents. The data presented in Figure 7 show that the mix design materials at the 0.9% are closer to the field mixtures at the 1.2% at both curing stages. This indicates that the selected mix at 1% would have been an appropriate target value.

The data in Tables 11 and 12 can be used to compare the properties of the field mixtures and cores at the same binder content of 0.75%. The field mixtures at the binder content of 0.75% have Mr at 77°F values of 136 and 280 ksi for the initial and final curing stages, respectively. The cores at the 0.75% binder content have a Mr at 77°F value of 163 ksi. This data supports the findings from the US 95 project that the cores properties fit somewhere between the initial and final curing stages of the field mixtures. A continuous monitoring of the CIR projects should establish the correspondence between the laboratory curing and field conditions.

SR 396 LOVELOCK PROJECT

This project was constructed in the summer of 1998 on SR 396 between mileposts PE4.00 and PE28.00 with a total length of 24 miles. The objective of the project was to mill the existing hot mixed asphalt (HMA) layer and construct it back into 2" of CIR material, 2" of new HMAC materials, and 3/4" open graded material.

Evaluation of the In-Place Materials

The evaluation of the in-place materials includes measuring resilient modulus (Mr) and tensile strength (TS) on cores and measuring the properties of the extracted binder. A total of thirty-three cores were obtained and used for the Mr, TS, and binder testing. Table 13 summarizes the Mr and TS properties of the cores. The objective of this evaluation is to assess the degree of aging and the variability of the in-place materials. The data in Table 13 show that the in-place materials have an average Mr of 1.0 million psi and an average TS of 195 psi which indicate that the in-place materials have experienced severe aging. On the other hand, the variability of the Mr and TS properties is relatively high as measured by the coefficient of variation which indicates that the in-place materials are not uniform throughout the length of the project.

Tables 13 also summarizes the properties of the extracted binder. The testing includes both conventional and rheological binder properties. Both the conventional and rheological properties indicate an aged binder with extremely high variability along the project.

This evaluation concluded that the in-place materials are significantly aged and exhibit extremely high variability along the length of the project. Therefore, the mix design should include a well selected representative material and should consider a binder that could significantly reduce the aging of the recycled materials.

Establish the Moisture-Density Curves

In this project, lime was added to the CIR materials in a slurry form at a 1 percent rate. Therefore, it was decided to establish moisture-density curves for each of the binders that will be included in the mix design evaluation. Since the optimum binder content were not known at this stage, moisture density curves were established for three levels of binder contents of each binder type. The following presents a summary of the combinations of binder types and percentages and moisture contents used for this project:

Binder Type	Binder Percent	Moisture Content
ERA-25	0.7, 1.7, 2.7%	2, 3, 4, 5% without lime
		2.9, 3.9, 4.9, 5.9 % with lime
CMS-2S	0.4, 1.4, 2.4%	2, 3, 4, 5% without lime

		2.9, 3.9, 4.9, 5.9 % with lime
ERA-75	0.6, 1.6, 2.6%	2, 3, 4, 5% without lime
		2.9, 3.9, 4.9, 5.9 % with lime

All percentages are expressed in terms of percent by dry weight of recycled asphalt pavement (RAP) materials. A total of eighteen moisture-density curves were established for this project. All eighteen moisture density curves were inspected to identify the optimum moisture content for each combination of binder type and binder content. It was concluded that optimum moisture contents are 3.0 and 3.9 percent for the without lime and with lime mixtures, respectively. The selected optimum moisture contents will be used in the mix design process.

Selection of Optimum Binder Content

The mix design process followed a modified version of the Hveem mix design procedure as described in the previous sections. The objectives of the mix design process were presented earlier. Tables 14, 15, and 16 summarize the mix design data for both the lime treated and untreated mixtures. The data presented in these tables are analyzed and decisions are made regarding the best binder type for the specific mixture, the corresponding optimum binder content, and whether or not lime treatment is necessary. The criteria used in the mix design process have been presented earlier and are summarized below.

a. reduce the brittleness of the aged existing mixtures

b. control the compactibility of the recycled mixtures in the field

c. provide a mixture with enough stability for early traffic

d. improve the moisture sensitivity of the recycled mixtures

Using the above criteria along with the data presented in Tables 14, 15, and 16, the following mix recommendations were made:

- The existing mixtures on SR 396 are extremely brittle. The average resilient modulus at 77°F on cores obtained from SR 396 is 1,000,000 psi which is considered extremely high for HMA mixtures.
- The ERA-25, CMS-2S, and ERA-75 binders have significantly reduced the brittleness of the existing mixtures as indicated by the reduced values of the recycled mixtures shown in Tables 14 and 15.
- The addition of 1% lime (by wt of RAP) have improved the compactibility and the moisture sensitivity of the recycled mixtures as indicated by the reduction in the air voids and the increase of the retained strength ratios (Tables 15 and 16). Table 16 shows that the addition of lime reduced the unconditioned Mr property of the mixtures. However, the Mr property of the conditioned mixtures has been significantly improved. For the location of this project, the conditioned Mr property is more critical than the unconditioned property, and therefore, lime should be used.
- The early stability issue is not of concern for this mixture due to its relatively high initial strength values as indicated by the strength values at the initial curing stage (see Table 15).
- In summary, all three binder types performed very well. However, the CMS-2S and ERA-75

showed better dry Mr values than the ERA-25 mixtures.

Based on the data analysis and observations presented above, the following mix designs were recommended for this project:

Binder Type:	CMS-2S
Binder Content:	1.4% by wt of RAP
Moisture Content:	3.9% by wt of RAP
Lime Content:	1.0% by wt of RAP

OR

Binder Type:	ERA-75
Binder Content:	1.0% by wt of RAP
Moisture Content:	3.9% by wt of RAP
Lime Content:	1.0% by wt of RAP

Evaluate Field Mixed Materials

The actual construction of this project took place during June, 1998. NDOT placed four different types of CIR mixtures for the purpose of evaluating the performance of a binder other than the CMS-2S and the effectiveness of lime on the performance of CIR mixtures. The following sections were constructed on this project:

1. CMS-2S with lime

2. CMS-2S without lime
3. ERA-75 with lime
4. ERA-75 without lime

Field mixed materials were collected during construction from each section. The resilient modulus, tensile strength, Hveem stability, and air voids properties of the sampled mixtures were measured at the initial, final, and long term curing stages. Table 17 summarizes the data for the three curing stages. The data indicate that there is a significant gain in strength between the initial and final curing stages for all types of mixtures. The gain in strength is a good indicator that the mixture will exhibit good resistance to early traffic.

Since this project includes special test sections, the moisture sensitivity of the field mixtures were evaluated in addition to the normal dry properties. The AASHTO T283 moisture conditioning procedure was used to evaluate the moisture sensitivity of CIR mixtures from all four test sections. Table 18 summarizes the moisture sensitivity data at the final curing stage. The data in Table 18 show that the CMS-2S with lime field mixtures provided the best resistance to moisture damage while the ERA-75 mixtures without lime showed the worst resistance to moisture damage.

In the case of the CMS-2S without lime mixtures, there is a great discrepancy between the Mr and TS retained ratios. This discrepancy was not present when the laboratory prepared mixtures were evaluated. At this point, this discrepancy is credited to the variability in the existing mixtures.

Evaluate Field Cores

The first set of cores were obtained during July, 1998 when the project was 2 month old. Table 19 summarizes the resilient modulus, tensile strength, and air voids data measured on the cores. The data show that the CMS-2S with lime mixtures have the highest strength while the CMS-2S without lime mixtures have the lowest strength. The major concern here is that the evaluation of the field mixtures as presented in Table 17 did not identify the CMS-2S without lime as being an extremely weak mix. It should be also recognized that the there is always a difference between the laboratory and field compaction efforts which could have contributed in this case.

Comparison of Mix Design and Field Mixtures

The objective of this comparison is to assess the effectiveness of the mix design process in simulating the conditions of the actual field mixtures. The overall evaluation includes the following three studies:

- Compare the properties of the mix design mixtures with the properties of the field mixtures.
- Compare the properties of the mix design mixtures with the properties of the cores.
- Compare the properties of the field mixtures with the properties of the cores.

Figures 8 and 9 compare the properties of mix design and field mixtures for all four types of mixtures for the initial and final curing stages, respectively. The data in the figures show close correlation between the mix design and field mixtures except for the CMS-2S without lime mixtures. This mixture has been generating erratic results throughout the entire evaluation process. It is recommended that this section be closely monitored in the future.

Figure 10 compares the properties of the mix design mixtures with field cores. All three mixtures show that the cores properties are between the initial and final curing stages. However, the CMS-2S mixtures show that the addition of lime provided a high rate of strength gain which could be very beneficial for early traffic usage as long as the mixtures do not continue to stiffen up and become brittle.

Figure 11 compares the properties of the field mixtures with the field cores. All three mixtures showed similar trends to the ones presented in Figure 10 and discussed above.

SUMMARY AND RECOMMENDATIONS

The research effort summarized in this report has developed a mix design methodology for CIR to be used on Nevada's low to medium traffic highways. The process uses the basic Hveem mix design methods for mixing and compacting the CIR mixtures along with the use of Mr and moisture sensitivity testing. The Mr property replaces the Hveem stability as a measure of the CIR mixtures stability and strength. The design procedure covers four critical stages: a) the evaluation of the in-place mixtures, b) the evaluation of the moisture density relationship, c) the evaluation of the stability of the CIR mixtures at various stages, and d) the evaluation of the moisture sensitivity of the CIR mixtures.

The proper completion of each one of these stages is very critical to the successful long term performance of the CIR mixtures. The evaluation of in-place mixtures provides a benchmark for the effectiveness of the new binder in reducing the brittleness of the CIR mixtures. Less brittle CIR mixtures will have less potential for cracking and moisture damage. The moisture density relationship provides the optimum moisture content to be used with any combination of CIR materials and binder. Too little moisture will result in compaction difficulties and too much moisture will lead to curing problems. The early and final stability of the CIR mixtures are critical to ensure that the CIR mixtures can handle early traffic and will not become too brittle as they are subjected to field aging conditions. The moisture sensitivity of CIR mixtures is evaluated to ensure that the aged and moisture damaged in-place materials are well designed to resist moisture damage which would lead to the early deterioration of the mixtures.

Based on the development of the mix design methodology and its implementation on three NDOT field projects, the following recommendations can be made.

- The addition of lime to CIR mixtures is necessary to ensure both an early stability and good resistance to moisture damage. All nine mixtures that were evaluated in this study showed that the CIR mixture without lime experienced significantly lower early stabilities and retained strength ratios as compared to the CIR mixtures with lime.
- The resilient modulus property can be effectively used to assess the stability/strength of CIR mixtures at various stages. The Mr property is highly sensitive to mixtures parameters and can be used to evaluate the effectiveness of different binders.
- The optimum moisture content of CIR mixtures with lime can be safely assumed to be around 4% by dry weight of RAP. If CIR mixtures are used without lime the optimum moisture content should be reduced to a 3% level. It is recommended that these values be used and the moisture density relationships should not be conducted for each CIR mixture.
- The CMS-2S binder has been very effective with all of the evaluated CIR mixtures. It reduced the brittleness the existing materials, provided good early and final stability and good resistance to moisture damage. The CMS-2S binder also showed good coating ability.

- The initial and final curing stages used in this study showed good correlations with the field mixtures and cores. It was shown that the properties of field cores always fit in-between the properties measured on the initial and final cured CIR mixtures. The mix design process should continue to evaluate the mixtures properties at both the initial and final curing stages. The initial curing stage should be used to assess the early strength of the mixture while the final curing stage should be used to assess the long term strength and the moisture damage resistance of the CIR mixtures.
- Field cores should continue to be obtained from the CIR projects and tested as a follow up on the mix design methodology. One major concern about the CIR mixtures is that the good level of early stability should not turn into a brittleness problem as the mixtures age in the field.

In summary, the findings of this research project suggest that lime should be used with CIR mixtures in Nevada, a 4% moisture content should be used, and the properties of the CIR mixtures at the initial and final curing stages along with the moisture sensitivity properties should be used to select the optimum binder type and content.

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Table 1. Properties of the existing materials, US 95 Mercury project.

Property	No. of Tests	Minimum	Maximum	Average	STD	CV (%)
Air Voids (%)	6	1.9	6.7	4.3	1.7	40
Mr at 77°F (ksi)	8	278	2,190	1,420	596	42
TS at 77°F (psi)	8	159	350	282	59	21
Binder Content (%)	9	5.36	7.30	6.45	0.54	8
Kinematic Vis. (Cst)	9	2,695	5,469	3,743	1,018	27
Absolute Vis. (P)	0	Too Hard	Too Hard			
Penetartion at 77°F	9	4	15	9	3.4	38
G^*/sin(d) (kPa)	4	46	135	77	40	52

Table 2. Properties of the mix design materials without lime, US 95 Mercury project.

Curing Stage	Binder Type	Binder Content (%)	Mr at 77F (Ksi)	TS at 77F (psi)	Stability	Air Voids (%)
Initial	ERA-25	1.7	52	NA	31	11.8
		2.2	47	NA	35	7.3
		2.7	65	NA	31	7.0
	CMS-2S	1.7	96	NA	35	12.0
		2.2	60	NA	28	17.0
		2.7	60	NA	46	10.6
	ERA-75	1.7	94	NA	42	15.1
		2.2	92	NA	40	12.7
		2.7	101	NA	30	9.0
Final	ERA-25	1.7	394	79	49	14.3
		2.2	383	70	41	13.9
		2.7	237	58	44	13.7
	CMS-2S	1.7	589	114	70	11.2
		2.2	399	103	64	10.0
		2.7	429	98	59	9.0
	ERA-75	1.7	425	87	61	15.4
		2.2	543	119	66	13.7
		2.7	497	140	69	11.2
Long Term	ERA-25	1.7	585	236	NA	NA
		2.2	594	134	NA	NA
		2.7	453	108	NA	NA
	CMS-2S	1.7	771	162	NA	NA
		2.2	767	144	NA	NA
		2.7	507	116	NA	NA
	ERA-75	1.7	1,033	191	NA	NA
		2.2	1,095	220	NA	NA
		2.7	880	166	NA	NA

Table 3. Properties of the mix design materials with lime, US 95 Mercury project.

Curing Stage	Binder Type	Binder Content (%)	Mr at 77F (Ksi)	TS at 77F (psi)	Stability	Air Voids (%)
Initial	ERA-25	1.7	229	NA	35	8.6
		2.2	148	NA	34	7.7
		2.7	131	NA	30	6.7
	CMS-2S	1.7	134	NA	31	6.8
		2.2	112	NA	33	9.1
		2.7	96	NA	25	5.0
	ERA-75	1.7	129	NA	42	11.7
		2.2	152	NA	49	10.2
		2.7	135	NA	45	7.3
Final	ERA-25	1.7	547	135	73	8.6
		2.2	377	83	64	10.4
		2.7	242	66	51	8.9
	CMS-2S	1.7	641	117	69	9.4
		2.2	485	108	70	8.9
		2.7	373	107	64	6.9
	ERA-75	1.7	652	139	82	10.9
		2.2	716	146	81	10.1
		2.7	707	153	79	10.4
Long Term	ERA-25	1.7	622	113	NA	NA
		2.2	420	94	NA	NA
		2.7	478	116	NA	NA
	CMS-2S	1.7	1,020	167	NA	NA
		2.2	854	154	NA	NA
		2.7	745	146	NA	NA
	ERA-75	1.7	524	125	NA	NA
		2.2	755	139	NA	NA
		2.7	914	206	NA	NA

Table 4. Moisture sensitivity properties of the final cured materials, US 95 Mercury project.

Treatment	Binder Type	Binder Content(%)	Unconditioned		Conditioned	
			Mr at 77F (ksi)	TS at 77F(psi)	Mr at 77F (ksi)	TS at 77F(psi)
Without Lime	ERA-25	1.7	372	79	353	71
		2.2	365	70	245	60
		2.7	233	58	199	68
	CMS-2S	1.7	552	114	330	64
		2.2	361	103	363	73
		2.7	413	98	274	70
	ERA-75	1.7	435	87	539	100
		2.2	512	119	552	80
		2.7	479	140	416	94
With Lime	ERA-25	1.7	521	135	748	139
		2.2	324	83	592	127
		2.7	231	66	877	179
	CMS-2S	1.7	632	117	830	149
		2.2	470	108	675	136
		2.7	369	107	500	114
	ERA-75	1.7	639	139	862	151
		2.2	687	146	1035	164
		2.7	664	153	441	117

Table 5. Properties of the field mixed materials, US 95 Mercury project.

Curing Stage	Sampling Station	Mr @ 77F (ksi)	Stab.	TS @ 77F (psi)	Air Voids (%)	Moisture Content (%)
Initial	20+50	135	16	NA	12.0	2.3
	51+60	139	40	NA	10.7	2.7
	80+50	164	46	NA	11.2	2.3
	83+60	105	29	NA	9.5	2.3
	96+00	101	18	NA	9.8	2.6
Final	20+50	379	35	NA	16.1	NA
	51+60	394	56	NA	14.2	NA
	80+50	555	56	NA	12.0	NA
	83+60	403	46	NA	15.2	NA
	96+00	390	60	NA	13.2	NA
Long Term	20+50	457	NA	43	NA	NA
	51+60	453	NA	37	NA	NA
	80+50	400	NA	35	NA	NA
	83+60	493	NA	39	NA	NA
	96+00	521	NA	38	NA	NA

Table 6. Properties of the cores, US 95 Mercury project.

Sampling Date	Sampling Station/Direction	Mr @ 77F (Ksi)	TS @ 77F (psi)	Air Voids (%)
August, 1997	24+50/N	286	50	14
	57+80/N	320	45	14
	83+60/N	282	54	13
	96+00/N	260	47	14
	20+50/S	240	45	14
	51+60/S	390	47	14
	80+50/S	410	54	12
	111+00/S	586	60	14
August, 1998	24+50/N	234	30	11.4
	57+80/N	316	33	14.3
	83+60/N	350	48	8.5
	96+00/N	270	28	15.7
	20+50/S	257	33	11.5
	51+60/S	305	41	11.9
	80+50/S	200	33	11.5
	111+00/S	305	43	14.4

Table 7. Properties of the existing materials, US 50 Eureka project.

Property	No. of Tests	Minimum	Maximum	Average	STD	CV (%)
Air Voids (%)	8	0.44	16.53	9.33	6.91	74
Mr at 77°F (ksi)	14	90	896	335	206	52
TS at 77°F (psi)	7	122	239	154	43	28
Binder Content (%)	14	4.96	7.13	5.98	0.62	10
Kinematic Vis. (Cst)	14	388	1,196	785	229	29
Absolute Vis. (P)	14	3,159	40,784	17,303	10,398	60
Penetartion at 77°F	14	23	57	34	12	35
$G^*/\sin(d)$ (kPa)	10	2	14	8	3.5	42

Table 8. Properties of the mix design materials without lime, US 50 Eureka project.

Curing Stage	Binder Type	Binder Content (%)	Mr at 77F (Ksi)	TS at 77F (psi)	Stability	Air Voids (%)
Initial	ERA-25	0.8	31	NA	13	4.6
		1.3	43	NA	12	3.4
		1.8	33	NA	18	4.4
	CMS-2S	0.4	52	NA	21	7.1
		0.9	42	NA	18	5.6
		1.4	31	NA	14	5.5
	ERA-75	0.9	25	NA	NA	4.1
		1.4	26	NA	NA	5.1
		1.9	21	NA	NA	3.4
Final	ERA-25	0.8	83	32	17	5.9
		1.3	58	39	13	3.5
		1.8	40	43	15	3.8
	CMS-2S	0.4	162	89	19	8.1
		0.9	98	79	15	6.4
		1.4	70	73	13	6.3
	ERA-75	0.9	134	43	18	3.8
		1.4	64	41	19	2.9
		1.9	60	36	14	2.1
Long Term	ERA-25	0.8	315	NA	NA	NA
		1.3	222	NA	NA	NA
		1.8	152	NA	NA	NA
	CMS-2S	0.4	604	NA	NA	NA
		0.9	484	NA	NA	NA
		1.4	325	NA	NA	NA
	ERA-75	0.9	289	NA	NA	NA
		1.4	194	NA	NA	NA
		1.9	201	NA	NA	NA

Table 9. Properties of the mix design materials with lime, US 50 Eureka project.

Curing Stage	Binder Type	Binder Content (%)	Mr at 77F (Ksi)	TS at 77F (psi)	Stability	Air Voids (%)
Initial	ERA-25	0.8	90	NA	23	0.2
		1.3	56	NA	19	1.6
		1.8	44	NA	17	1.0
	CMS-2S	0.4	136	NA	23	0.9
		0.9	74	NA	23	1.8
		1.4	70	NA	20	0.7
	ERA-75	0.9	98	NA	20	0.9
		1.4	56	NA	25	2.2
		1.9	63	NA	17	0.4
Final	ERA-25	0.8	236	53	29	1.0
		1.3	209	46	27	1.7
		1.8	189	43	26	2.2
	CMS-2S	0.4	261	96	26	2.6
		0.9	204	82	21	3.1
		1.4	126	71	15	1.3
	ERA-75	0.9	262	66	36	0.5
		1.4	164	52	25	2.4
		1.9	165	50	22	1.6
Long Term	ERA-25	0.8	322	68	NA	NA
		1.3	293	53	NA	NA
		1.8	230	46	NA	NA
	CMS-2S	0.4	632	102	NA	NA
		0.9	477	95	NA	NA
		1.4	418	94	NA	NA
	ERA-75	0.9	298	68	NA	NA
		1.4	235	57	NA	NA
		1.9	230	62	NA	NA

Table 10. Moisture sensitivity properties of the final cured materials, US 50 Eureka project.

Treatment	Binder Type	Binder Content(%)	Unconditioned		Conditioned	
			Mr at 77F (ksi)	TS at 77F(psi)	Mr at 77F (ksi)	TS at 77F(psi)
Without Lime	ERA-25	0.8	110	32	20	27
		1.3	184	39	59	37
		1.8	67	43	72	42
	CMS-2S	0.4	250	89	246	78
		0.9	195	79	260	77
		1.4	155	73	216	71
	ERA-75	0.9	114	43	59	36
		1.4	134	41	65	20
		1.9	133	36	46	19
With Lime	ERA-25	0.8	231	53	235	65
		1.3	210	46	225	56
		1.8	185	43	166	48
	CMS-2S	0.4	159	96	426	109
		0.9	110	82	372	96
		1.4	81	71	206	76
	ERA-75	0.9	260	66	335	83
		1.4	161	52	234	65
		1.9	169	50	207	62

Table 11. Properties of the field mixed materials, US 50 Eureka project.

Curing Stage	Binder Content	Mr @ 77F (ksi)	Stab.	Air Voids (%)	Moisture Content (%)
Initial	0.60	43	20	6.8	3.7
	0.65	130	19	9.2	3.4
	0.75	136	22	0.6	3.4
	1.20	91	15	0.0	4.0
	1.20	72	15	1.6	NA
Final	0.60	214	20	8.3	NA
	0.65	NA	14	3.4	NA
	0.75	280	38	4.5	NA
	1.20	231	25	1.4	NA
	1.20	175	23	3.0	NA

Table 12. Properties of the cores, US 50 Eureka project.

Sampling Date	Binder Content	Sampling Station/ Direction	Mr @ 77F (Ksi)	TS @ 77F (psi)	Air Voids (%)
August, 1998	0.75	46+00/E	163	34	6.0
	0.45	89+00/W	187	25	7.8
	0.45	89+00/W	197	18	7.7
	0.45	89+00/W	285	20	7.7
	0.65	143+00/W	234	25	4.8
	0.65	143+00/W	211	28	5.1
	0.65	143+00/W	111	34	6.8

Table 13. Properties of the existing materials, SR 396 Lovelock project.

Property	No. of Tests	Minimum	Maximum	Average	STD	CV (%)
Air Voids (%)	12	0.9	6.1	3.0	1.6	54
Mr at 77°F (ksi)	21	285	2,179	1,030	550	54
TS at 77°F (psi)	21	122	391	195	54	28
Binder Content (%)	33	3.71	7.15	5.18	0.78	15
Kinematic Vis. (Cst)	32	630	2,774	1,378	589	43
Absolute Vis. (P)	24	8,816	206,506	43,098	60,913	91
Penetartion at 77°F	33	6	34	20	7	34
$G^*/\sin(d)$ (kPa)	18	2	89	32	29	92

Table 14. Properties of the mix design materials without lime, SR 396 Lovelock project.

Curing Stage	Binder Type	Binder Content (%)	Mr at 77F (Ksi)	TS at 77F (psi)	Stability	Air Voids (%)
Initial	ERA-25	1.2	38	NA	22	10.2
		1.7	36	NA	18	9.2
		2.2	33	NA	16	9.0
	CMS-2S	0.9	118	NA	38	13.4
		1.4	81	NA	32	12.8
		1.9	51	NA	28	11.9
	ERA-75	1.1	91	NA	19	12.1
		1.6	62	NA	22	11.6
		2.1	60	NA	18	10.3
Final	ERA-25	1.2	168	32	31	9.7
		1.7	130	39	24	9.3
		2.2	82	43	22	8.7
	CMS-2S	0.9	413	89	68	14.5
		1.4	319	79	61	13.5
		1.9	308	73	48	12.4
	ERA-75	1.1	318	43	39	12.6
		1.6	260	41	37	9.4
		2.1	205	36	28	9.0
Long Term	ERA-25	1.2	397	75	NA	NA
		1.7	244	63	NA	NA
		2.2	271	54	NA	NA
	CMS-2S	0.9	547	79	NA	NA
		1.4	436	87	NA	NA
		1.9	534	88	NA	NA
	ERA-75	1.1	386	90	NA	NA
		1.6	435	86	NA	NA
		2.1	398	76	NA	NA

Table 15. Properties of the mix design materials with lime, SR 396 Lovelock project.

Curing Stage	Binder Type	Binder Content (%)	Mr at 77F (Ksi)	TS at 77F (psi)	Stability	Air Voids (%)
Initial	ERA-25	1.2	131	NA	20	5.3
		1.7	125	NA	21	3.9
		2.2	98	NA	15	3.3
	CMS-2S	0.9	267	NA	44	9.7
		1.4	206	NA	41	8.3
		1.9	176	NA	34	6.3
	ERA-75	1.1	211	NA	29	6.9
		1.6	195	NA	26	6.2
		2.1	162	NA	22	4.7
Final	ERA-25	1.2	635	101	70	9.2
		1.7	571	85	70	9.0
		2.2	441	75	65	7.9
	CMS-2S	0.9	621	72	54	6.7
		1.4	523	76	46	5.4
		1.9	495	94	33	4.5
	ERA-75	1.1	484	99	64	7.2
		1.6	521	92	56	7.1
		2.1	430	83	46	6.8
Long Term	ERA-25	1.2	557	95	NA	NA
		1.7	592	89	NA	NA
		2.2	606	84	NA	NA
	CMS-2S	0.9	682	70	NA	NA
		1.4	598	84	NA	NA
		1.9	789	94	NA	NA
	ERA-75	1.1	798	120	NA	NA
		1.6	604	95	NA	NA
		2.1	686	100	NA	NA

Table 16. Moisture sensitivity properties of the final cured materials, SR 396 Lovelock project.

Treatment	Binder Type	Binder Content(%)	Unconditioned		Conditioned	
			Mr at 77F (ksi)	TS at 77F(psi)	Mr at 77F (ksi)	TS at 77F(psi)
Without Lime	ERA-25	1.2	640	44	46	14
		1.7	562	70	41	16
		2.2	429	59	40	16
	CMS-2S	0.9	598	79	20	5
		1.4	535	68	22	10
		1.9	479	64	47	15
	ERA-75	1.1	491	68	85	24
		1.6	534	72	113	34
		2.1	421	61	126	35
With Lime	ERA-25	1.2	176	101	725	128
		1.7	110	85	502	112
		2.2	89	75	522	113
	CMS-2S	0.9	395	72	401	62
		1.4	325	76	476	87
		1.9	315	94	628	106
	ERA-75	1.1	301	99	617	120
		1.6	250	92	555	118
		2.1	211	83	491	121

Table 17. Properties of the field mixed materials, SR 396 Lovelock project.

Curing Stage	Mixture Type	Mr @ 77F (ksi)	Stab.	TS @ 77F (psi)	Air Voids (%)	Moisture Content (%)
Initial	CMS-2S/ Lime	262	43	NA	7.8	3.7
	CMS-2S	161	43	NA	9.3	3.8
	ERA-75/ Lime	187	43	NA	6.8	4.8
	ERA-75	101	33	NA	11.4	4.2
Final	CMS-2S/ Lime	509	60	NA	9.8	NA
	CMS-2S	552	61	NA	11.4	NA
	ERA-75/ Lime	408	60	NA	10.7	NA
	ERA-75	383	51	NA	10.1	NA
Long Term	CMS-2S/ Lime	338	NA	50	NA	NA
	CMS-2S	432	NA	46	NA	NA
	ERA-75/ Lime	418	NA	37	NA	NA
	ERA-75	231	NA	44	NA	NA

Table 18. Moisture sensitivity properties of the field mixtures, final cured, SR 396 Lovelock project.

Binder Type	Unconditioned		Conditioned		Mr Ratio (%)	TS Ratio (%)
	Mr at 77F (ksi)	TS at 77F(psi)	Mr at 77F (ksi)	TS at 77F (psi)		
CMS-2S/ Lime	574	40	390	28	68	70
CMS-2S	546	35	460	8	84	23
ERA-75/ Lime	399	38	151	24	38	63
ERA-75	279	37	43	9	15	24

Table 19. Properties of the cores, SR 396 Lovelock project, sampled on 7-29-98.

Mixture Type	Milepost/ Direction	Mr @ 77F (Ksi)	TS @ 77F (psi)	Air Voids (%)
CMS-2S/ Lime	25.03/LT	572	50	8.0
CMS-2S/ Lime	25.03/LT	522	60	8.0
CMS-2S/Lime	25.03/LT	466	67	7.0
CMS-2S	21.72/LT	142	30	7.0
ERA-75/ Lime	8.00/LT	266	30	12.0
ERA-75/ Lime	8.00/LT	220	39	12.0
ERA-75/ Lime	8.00/LT	203	35	12.0

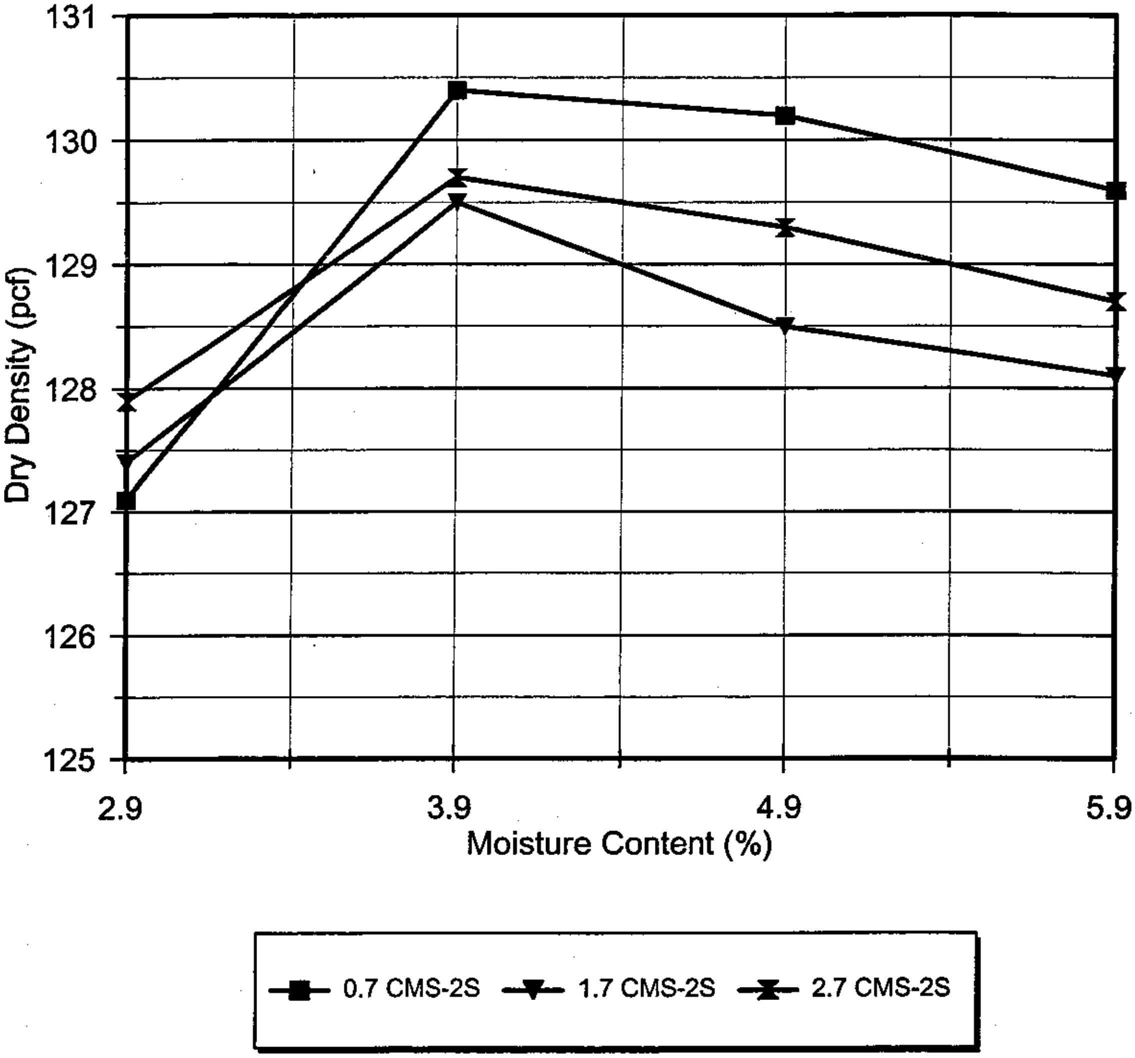

Figure 1. Typical moisture-density curve for CMS-2S with lime mixtures.

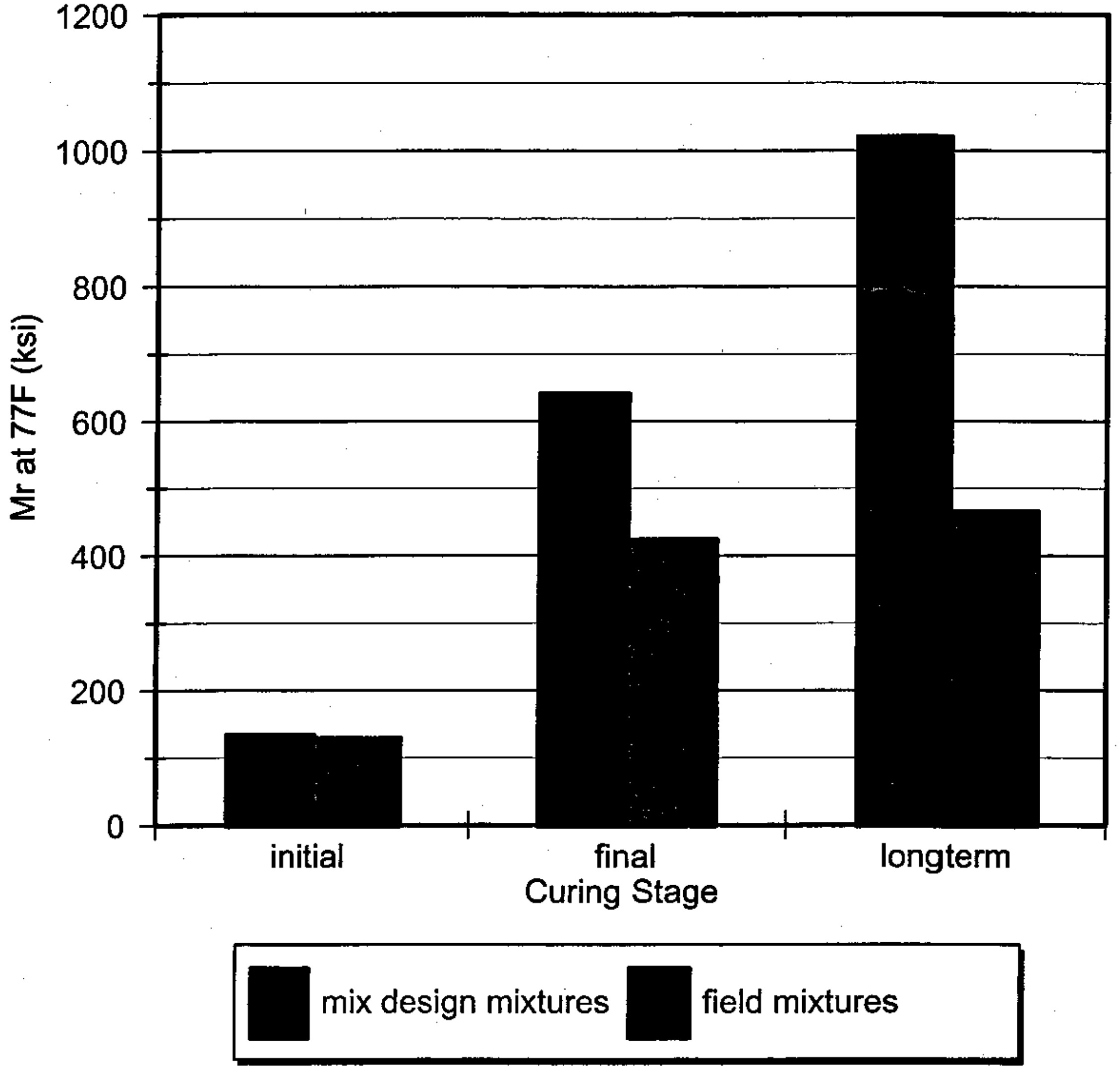

Figure 2. Comparison of mix design and field mixtures, CMS-2S/lime, US 95 Mercury.

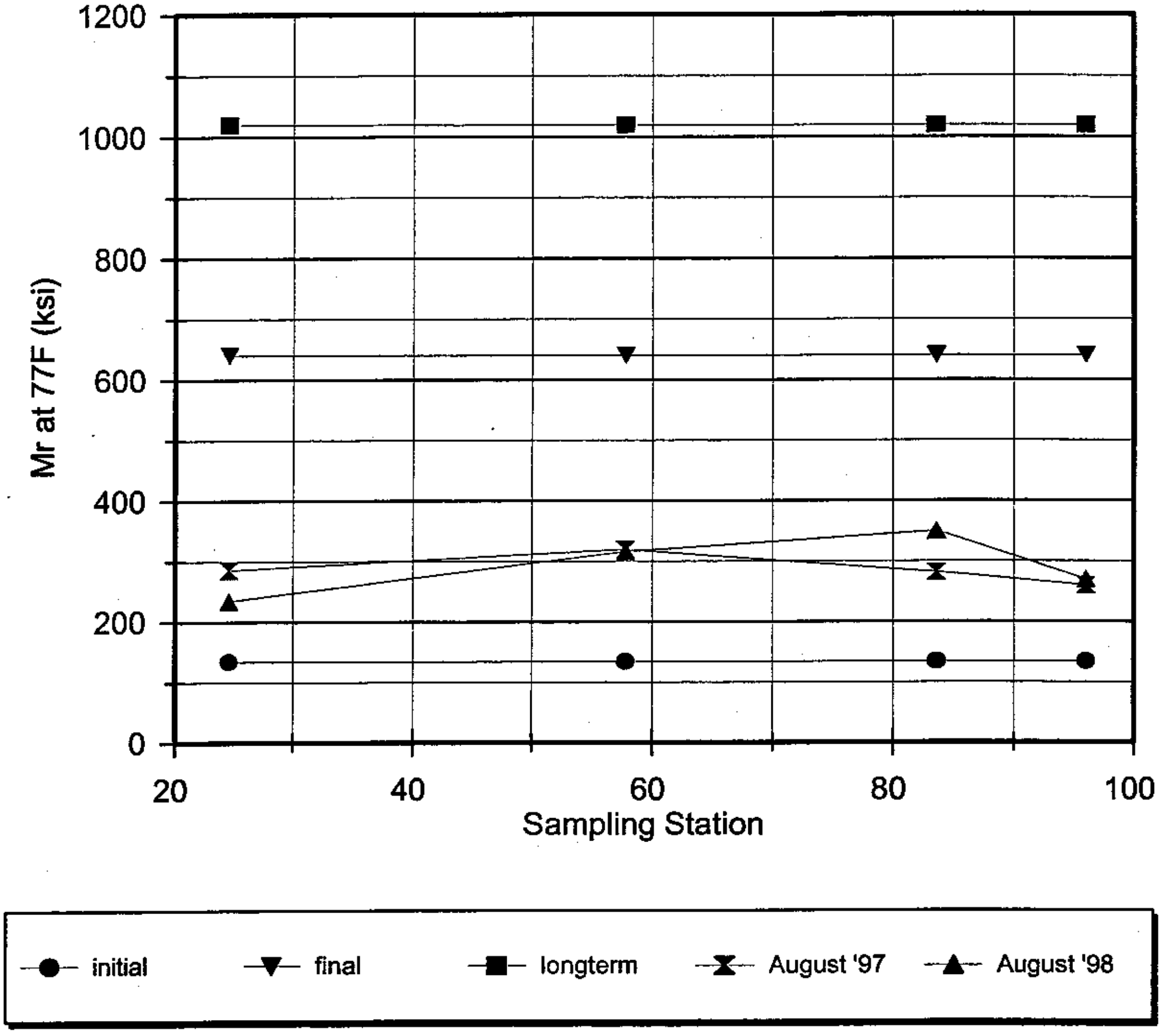

Figure 3. Comparison of mix design and field cores, CMS-2S/lime, US 95 Mercury, north direction.

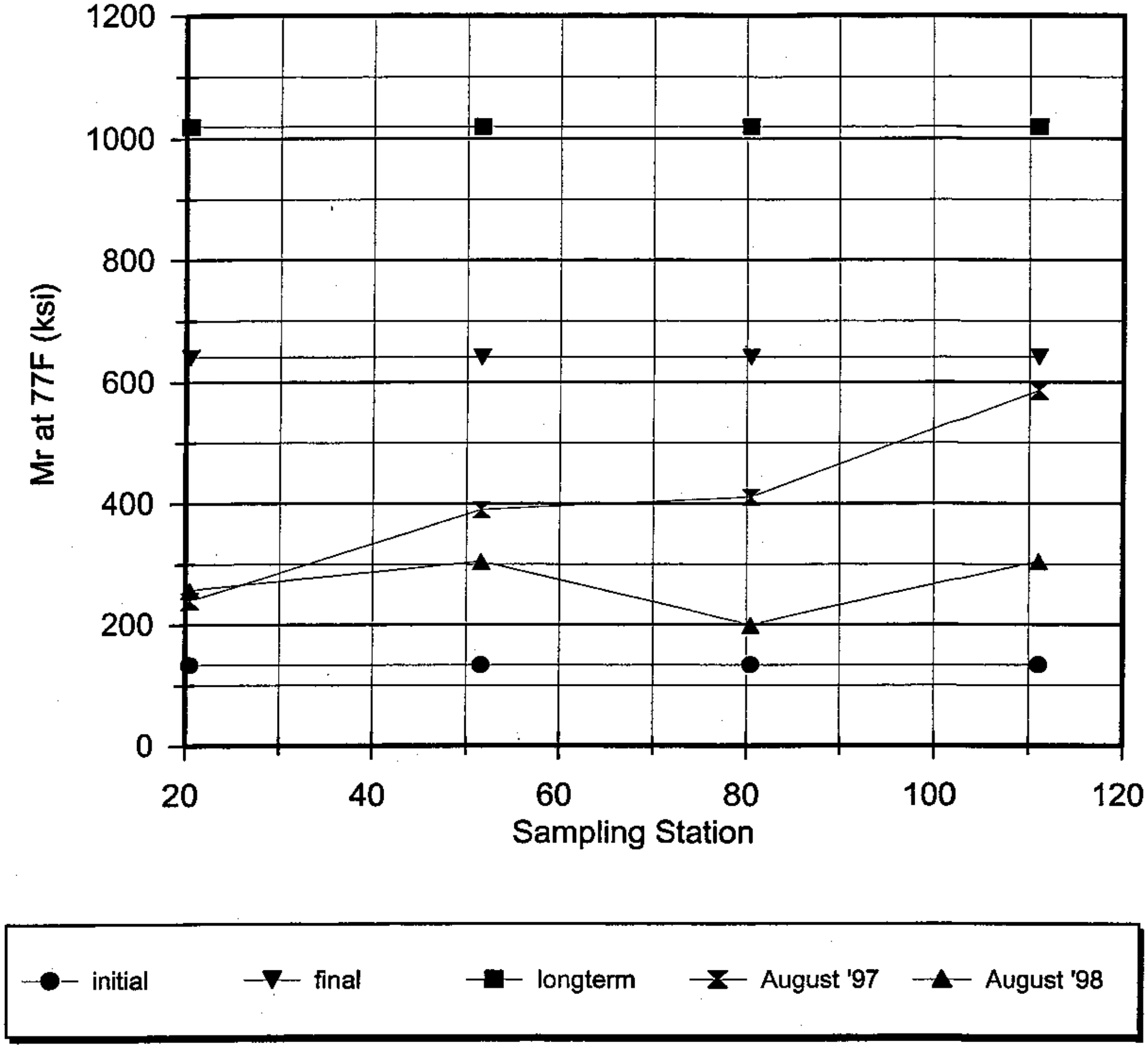

Figure 4. Comparison of mix design and field cores, CMS-2S/lime, US 95 Mercury, south direction.

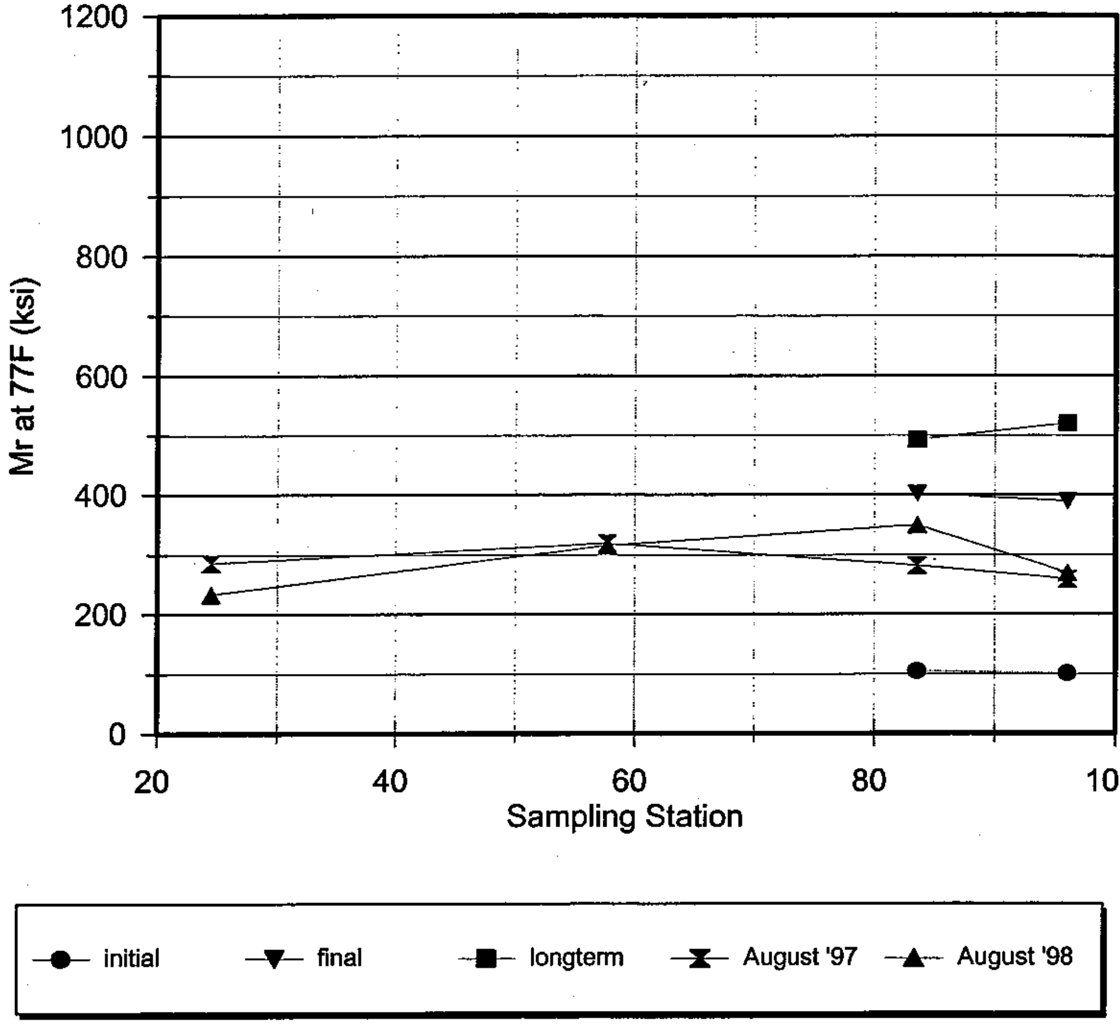

Figure 5. Comparison of field mixtures and field cores, CMS-2S/lime, US 95 Mercury, north direction.

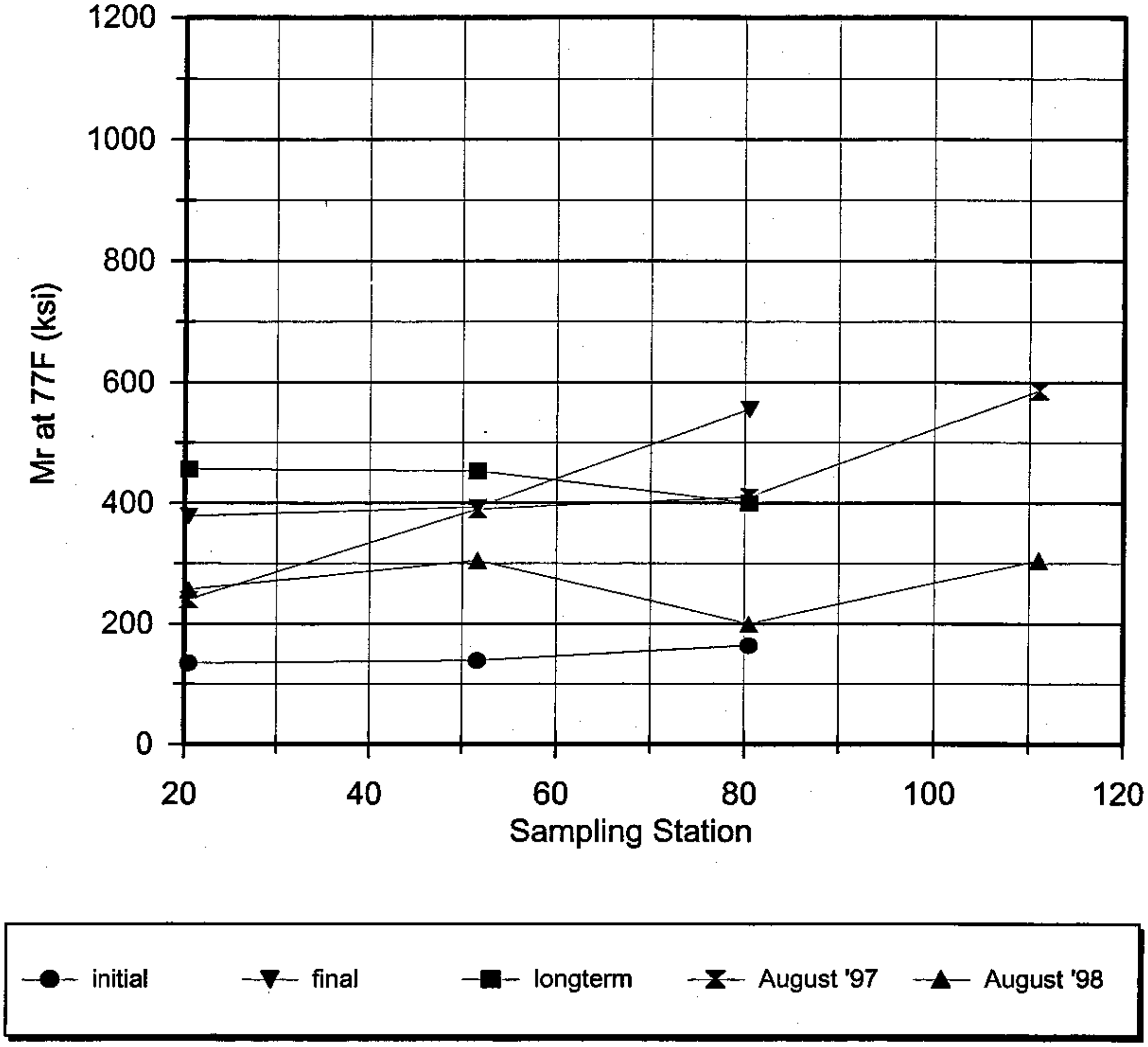

Figure 6. Comparison of field mixtures and field cores, CMS-2S/lime, US 95 Mercury, south direction.

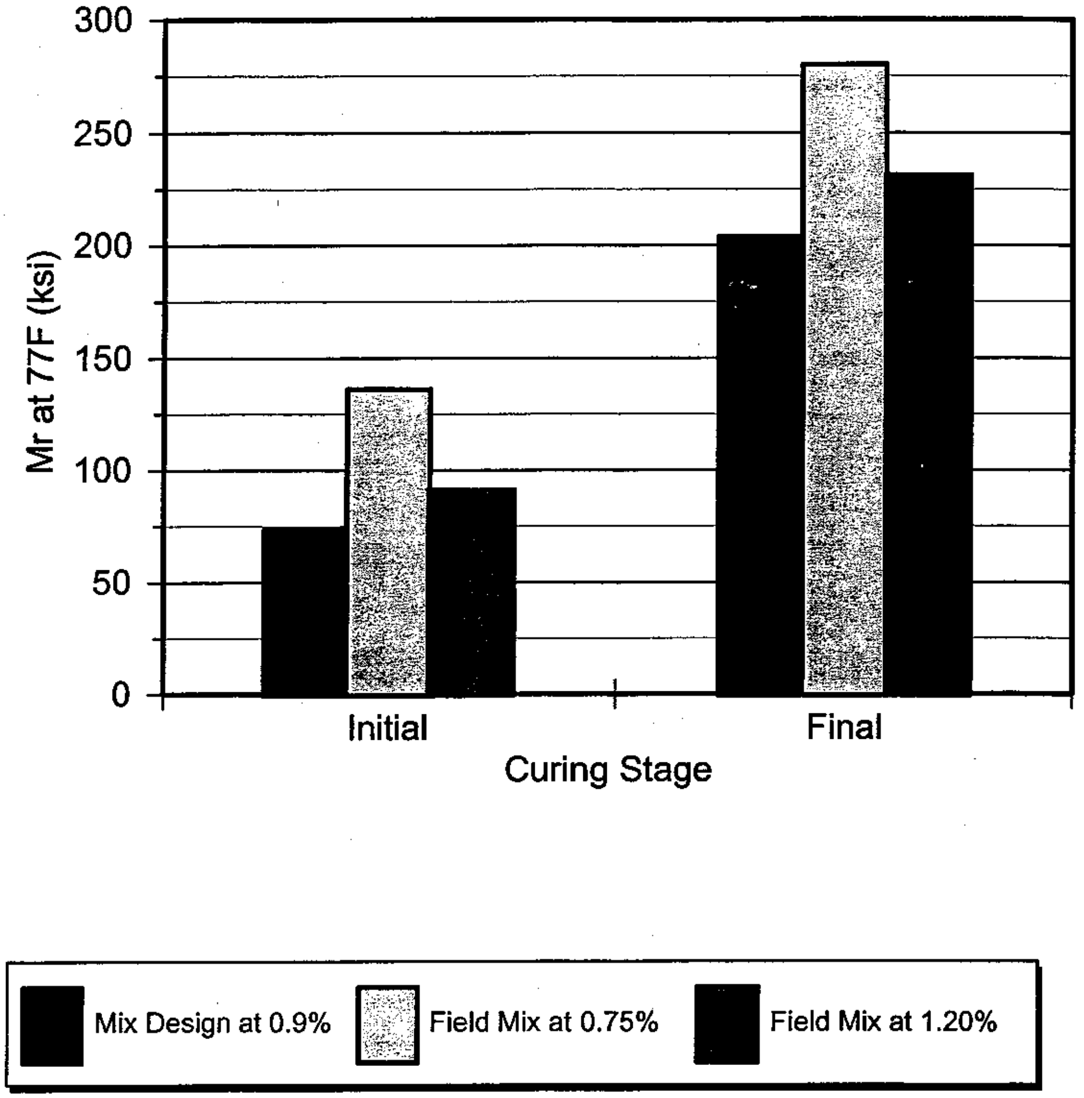

Figure 7. Comparison of mix design and field mixtures, CMS-2S/lime, US 50 Eureka.

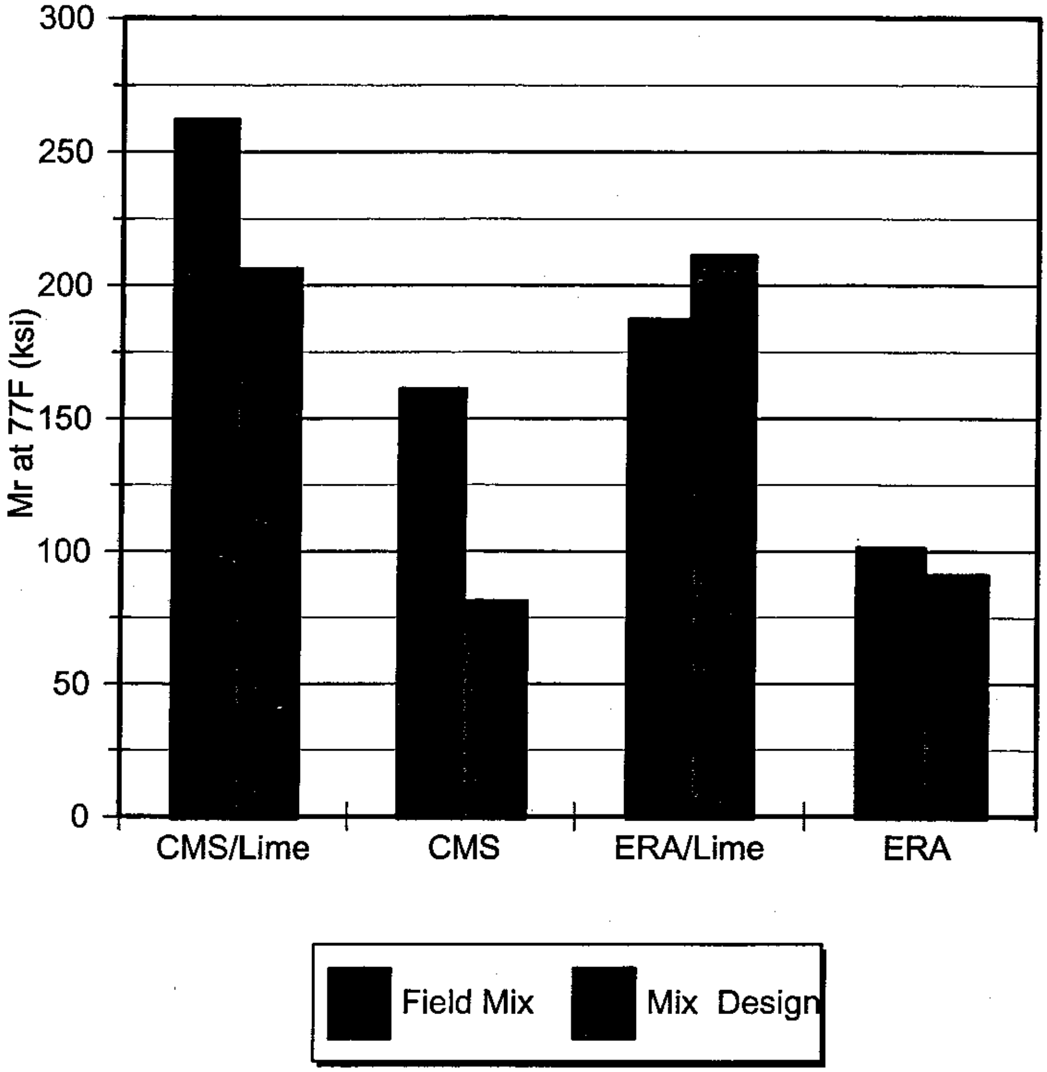

Figure 8. Comparison of mix design and field mixtures, initial curing, SR 396, Lovelock.

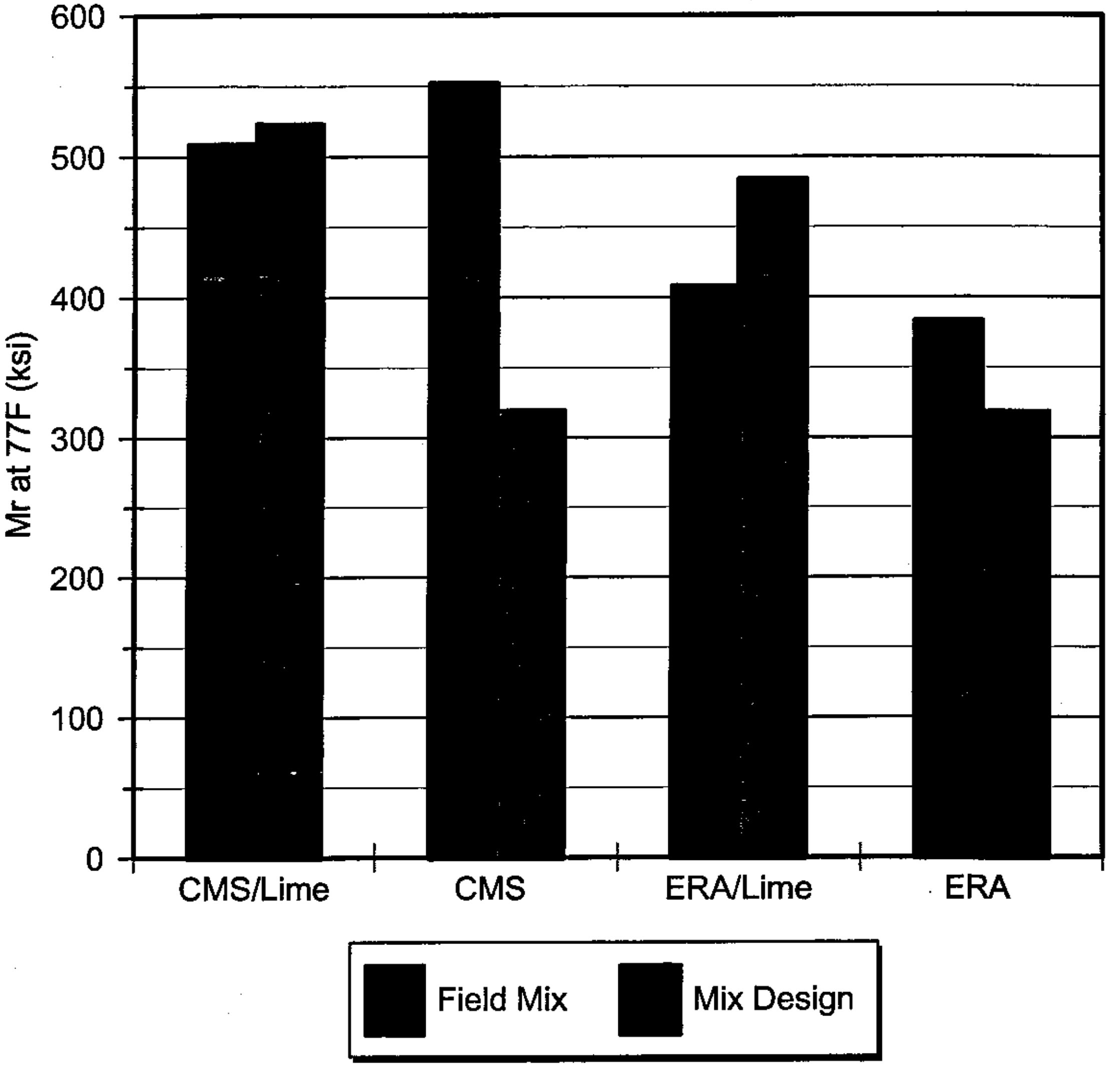

Figure 9. Comparison of mix design and field mixtures, final curing, SR 396, Lovelock.

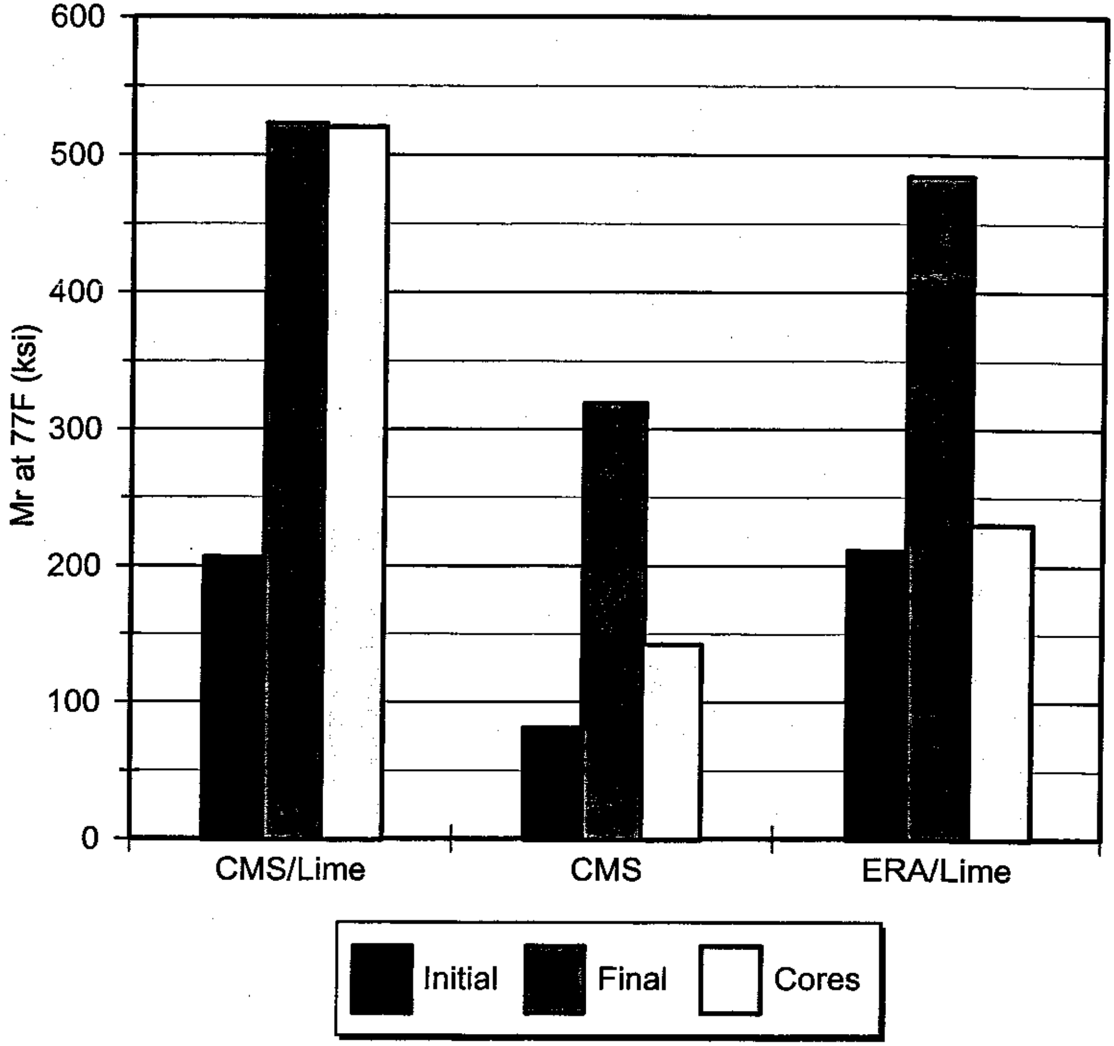

Figure 10. Comaprison of mix design and field cores, SR 396, Lovelock.

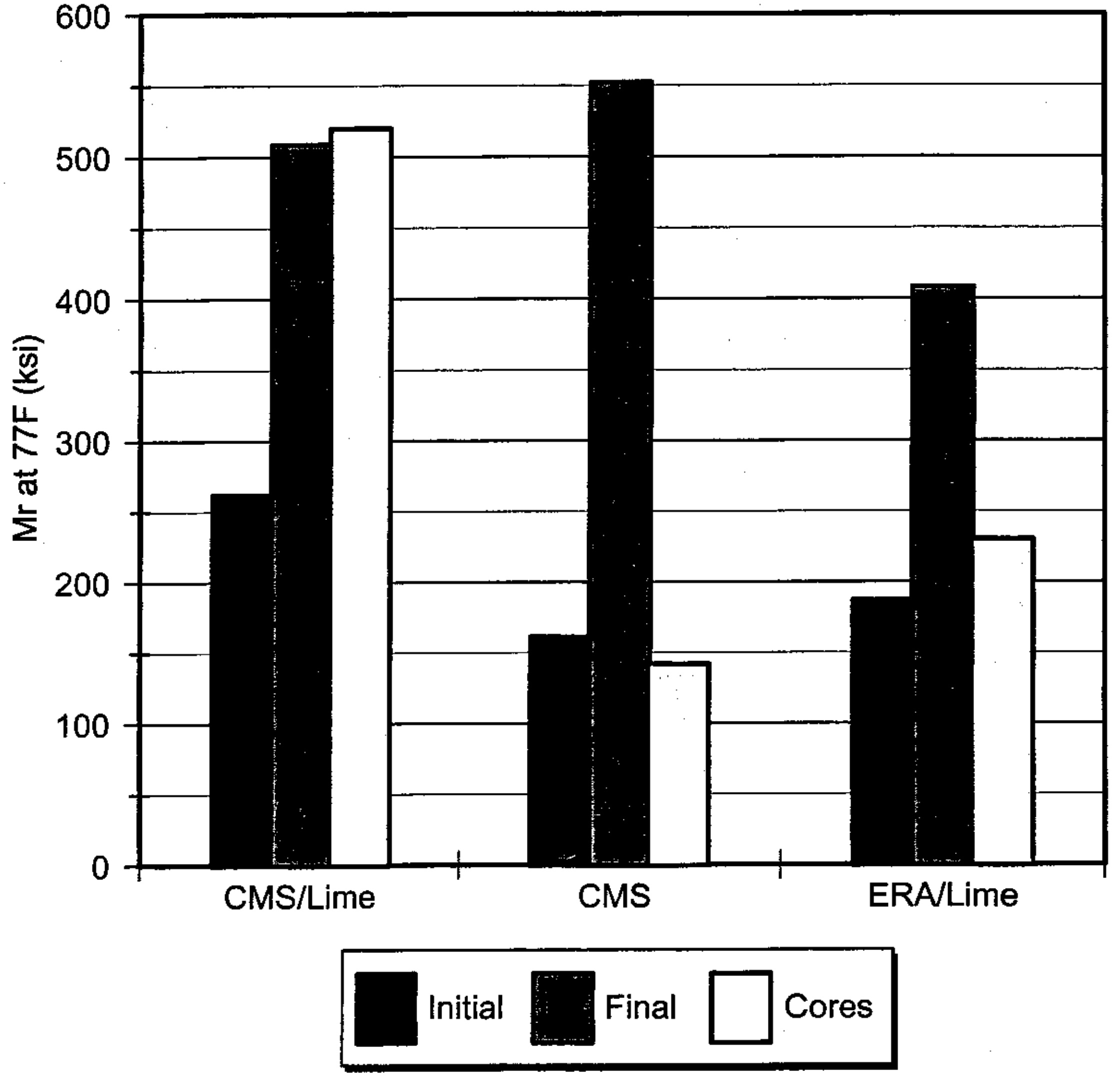

Figure 11. Comparison of field mixtures and field cores, SR 396, Lovelock.

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