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COMPREHENSIVE SUBGRADE DEFLECTION ACCEPTANCE CRITERIA

**PHASE III
FINAL REPORT**



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16. Abstract This report has presented the findings of Phase III of research conducted to aid in the development of subgrade deflection acceptance criteria for WisDOT. The reconfigured rolling wheel deflectometer (RWD), portable truck-mounted deflection measurement systems, and automated dynamic cone penetrometer (DCP) were utilized on subgrade construction projects throughout the 2000 construction season. Laboratory analysis of soil properties, including Proctor, CBR and unconfined compression tests, were also conducted. The research findings have validated the concept of using deflection testing results to identify areas of poor in-place stability within constructed subgrades. It is recommended that pilot implementations of deflection acceptance testing be conducted in conjunction with subgrade penetration testing and moisture controls until more data has been collected, especially in moisture sensitive fine grained soil types. The use of deflection acceptance testing, in conjunction with in-situ penetration tests, should provide the data necessary to determine if the in-place support capacity for a given soil is sufficient to provide a stable construction platform for subsequent paving operations. However, it is important to note that both the RWD and DCP test results are related to the moisture-density conditions at the time of testing. Soils that show acceptable results (i.e., low deflections) may subsequently weaken due to changes in moisture content, freezing/thawing, etc. In instances where subgrade acceptance is well in advance of base course application, subgrade moisture changes may result in decreased soil support.			
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COMPREHENSIVE SUBGRADE DEFLECTION ACCEPTANCE CRITERIA

PHASE III FINAL REPORT WI/SPR 02-01
WisDOT Highway Research Study # 98-1
SPR # 0092-45-95

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1.0 INTRODUCTION

In late 1995 the WisDOT Division of Highways Quality Steering Team (QST) began a detailed process redesign analysis of their current subgrade design and construction process. The charge of the QST was to develop a subgrade design and construction process which would "improve subgrade quality, limit contract change orders, and reduce unplanned program costs." The final report prepared by the QST, dated May 12, 1997, presented a prioritized listing of 21 recommendations aimed at improving both the service to the process customers and the quality of constructed subgrades. The recommended development of specifications for deflection acceptance criteria for completed subgrades to replace all current compaction specifications was deemed essential for process improvement.

In November, 1997, a deflection specification team was established to develop the framework and form for deflection acceptance specifications for subgrade construction. As part of this effort, a research contract was awarded in July, 1998, to the Marquette Center for Highway and Traffic Engineering to provide information and recommendations to the specification development team which would be applicable for acceptance testing of finished subgrades as well as intermediate layers of embankment construction.

This report documents the results of Phase III of this research effort. The previous results of Phase I and II activities have been documented in WisDOT Report WI/SPR-03-00 dated March, 2000. The pertinent Phase I & II research results can be summarized as follows:

1. The Rolling Wheel Deflectometer (RWD), which was designed and fabricated by Marquette University research staff, provides efficient collection of deflection data along completed subgrade surfaces.
2. The Automated Dynamic Cone Penetrometer (ADCP), which was designed and fabricated by Marquette University research staff, provides efficient collection of the penetration resistance of completed subgrades to a depth of 1 meter. This data can be used to determine the stability of the completed subgrades in terms of the in-place California Bearing Ratio (CBR).
3. To provide an adequate construction platform, the upper 24 inches of a completed subgrade should provide a minimum CBR value of 6.

4. Deflection testing, conducted on fine-grained soils with the Rolling Wheel Deflectometer (RWD), have provided useful data trends of deflection versus in-place CBR which can aid in the development of deflection acceptance criteria.
5. Deflection testing of non-cohesive soils, such as clean sands, may not be an adequate indicator of in-place stability due to the lack of confinement at the surface of these materials.
6. Supplemental field data, such as in-place moisture-density and/or dynamic cone penetrometer (DCP) tests may be needed to fully differentiate acceptable and non-acceptable subgrades.

The primary objectives of Phase III of this study were 1) to supplement the database of subgrade deflection response established during Phases I & II, 2) to determine if deflection testing with an instrumented quad-axle dump truck was a viable alternative to RWD testing, and 3) to provide recommendations for the development of pilot subgrade deflection acceptance specifications which could be incorporated into selected subgrade construction projects during the Year 2001 construction season. To meet these objectives, additional testing was conducted by the Marquette University research staff on selected construction projects during the Year 2000 construction season. Field tests completed by Marquette staff include deflection tests using the re-configured RWD, penetration tests using the automated and hand-held DCP, and deflection tests using an instrumented quad-axle dump truck. During field deflection testing, representatives from WisDOT were present to conduct in-place moisture-density tests using the nuclear gage. Laboratory tests were also conducted by Marquette staff on soil samples obtained from each project, including standard Proctor compaction tests, laboratory CBR tests using the fabricated Proctor specimens, and unconfined compression tests on smaller-sized compaction specimens.

2.0 FIELD TEST PROGRAM

Subgrade deflection tests were conducted at selected subgrade construction sites in Wisconsin during the Year 2000 construction season. Deflection tests were conducted over previously accepted grades as well as over subgrades purposely placed and compacted in a manner which would generally be considered as unacceptable. These latter tests were conducted to provide deflection data illustrative of subgrade conditions where the upper portions of the subgrade would be considered acceptable but lower portions would not. Site clearances were provided by the grading contractors to allow for testing prior to base course applications. The collected deflection and/or penetration data was not used for subgrade acceptance on any of the included projects.

The field test results for each project are presented in both tabular and graphical form. Tabular results provide indications of in-place moisture-density, CBR, rolling deflection range, and residual rut depth range for those locations where CBR and/or nuclear tests were performed. Graphical results provide profiles of rolling deflection and residual rut depths as well as comparative average rolling deflections versus in-place subgrade CBR. For these comparative figures, the average rolling deflection was calculated based on deflections measured within 5 feet +/- of the DCP test location and CBR was calculated based on total penetration through each 12 inch portion of the upper 24 inches of subgrade as well as total penetration through the full 24 inches

2.1 USH 41 - Kaukauna

Subgrade deflection tests were conducted in April, 2000 along a previously accepted tangent section adjacent to USH 41 near Kaukauna. This section of subgrade is composed of sandy silts and was completed under State Project ID 1131-08-72. Deflection tests were conducted along a short, 250 ft section of the grade using the reconfigured RWD with a total wheel load of 11,580 lb. Comparative DCP testing was also conducted at selected locations. Nuclear soil testing and standard Proctor tests were conducted by WisDOT D3 staff.

Two passes of the RWD were completed over the grade, with the first pass being observed by WisDOT project staff. **Table 2.1.1** provides comparative test data for those

locations where nuclear tests were performed. **Figures 2.1.1 and 2.1.2** illustrate the collected deflection profiles. **Figures 2.1.3 to 2.1.5** illustrate the average rolling deflection versus subgrade CBR. During the first test pass, no objectionable portions of subgrade were identified by the WisDOT observers. Which is in agreement with the low deflections recorded. The second RWD pass, which was not observed by WisDOT engineers, resulted in significantly higher deflections for large portions of the test section. This dramatic increase in deflections was most likely due to the in-place moisture-density of the silty soils. Nuclear tests indicated relative compaction values from 86.9% to 92.6% with water contents significantly above optimum. For these moisture-density conditions, repeated rolling has the effect of increasing density and transitioning the soil through the line of optimums. When this occurs, significant weakening of the soil may be observed, as was the case for the second test run.

2.2 CTH YY - Menomonee Falls

Subgrade deflection tests were conducted in June, 2000 during the reconstruction of CTH YY. Deflection tests were conducted along a short, 150 ft section of clayey fill materials which were purposely placed to a depth of 2 ft with minimal compaction approximately 3 days prior to testing.

The as-placed fill section was tested using the reconfigured RWD with a total wheel load of 11,580 lb with comparative DCP testing conducted at selected locations. Nuclear soil testing was conducted by WisDOT D2 staff with Proctor test conducted by Marquette staff. The initial deflection and DCP tests indicated higher in-place stability than had been anticipated. As such, the grade was reworked to a depth of approximately 2 feet with a track dozer. Surface compaction of the re-worked grade was completed with a steel drum roller without vibration. Subsequent series' of deflection, DCP and nuclear tests were performed after varying numbers of roller passes. **Table 2.2.1** provides comparative test data for those locations where nuclear tests were performed. **Figures 2.2.1 through 2.2.4** illustrate the collected deflection profiles and **Figures 2.2.5 through 2.2.7** illustrate average deflections and residual rutting versus in-place CBR. The deflection profiles indicate a significant increase in deflections after initial reworking of the soils, with DCP

testing indicating CBR values less than 6 for the majority of locations. After subsequent rolling, the stability of the upper 12 inches of the subgrade was increased to CBR values above 6 and a significant reduction in deflections was noted, effectively masking the weaker soils from 12 - 24 inches below grade.

2.3 STH 164 - Waukesha

Subgrade deflection tests were conducted in July, 2000 during the widening of STH 164. Deflection tests were conducted along a short, 200 ft section of silty fill materials which were previously placed but purposely reworked to a depth of 2 ft with minimal compaction on the evening prior to deflection testing.

The reworked fill section was tested using the reconfigured RWD with a total wheel load of 11,580 lb with comparative DCP testing conducted at selected locations. Nuclear soil testing was conducted by WisDOT D2 staff with Proctor test conducted by Marquette staff. Surface compaction of the re-worked grade was completed with a steel drum roller with and without vibration. Subsequent series' of deflection, DCP and nuclear tests were performed after varying numbers of roller passes.

Table 2.3.1 provides comparative test data for those locations where nuclear tests were performed. **Figures 2.3.1 through 2.3.3** illustrate the collected deflection profiles. **Figures 2.3.4 through 2.3.6** illustrate average deflections and residual rutting versus in-place CBR. DCP testing indicated that the in-place CBR was above 6 for the majority of cases, regardless of how the subgrade was worked. Average surface deflections of approximately 1.25 inches were recorded where the lower 12 inches of the subgrade was in the range of CBR = 6.

2.4 STH 33 - Beaver Dam

Subgrade deflection tests were conducted in July, 2000 during the reconstruction of STH 33 between Beaver Dam and Horicon. Deflection tests were conducted along a short, 100 ft section of silty soils over which a nominal 24" layer of breaker run was placed. Comparative DCP testing was conducted at selected subgrade locations prior to breaker run placement. Nuclear soil testing was not conducted but Proctor and unconfined

compression tests were conducted by Marquette staff on recovered soil samples.

Deflection tests were conducted immediately after placement and compaction of the breaker run using the reconfigured RWD with a total wheel load of 11,580 lb.

Additionally, comparative RWD tests were conducted after the placement and compaction of a 1 inch layer of reclaimed asphaltic materials over the breaker run.

These two test series were conducted 1) to determine if the 24" breaker run layer provided sufficient cover over the poor silty soils, and 2) to determine the effects of the open texture of the breaker run surface on deflection readings.

Table 2.4.1 provides comparative test data for those locations where DCP tests were performed. **Figures 2.4.1 through 2.4.3** illustrate the collected deflection profiles. The deflection results indicate the breaker run layer effectively protects the lower strength subgrade. For those tests conducted directly over the breaker run, deflections were generally in the range of 0.0 to 0.5 inches, with most of the variation attributable to scatter produced by the open texture of the breaker run surface. After placement of the AC skim layer, deflections and scatter were significantly reduced to the range of 0.0 to 0.25 inches.

2.5 STH 60 - Columbus

Subgrade deflection tests were conducted in August, 2000 during the reconstruction of STH 60 between North Leeds and Columbus. Deflection tests were conducted along a short, 150 ft section of mixed fill materials which were placed to a depth of 2 ft with minimal compaction immediately prior to deflection testing.

The fill section was tested using the reconfigured RWD with a total wheel load of 10,300 lb with comparative DCP testing conducted at selected locations. Nuclear soil testing was conducted by WisDOT D1 staff with Proctor test conducted by Marquette staff. Surface compaction of the fill was completed with a steel drum roller with and without vibration. Subsequent series' of deflection, DCP and nuclear tests were performed after varying numbers of roller passes.

Table 2.5.1 provides comparative test data for those locations where DCP tests were performed. **Figures 2.5.1 through 2.5.3** illustrate the collected deflection profiles. **Figures 2.5.4 through 2.5.6** illustrate average deflections and residual rutting versus in-

place subgrade CBR. The deflection results clearly indicate a weak zone near station 1+30 where the upper 12 inches of the subgrade had low CBR values. Additionally, tests conducted near station 0+26 also show the effects of low CBR values in the upper 12 inches.

2.6 124th St - Milwaukee

Subgrade deflection tests were conducted in August, 2000 during the realignment of 124th Street just South of STH 74/100. Deflection tests were conducted along a short, 100 ft section of clayey materials which were re-worked to a depth of 2 ft with minimal compaction immediately prior to deflection testing. An additional series of RWD tests were conducted along an adjacent clayey fill section which was placed and compacted approximately 2 weeks before testing.

The test section was tested using the reconfigured RWD with a total wheel load of 11,800 lb with comparative DCP testing conducted at selected locations. Nuclear soil testing was conducted by WisDOT D2 staff with Proctor test conducted by Marquette staff. Surface compaction of the fill was completed with a steel drum roller with and without vibration. Subsequent series' of deflection, DCP and nuclear tests were performed after varying numbers of roller passes.

Table 2.6.1 provides comparative test data for those locations where DCP tests were performed. **Figures 2.6.1 through 2.6.3** illustrate the collected deflection profiles. **Figures 2.6.4 through 2.6.6** illustrate average deflections and residual rutting versus in-place subgrade CBR. For those locations where the CBR value was below 6 in the upper 12 inches, average deflection of approximately 1.25 inches were noted.

2.7 STH 60 - Lodi

Subgrade deflection tests were conducted in August, 2000 during the reconstruction of STH 60 near Lodi. Deflection tests were conducted in conjunction with a UW-Madison research project comparing various subgrade/subbase stabilization processes. For the purposes of this report, test conducted along a control and a fly ash stabilized subgrade will be reported. The control section was composed of 24 inches of select material over

the native silty soils. The fly ash section was composed of native silty soils stabilized to a depth of 12 inches with 9% Class C fly ash by dry weight of soils. Tests were conducted using the reconfigured RWD with a total wheel load of 11,800 lb with comparative DCP testing conducted at selected locations by UW-Madison research staff. Nuclear soil testing was not conducted during testing and no laboratory analysis of soil properties are available.

Table 2.7.1 provides comparative test data for those locations where DCP tests were performed. **Figures 2.7.1 and 2.7.2** illustrate the collected deflection profiles. **Figures 2.7.3 through 2.7.5** illustrate average deflections and residual rutting versus in-place CBR for the stabilized silts. The test results indicate that both the select material and the silt stabilization provide stable construction platforms with minimal deflection. The stabilized silts also masked low CBR values recorded for the lower 6 to 8 inches of the upper 24 inches of subgrade. It is also interesting to note the marked change in deflection response for the stabilized silts near station 266+00. The western end of this test site, between stations 263+00 and 266+00 were compacted with the vibrator turned on while the remaining portions were compacted without vibration. The higher deflections recorded over the western end indicate that the vibratory compaction may have weakened the bonding from the initial setting up of the fly ash.

2.8 USH 10 - Waupaca

Subgrade deflection tests were conducted in September, 2000 during the widening of USH 10 near Waupaca. Tests were conducted along a 400 ft section of sandy soils immediately prior to base course placement using the reconfigured RWD with a total wheel load of 11,800 lb. Comparative DCP testing was conducted at selected locations. Proctor analysis of the soils was conducted by Marquette staff but no Nuclear soil testing was conducted.

Table 2.8.1 provides comparative test data for those locations where DCP tests were performed. **Figure 2.8.1** illustrates the collected deflection profiles. **Figures 2.8.2 through 2.8.4** illustrate average deflections and residual rutting versus in-place subgrade CBR. In general, deflections of approximately 1.0 to 1.25 inches were recorded where in-

place CBR values were above 6.

2.9 STH 57 - Fredonia

Subgrade deflection tests were conducted in October and November, 2000 during the widening of STH 57 near Fredonia. Comparative DCP testing was conducted at selected locations. Nuclear soil testing was conducted by WisDOT D2 staff and Proctor analysis of the soils was conducted by Marquette staff.

Deflection tests were conducted in October along a 2-mile section of accepted red clay soils prior to base course placement. The November tests were conducted along a 1200 ft section of recently placed red clay fill. During both test series, the reconfigured RWD was being pulled by an instrumented quad-axle dump truck loaded to approximately 25,000 lb on the front axle. Deflection tests conducted at this project location, which provided the opportunity to assess the viability of using an instrumented quad-axle dump truck during routine deflection acceptance testing, were made possible through the fabrication of various sensor mounting brackets by Michels Pipeline, Inc. **Figures 2.9.1 and 2.9.2** illustrate the deflection sensor array utilized on the quad-axle truck set-up. As developed, this hardware requires approximately 1 hour to install and calibrate prior to testing. Once instrumented, the quad-axle truck would not be available for routine materials hauling. Dismantling of the hardware requires approximately 45 minutes.

Tables 2.9.1 through 2.9.3 provide comparative test data for those locations where DCP tests were performed. **Figures 2.9.3 through 2.9.8** illustrate the collected deflection profiles from the October and November tests. It should be noted that the October tests were conducted over a previously accepted grade which had experienced significant drying prior to deflection testing, thus yielding a very firm and resistant platform. These red clay soils experience significant softening upon moisture gain, as was evident in localized areas where overflow during water ballasting was experienced. The November tests were conducted over recently placed fill materials which had little to no moisture loss after placement. Furthermore, only the eastern portion of this fill (northbound deflection test run) was rolled immediately prior to testing. The western portion (southbound deflection test run) was not rolled to assess the impacts of a roughened, loose textured

surface on deflection results. The deflection profiles obtained over the unrolled surface indicate an increase in the data scatter as well as increased deflections due to the loose surface.

The deflection results obtained during the November truck tests indicated numerous data irregularities resulting from malfunctioning sensors on both the front and rear sensor racks. These results were further analyzed to determine if a reduced sensor configuration could provide sufficient data for acceptance testing. If acceptable, the reduced configuration would significantly reduce mounting and dismantling times and would allow the instrumented truck to be utilized for routine hauling between tests. **Figures 2.9.9 through 2.9.14** illustrate deflection profiles for various sensor combinations selected for analysis using data recorded by the RWD and the instrumented truck. In all cases, the original RWD profile, which represents the baseline “truth” readings, is provided for comparison. The three sensor analysis utilizes two of the front sensors and the axle sensor difference between readings for the front. These deflection comparisons indicate very good agreement between the three sensor configuration and the full array representing baseline “truth” values. Good agreement is also noted for single axle sensor and baseline values, however some resolution is lost with this simplified configuration.

Figures 2.9.15 through 2.9.17 illustrate average RWD and truck deflections versus in-place subgrade CBR. For these tests, deflections exceeding approximately 1.5 inches were noted in areas with CBR values below 6.

2.10 Discussion of Field Test Results

The RWD test results obtained generally validate the concept that deflections may be used as an indicator of low in-place soil strength. Surface deflections in excess of 2.0 inches were measured during 1998 testing at locations where subsequent DCP testing indicated CBR values less than 6 within portions of the upper 24 inches of subgrade. Field data collected in 1999 with the reconfigured RWD is relatively consistent with data collected during the initial phase of this project. Areas with weak subgrade surfaces to depths of 12 or more inches were readily identified. However, areas with weak subgrades in the depth of 12 to 24 inches below the surface overlain by stiff subgrade materials were not as easily

differentiated. Deflection data collected with the instrumented quad-axle truck has shown similar trends; however the quantity and quality of this data is low as compared to that collected with the RWD.

The year 2000 deflection data indicates a variation of deflection results from the included projects. **Figures 2.10.1 to 2.10.4** provide summaries of deflection results versus in-place CBR for the variety of soils tested. **Figure 2.10.5** provides a summary of the 1998 - 2000 deflection results versus in-place CBR, with all deflection results normalized to a common loading of 12,000 lb. Based on these figures, a deflection threshold of approximately 1.5 inches is recommended for use during pilot implementations to differentiate low strength soils with $CBR < 6$ in the upper 12 inches. This threshold may not capture every project occurrence of $CBR < 6$, and in fact may occur where $CBR > 6$, but it appears to be the most appropriate selection based on the collected data. During pilot implementations, companion DCP testing at locations with deflections in the range of 1.0 to 2.0 inches would further clarify the in-place soil strengths and aid in determining the percentage of situations where poor soils would be accepted and/or good soils would be rejected by this threshold.

3.0 LABORATORY TEST PROGRAM

Laboratory testing, including Proctor, CBR, and unconfined compression were conducted on soil samples obtained during field deflection testing. For the Proctor and CBR tests, soil samples were oven dried, pulverized, and passed through a No. 10 sieve prior to testing. Compaction and CBR tests were conducted on all minus No. 10 materials using a standard 4-inch diameter mold.

Unconfined compression tests were conducted on the silt soils obtained from STH 33 near Beaver Dam and on the red clay soils obtained from STH 57 near Fredonia. These soils were selected to obtain comparative strength data for two common classes of fine-grained, moisture sensitive soils. The soil samples were oven dried, pulverized, and passed through a No. 40 sieve prior to testing. Compaction and unconfined compression tests were conducted on all minus No. 40 materials.

3.1 Proctor and CBR Analysis

Moisture-density curves were developed for each soil sample by the Marquette research staff. Standard Proctor compaction protocol was followed for all tests. Standard CBR tests were performed on each specimen immediately after compaction. **Figures 3.1.1 through 3.1.8** illustrate the moisture-density and CBR vs moisture relations for each soil tested. As illustrated, the fine-grained soils exhibit typical trends of decreasing CBR with increasing moisture content at compaction. Furthermore, the loss in strength at moisture contents above optimum is most dramatic for silty soils. Based on the CBR trends, one may conclude that compaction of silts at moisture contents below optimum would be desirable to provide higher support stability. While this conclusion may be appropriate immediately after compaction, it woefully neglects the fact that moisture gain after compaction can significantly decrease the strength of moisture sensitive soils. This moisture-strength loss effect is best seen by conducting CBR tests after soaking of the compacted specimens, which was done as part of the unconfined compression tests described below.

3.2 Unconfined Compression Testing

Unconfined compression tests were conducted on the silt and clay soils from STH 33 and STH 57, respectively. Specimens were compacted using the Harvard miniature compaction apparatus at selected moisture contents on either side of optimum as determined from the Proctor tests. This Harvard apparatus utilizes a kneading type compaction produced by a spring actuated plunger and results in compacted specimens 1.3 inches in diameter and 2.8 inches in length. Two replicate specimens were compacted at each moisture content with one specimen tested immediately after compaction and the other allowed to soak in water for 48 hours prior to testing.

Table 3.1.1 provides comparative test data for the soaked and unsoaked specimens. The unconfined compression strengths were used to estimate the CBR of each specimen using the relation:

$$\text{CBR} = q_u / 4.5$$

where: CBR = California bearing ratio, %
 q_u = unconfined compression strength, psi

Figures 3.2.1 through 3.2.4 illustrate the compaction and CBR trends for these soils. As expected, for those specimens compacted on the dry side of optimum, the soaking resulted in a significant moisture gain and concurrent strength loss.

A final series of tests were conducted on the STH 33 silt to illustrate the effects of relative compaction on soil strength. Harvard specimens were compacted near optimum moisture content with varying levels of compaction effort to simulate field conditions where moisture content is properly controlled but full compaction is not attained. As shown in **Figure 3.2.5**, decreased relative compaction results in a significant loss of strength.

3.3 Discussion of Laboratory Tests

The Proctor/CBR test results clearly indicate the relations between compaction moisture content and resultant soil strength. In normal practice tests such as these can be used to

provide an indication of the expected in-place soil strength after compaction if proper compaction controls are utilized, i.e., full compaction near optimum moisture. For those soils where sufficient stability cannot be attained through proper compaction, select materials can be specified to ensure an adequate construction platform is produced. Furthermore, where laboratory testing clearly indicates a CBR in excess of 6 should be easily attained, consideration should be given to tightening acceptance criteria to ensure that the pavement designer's expectations of soil support strength are realized.

The unconfined compression tests on soaked and unsoaked specimens further illustrate the detrimental effects of moisture gain on fine-grained soils compacted on the dry side of optimum. Combined with Proctor/CBR results, these tests can be utilized to indicate acceptable moisture contents during compaction to ensure that significant strength loss does not occur after grade acceptance. When viewed as a whole, these limited lab tests indicate a need for establishing and controlling moisture contents during compaction. Without these controls, the acceptance of a completed subgrade based on in-placed stability by deflection testing or any other means can lead to erroneous conclusions regarding the long-term performance of the subgrade.

4.0 DEFLECTION ACCEPTANCE CRITERIA

The results of study Phases 1 and 2 recommended the development of deflection acceptance criteria based on in-place subgrade stability as defined by the soil CBR value. A soil CBR value of 6 was selected to represent the lower threshold of soil strength required to provide an adequate construction platform and limit subgrade rutting under construction traffic to ½ inch or less. CBR values in excess of 6 should be readily achieved for many soil types if proper compaction techniques are followed. For these soils, lowering the threshold of acceptability to a CBR of 6 may defeat the purpose of the specifications and result in completed grades with stabilities far below designer's expectations. On the other hand, poorer soils which are expected to have CBR values in the range of 6 - 10 after proper compaction may be considered as candidates for acceptance testing to ensure the desired minimal strength is achieved. The above discussion illustrates the challenge of developing deflection-based acceptance criterion that will adequately cover the full range of soil strength variations that may be encountered in the field. The trends of deflection versus in-place CBR developed from this study indicate that subgrade deflection measurements under controlled loading conditions may be useful for identifying test locations where in-place strength is adequate for construction operations, provided those operations occur without significant moisture change in the soils. However, unless the moisture sensitivity of the soils has been established and proper moisture controls have been effected during construction, any soil strength measure can be viewed as transient and adverse changes in strength may be likely.

It is recommended that Year 2001 pilot implementations of the deflection specifications be confined to projects where moisture sensitive silts and clays are anticipated to be in place within the upper 24 inches of completed grades. A deflection acceptance threshold of 1.5 inches under a standard single wheel loading of 12,000 lb is recommended for use during pilot implementations. Implementation of the pilot specifications should be viewed as a learning experience for both WisDOT and subgrade contractors and should not be used for actual subgrade acceptance, but rather as a supplemental data source from which future acceptance decisions could be based. Based on deflection data gathered during the pilot implementations with both the RWD and

instrumented quad-axle dump trucks, final acceptance criteria should be judiciously selected so that associated risks are responsibly shared between WisDOT and the subgrade contractor.

4.1 Deflection Testing Equipment

It is recognized that WisDOT and industry desire the use of a loaded dump truck for performing deflection testing. This desire is reasonable as the quad-axle dump truck type is predominately used for material placement during current pavement construction. The use of quad-axle dump trucks for subgrade testing also eliminates the restriction on equipment availability for virtually any site location. The results of truck/trailer comparative testing on STH 57 indicate a simplified sensor array, including three sensors per wheel track targeted off the front tires, may provide practical results suitable for acceptance testing.

For the purposes of pilot implementations during the 2001 construction season, it is recommended that a six sensor array be utilized on quad-axle instrumentations, with three sensors dedicated to each wheel track of the truck. **Figure 4.1.1** illustrates this simplified configuration. All measurement equipment would be confined to the area between the front wheel base of the truck and therefore, once instrumented, the truck could be utilized for common material hauling with minimal safeguards. Where desired, the fully instrumented RWD could be used in tandem with the instrumented truck to provide comparative measures.

It is recommended that pilot implementations of the deflection acceptance specifications utilize the following guidelines for truck instrumentation:

1. The dump truck should be loaded to a sufficient gross load to produce a distributed front axle loading of approximately 24,000 lbs with the pusher axles raised. Total load as well as front axle loading should be verified by a certified weigh ticket.
2. Front axle flotation tires, which are normally G286 super single tires inflated to 110 - 125 psi, should be specified.
3. Deflection instrumentation should be mounted in such a way as to provide recordation of both front tire wheel tracks. A total of three sensors are suggested

for each wheel track, with 2 sensors mounted to the front bumper and one sensor mounted on the front axle.

4. A distance measuring instrument (DMI) must be provided on the truck and set up in such a way as to ensure that firing interval of the DMI is matched to the spacing between the bumper and axle mounted sensors.
5. A paint marking system may be mounted to the front bumper to provide positive surface marks indicating locations where wheel deflections exceed threshold values.

4.2 Deflection Testing Pattern

It is recommended that deflection tests be conducted over the full-width of the constructed subgrade as defined by the edge limits of the proposed pavement shoulders. Tests should be conducted with a minimum of one pass of the loaded truck along each shoulder and proposed driving lane. Deflection testing should be performed at normal walking speeds not to exceed 5 mph nor be less than 2.5 mph. Deflection testing should be completed with the pusher axle wheels raised during testing with all load distributed between the front steering axle and the rear tandem axle during testing.

4.3 Deflection Acceptance Criteria

The deflection data gathered during this research study indicates rolling deflections exceeding 1.50 inches are representative of cohesive soils with upper layer CBR values below 6. For use within Year 2001 pilot implementations, this threshold value should be utilized to identify potentially "failed" test locations. In these locations, supplemental subgrade testing, including DCP and nuclear testing, should be conducted at selected locations to better define the strength and soil profile of the constructed subgrade layer. Comparative testing is also recommended in selected areas where deflections exceed 1.0 inch to aid in the establishment of a final acceptance criteria. The combined results of all field tests in "failed" areas are expected to aid in the identification of potential causes of low stability as well as enumerating viable corrective actions.

4.4 Supplemental Test Requirements

For those projects selected for pilot implementation, laboratory testing of soils expected to be used for construction should be conducted to establish moisture-density and compacted strength profiles for soaked and unsoaked specimens. These results should be provided to the grading contractor to ensure that agency expectations are clearly enumerated. During subgrade construction, compaction moisture contents should be monitored, particularly in the upper 24 inches, to provide evaluation data for assessing resultant deflection profiles.

5.0 SUMMARY AND RECOMMENDATIONS

This report has presented the findings of Phase III of research conducted to aid in the development of subgrade deflection acceptance criteria for WisDOT. The reconfigured rolling wheel deflectometer (RWD), portable truck-mounted deflection measurement systems, and automated dynamic cone penetrometer (DCP) were utilized on subgrade construction projects throughout the 2000 construction season. Laboratory analysis of soil properties, including Proctor, CBR and unconfined compression tests, were also conducted.

The research findings indicate that deflection test results may be appropriate for identifying areas of poor in-place stability within constructed subgrades. However, deflection testing alone may not provide all of the data necessary to properly differentiate acceptable and non-acceptable subgrade stabilities. It is recommended that pilot implementations of deflection acceptance testing be conducted in conjunction with subgrade penetration testing and moisture controls until more data has been collected, especially in moisture sensitive fine grained soil types. The use of deflection acceptance testing, in conjunction with in-situ penetration tests, should provide the data necessary to determine if the in-place support capacity for a given soil is sufficient to provide a stable construction platform for subsequent paving operations. However, it is important to note that both the RWD and DCP test results are related to the moisture-density conditions at the time of testing. Soils that show acceptable results (i.e., low deflections) may subsequently weaken due to changes in moisture content, freezing/thawing, etc. In instances where subgrade acceptance is well in advance of base course application, subgrade moisture changes may result in decreased soil support.

The overall objectives of this research have been met, particularly in the development of useful correlations between subgrade deflections and in-place subgrade stability as measured by the California Bearing Ratio (CBR). Deflection data collected to date using instrumented quad-axle trucks indicates this data source may also be adequate for acceptance, provided deflection criteria are judiciously selected to responsibly apportion risks between WisDOT and subgrade contractors. It is recommended that pilot implementations of deflection acceptance testing be conducted during the 2001

construction season to determine if a practical testing protocol can be implemented to fulfill agency goals for quality subgrade construction with minimal disruption to normal construction practices. During the piloting process, subgrade contractors would be at no additional risk of subgrade rejection. Instead, this piloting process can be viewed from an educational standpoint whereby the testing effort necessary to support full implementation of deflection acceptance criteria can be identified and both WisDOT and subgrade contractors can more clearly see the causal relationships between soil type, compaction moisture content, compactive effort, and in-place subgrade stability.

Table 2.1.1: Comparative Field Test Data for USH 41 - Kaukauna

Test Station	Nuclear Tests ⁽¹⁾		In-Place CBR (Depth) ⁽⁴⁾	RWD Deflection Range, inches Run1 (Run2)	RWD Rut Depth Range, inches Run1 (Run2)
	% Relative Compaction ⁽²⁾	% Optimum Moisture ⁽³⁾			
0+91	92.6	n.a.	2-6 (0-6") 10-20 (6-24")	0.1 - 0.4 (0.5 - 1.4)	0.1 - 0.3 (0.5 - 1.1)
1+46	92.0	143.1	4 (0-3") 10-30 (3-24")	0.1 - 0.7 (0.9-2.3)	0.0 - 0.4 (0.9-2.)
1+94	86.9	132.5	7 (0-2") 10-30 (2-24")	0.1 - 0.5 (0.0 - 0.1)	0.0 - 0.3 (0.0 - 0.1)

(1) All nuclear tests conducted after second RWD run.

(2) Maximum Dry Density = 118.2 - 118.7 pcf

(3) Optimum Moisture Content = 11.6 - 11.7%

(4) DCP Testing conducted after RWD run 2.

Table 2.2.1: Comparative Field Test Data for CTH YY - Menomonee Falls

Test Station	Nuclear Tests ⁽¹⁾		In-Place CBR (Depth)	RWD Deflection Range, inches	RWD Rut Depth Range, inches
	% Relative Compaction ⁽²⁾	% Optimum Moisture ⁽³⁾			
Initial As-Placed Fill					
0+50	101.3	128.9	5-6 (0-5") 7-30 (5-10") 3-8 (10-24")	0.4 - 0.5	0.0 - 0.1
1+25	105.4	114.1	6-18 (0-3") 2-5 (3-14") 9 (14-16") 2-6 (16-24")	0.8 - 1.0	0.3 - 0.4
After Re-working +2 Roller Passes					
0+50	94.5	130.5	4-5 (0-2") 5-18 (2-5") 4-6 (5-14") ⁽⁵⁾	0.8 - 1.3	0.8 - 1.0
1+25	99.8	128.9	3-6 (0-24")	1.0 - 1.5	0.4 - 0.9
1+25 ⁽⁴⁾	85.3	212.5			
After 4 Additional Roller Passes (6 Total Passes)					
0+50	99.1	135.2	6-7 (0-3") 5-6 (3-6") 3-7 (6-24")	0.6 - 0.8	0.5 - 0.7
1+25	99.9	135.2	4-5 (0-3") 5-7 (3-10") 8-12 (10-12") 3-6 (12-24")	0.2 - 0.3	0.0 - 0.1
After 4 Additional Roller Passes (10 Total Passes)					
0+50	100.2	125.8	8-10 (0-2") 4-6 (2-10") 9-10 (10-12") 4-6 (12-24")	0.4 - 0.7	0.2 - 0.5
1+25	99.6	118.0	n.a.	0.4 - 0.6	0.1 - 0.3

(1) All nuclear tests at 8" depth except as noted.

(2) Maximum Dry Density = 117.4 pcf

(3) Optimum Moisture Content = 12.8%

(4) Nuclear test at 12" Depth.

(5) DCP testing terminated due to cobble obstructions

Table 2.3.1: Comparative Field Test Data for STH 164 - Waukesha

Test Station	Nuclear Tests ⁽¹⁾		In-Place CBR (Depth)	RWD Deflection Range, inches	RWD Rut Depth Range, inches
	% Relative Compaction ⁽²⁾	% Optimum Moisture ⁽³⁾			
Initial Re-worked Fill + 3 Static Roller Passes					
0+61	92.6	74.3	7 (0-3") 10-30*(3-15") 6-20 (15-21") 3-6 (21-24")	1.0 - 1.4	0.6 - 0.9
1+25	95.5	104.1	4 (0-2") 7-30 (2-9") 5-6 (9-12") 8-10 (12-14") 5-6 (14-18") 7-14 (18-21") 4 (21-24")	0.7 - 0.9	0.1 - 0.4
1+85	97.5	90.5	6 (0-2") 8-20 (2-15") 3-6 (15-22") 8-20 (22-24")	0.6 - 0.9	0.1 - 0.3
After 2 Additional Static Roller Passes (5 Passes Total)					
0+61	98.9	87.8	8-30*(0-16") 5 (16-18") 6-14 (18-24")	0.6 - 0.7	0.0 - 0.3
1+25	98.2	105.4	n.a.	0.5 - 0.8	0.0 - 0.1
1+85	97.1	89.2	n.a.	0.7 - 0.9	0.0 - 0.1
After 2 Additional Static + 4 Vibratory Roller Passes (11 Total Passes)					
0+61	98.0	74.3	n.a.	0.7 - 1.0	0.1 - 0.2
1+25	99.1	102.7	n.a.	0.8 - 0.9	0.0
1+25 ⁽⁴⁾	80.6	266.2	n.a.		
1+85	104.5	81.1	8-30(0-12") ⁽⁵⁾	1.0 - 1.4	0.2 - 0.5

(1) All nuclear tests at 8" depth except as noted.

(2) Maximum Dry Density = 136.8pcf

(3) Optimum Moisture Content = 7.6%

(4) Nuclear test at 14" Depth.

(5) DCP testing terminated due to cobble obstructions

Table 2.4.1: Comparative Field Test Data for STH 33 - Beaver Dam

Test Station	In-Place CBR (Depth) ⁽¹⁾	RWD Deflection Range, inches	RWD Rut Depth Range, inches
Initial Run After Placement of 24" Breaker Run			
6+645	7-15 (0-10") 2-4 (10-24")	0.3 - 0.7	0. - 0.4
6+653	4 (0-2") 7-15 (2-24")	0.2 - 0.6	0.0 - 0.2
6+660	3-5 (0-21") 7-15 (21-24")	0.1 - 0.3	0.0 - 0.3
Initial Run After Placement of 1" Reclaimed AC Skim Coat			
6+645		0.0 - 0.4	0.1 - 0.3
6+653		0.2 - 0.4	0.1 - 0.2
6+660		0.1 - 0.3	0.0 - 0.2
Second Run After Placement of 1" Reclaimed AC Skim Coat			
6+645		0.0 - 0.1	0.0
6+653		0.0 - 0.1	0.0
6+660		0.0 - 0.1	0.0 - 0.1

(1) DCP Testing conducted prior to breaker run placement.

Table 2.5.1: Comparative Field Test Data for STH 60 - Columbus

Test Station	Nuclear Tests		In-Place CBR (Depth)	RWD Deflection Range, inches	RWD Rut Depth Range, inches
	% Relative Compaction ⁽¹⁾	% Optimum Moisture ⁽²⁾			
Initial Run After 2 Static Roller Passes					
0+26	106.4 (6") 105.6 (10")	39.5 (6") 39.3 (10")	10-30 (0-12") 8-20 (12-18") 6-8 (18-24")	0.5 - 1.1	0.4 - 0.8
1+00	100.3 (6") 102.1 (12")	55.5 (6") 54.1 (12")	n.a.	0.7 - 1.0	0.4 - 0.8
1+30	97.1 (6") 95.7 (12") 90.8 (18") 87.9 (24")	80.5 (6") 83.1 (12") 132.9 (18") 137.1 (24")	2-3 (0-12") 6-10 (12-18") 10-30 (18-24")	3.0 - 3.7	2.1 - 2.9
After 2 Additional Vibratory Roller Passes (4 Passes Total)					
0+26	101.7 (6") 102.9 (12")	74.9 (6") 72.6 (12")	n.a.	0.6 - 1.1	0.5 - 0.7
1+00	105.9 (6") 104.4 (12")	71.9 (6") 72.5 (12")	6-30*(0-8") 2-5 (8-22") 7-14 (22-24")	0.8 - 0.9	0.3 - 0.5
1+30	92.5 (6") 94.0 (12")	102.5 (6") 101.8 (12")	1-4 (0-10") 8-30* (10-24")	2.5 - 3.7	1.7 - 3.1
After Blading + 4 Vibratory Roller Passes (8 Total Passes)					
0+26	102.1 (6") 105.9 (12")	52.6 (6") 51.2 (12")	2-4 (0-6") 7-10 (6-10") 15+ (10-21")	0.9 - 1.1	0.3 - 0.5
1+00	109.6 (6") 110.3 (12")	56.2 (6") 55.3 (12")	7-16 (0-6") 2-5 (6-24")	0.8 - 1.1	0.3 - 0.7
1+30	96.9 (6") 94.4 (12")	95.7 (6") 97.7 (12")	n.a.	2.8 - 3.8	1.8 - 2.9

(1) Maximum Dry Density = 117.0 pcf

(2) Optimum Moisture Content = 17.5%

Table 2.2.1: Comparative Field Test Data for 124th St. - Milwaukee

Test Station	Nuclear Tests ⁽¹⁾		In-Place CBR (Depth)	RWD Deflection Range, inches	RWD Rut Depth Range, inches
	% Relative Compaction ⁽²⁾	% Optimum Moisture ⁽³⁾			
Initial Run After Blading + 2 Static Roller Passes					
0+00	91.6	104.7	5 (0-3") 6-7 (3-8") 3-6 (8-24")	0.8 - 1.1	0.4 - 0.6
0+50	95.3	99.3	6-20 (0-10") 4-6 (10-16") 8-20 (16-24")	0.9 - 1.2	0.8 - 1.0
1+00	100.2	104.0	6-20 (0-8") 3-5 (8-14") 6-16 (14-24")	1.0 - 1.4	0.8 - 1.1
After Blading + 3 Additional Static Roller Passes (5 Passes Total)					
0+25	103.4	98.0	7-20 (0-5") 1-5 (5-14") 7-20 (14-24")	1.0 - 1.1	0.7 - 0.8
0+50	91.1	102.7	6-15 (0-4") 3-6 (4-16") 8-20 (16-24")	0.8 - 1.0	0.4 - 0.7
1+00	98.2	132.0	4-6 (0-4") 6-8 (4-7") 3-6 (7-15") 6-8 (16-24")	0.9 - 1.3	0.6 - 1.1
After 4 Additional Static Roller Passes (9 Total Passes)					
0+15	105.4	89.3	7-20 (0-9") 3-5 (9-15") 7-20 (15-24")	0.5 - 0.8	0.5 - 0.8
0+50	96.8	100.7	n.a.	0.5 - 0.7	0.4 - 0.5
1+00	98.9	140.0	3-5 (0-12") 9-15 (12-24")	0.9 - 1.0	0.7 - 0.8

(1) Nuclear testing conducted at a depth of 8".

(2) Maximum Dry Density = 114.0 pcf

(3) Optimum Moisture Content = 15.0%

Table 2.7.1: Comparative Field Test Data for STH 60 - Lodi

Test Station	In-Place CBR (Depth)	RWD Deflection Range, inches	RWD Rut Depth Range, inches
Control Section(1)			
260+00	2-3 (0-24")	0.1 - 0.5	0.1 - 0.4
261+00	2-6 (0-24")	0.1 - 0.3	0.0 - 0.3
Fly Ash Stabilized Section			
264+00	20-30 (0-5") 10-20 (5-12") 7-12 (12-24")	0.2 - 0.5	0.0 - 0.2
265+00	10-20 (0-9") 7-10 (9-15") 4-6 (15-24")	0.3 - 0.5	0.0 - 0.1
266+00	10-30 (0-14") 9-10 (14-16") 1-3 (165-24")	0.3 - 0.5	0.0 - 0.1
267+00	10-30 (0-10") 9-10 (10-15") 3-4 (15-24")	0.1 - 0.3	0.0 - 0.1
268+00	7-16 (0-10") 3-6 (10-22") 10-22 (22-24")	0.1 - 0.3	0.0 - 0.1
269+00	8-16 (0-11") 3-6 (11-24")	0.2 - 0.4	0.0 - 0.1
270+00	10-30 (0-16") 4-6 (16-24")	0.0 - 0.4	0.0 - 0.3

(1) CBR Tests conducted prior to select fill

Table 2.8.1: Comparative Field Test Data for USH 10 - Waupaca

Test Station	In-Place CBR (Depth)	RWD Deflection Range, inches	RWD Rut Depth Range, inches
987+00	8-12 (0-4") 4 (4-6") 8-30 (6-24")	1.0 - 1.3	0.4 - 0.7
988+00	7-16 (0-4") 4-7 (4-10") 12-30*(10-18") ⁽¹⁾	0.6 - 0.8	0.1 - 0.3
989+00	3 (0-4") 10-30 (4-22") 7-10 (22-24")	0.7 - 1.1	0.4 - 0.6
990+00	5 (0-2") 15-30 (2-4") 6-8 (4-18") 14-30 (18-24")	0.7 - 1.0	0.4 - 0.5

(1) CBR Tests terminated due to obstruction

Table 2.9.1: Comparative Field Test Data for October Tests on STH 57 - Fredonia

Test Station	Nuclear Tests ⁽¹⁾		In-Place CBR (Depth)	RWD Deflection Range, inches	RWD Rut Depth Range, inches	Quad-Axle Deflection Range, Inches ⁽⁴⁾	Quad-Axle Rut Depth Range, inches ⁽⁴⁾
	% Relative Compaction ⁽²⁾	% Optimum Moisture ⁽³⁾					
2+870			20-30* (0-24")				
3+270			10-30* (0-18") 8-14 (18-24")				
3+680			20-30* (0-12") 10-20 (12-24")				
4+080			20-30* (0-24")				
4+485			10-20 (0-24")				
4+800			10-30* (0-24")				

(1) Nuclear testing conducted at a depth of 8".

(2) Maximum Dry Density = 116.5 pcf

(3) Optimum Moisture Content = 17.5%

(4) Front Axle loaded to 25,760 lbs

Table 2.9.2: Comparative Field Test Data for Northbound November Tests on STH 57 - Fredonia

Test Station	Nuclear Tests ⁽¹⁾		In-Place CBR (Depth)	RWD Deflection Range, inches	RWD Rut Depth Range, inches	Quad-Axle Deflection Range, Inches ⁽⁴⁾	Quad-Axle Rut Depth Range, inches ⁽⁴⁾
	% Relative Compaction ⁽²⁾	% Optimum Moisture ⁽³⁾					
8+268	100.6	84.9	9-19 (0-24")	0.6 - 0.7	0.2	0.9 - 1.2	0.4 - 1.0
8+433	98.7	117.7	2-5 (0-24")	1.2 - 1.7	0.8 - 1.3	1.2 - 1.6	1.1 - 1.3
8+520	(103.7)	(79.6)	13 (0-6") 6-7 (6-24")	0.4 - 0.5	0.2 - 0.3	0.3 - 0.6	0.1 - 0.7
8+560	n.a.	n.a.	2-5 (0-24")	1.4 - 1.7	0.9 - 1.1	0.9 - 1.5	0.8 - 1.4

Table 2.9.3: Comparative Field Test Data for Southbound November Tests on STH 57 - Fredonia

Test Station	Nuclear Tests ⁽¹⁾		In-Place CBR (Depth)	RWD Deflection Range, inches	RWD Rut Depth Range, inches	Quad-Axle Deflection Range, Inches ⁽⁴⁾	Quad-Axle Rut Depth Range, inches ⁽⁴⁾
	% Relative Compaction ⁽²⁾	% Optimum Moisture ⁽³⁾					
8+320	105.1 (100.9)	79.3 (102.8)	11-15 (0-9") 7-9 (9-24")	0.2 - 0.6	0.0 - 0.3	0.4 - 0.9	0.3 - 0.8
8+384	101.8 (99.5)	120.9 (114.7)	5-6 (0-24")	0.4 - 0.7	0.2 - 0.4	0.2 - 1.0	0.1 - 0.6
8+495	100.1 (105.3)	81.8 (107.5)	8 (0-6") 3-4 (6-12") 8 (12-16") 5-6 (16-24")	1.5 - 1.9	0.6 - 1.3	1.1 - 1.9	0.7 - 1.4

(1) Nuclear testing conducted at a depth of 8".

(2) Maximum Dry Density = 116.5 pcf

(3) Optimum Moisture Content = 17.5%

(4) Front Axle loaded to 25,160 lbs

Table 3.1.1 - Unconfined Compression Test Results

Test Specimen	Moisture Content During Compaction, %	Compacted Dry Density pcf	Test Results Immediately After Compaction		Test Results After 48 Hour Soaking		
			Qu, psi	CBR	Moisture Content, %	qu, psi	CBR
STH 33 Silt							
1	10.4	115.4	38.03	8	14.9	15.91	4
2	12.3	118.4	46.08	10	14.3	36.49	8
3	15.4	114.7	15.07	3	16.0	14.77	3
STH 57 Red Clay							
1	13.2	114.3	42.79	10	16.3	18.44	4
2	14.2	115.9	54.21	12	15.1	36.49	8
3	17.2	111.8	19.49	4	17.5	17.64	4

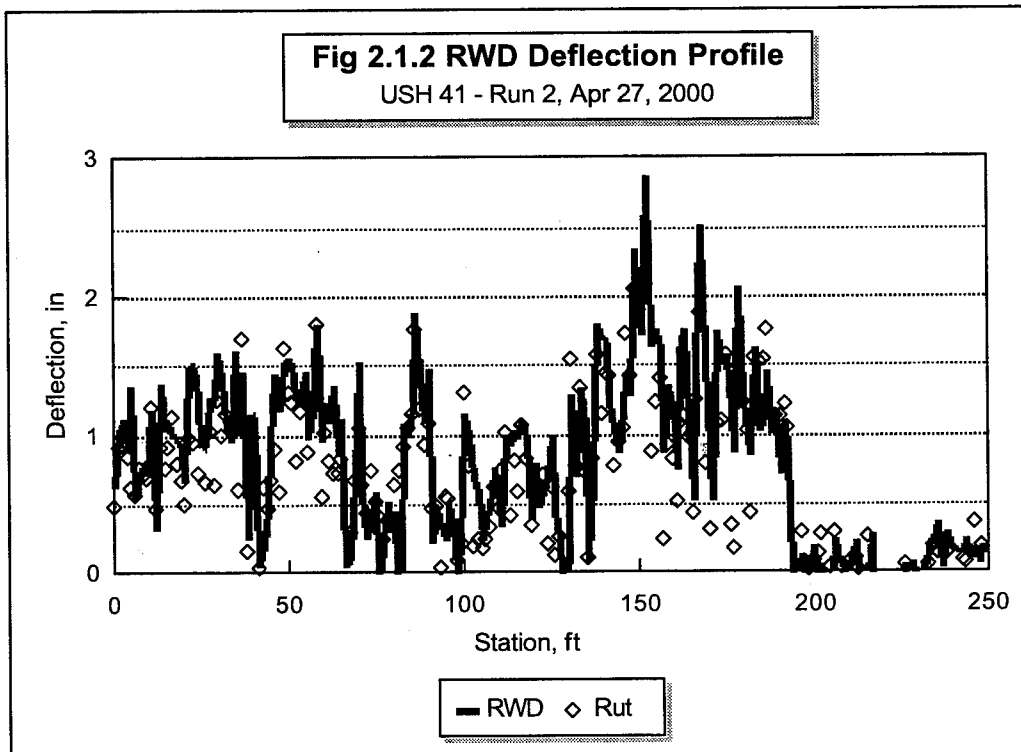
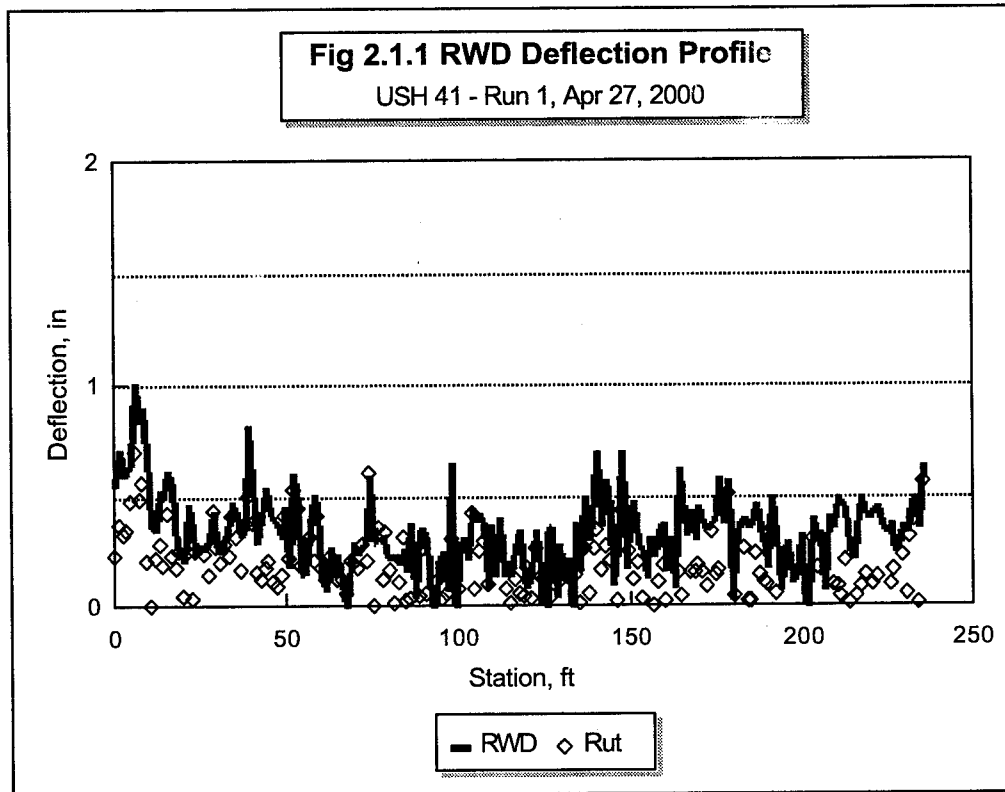


Figure 2.1.3 Deflection vs CBR

USH 41 - Sandy Silt

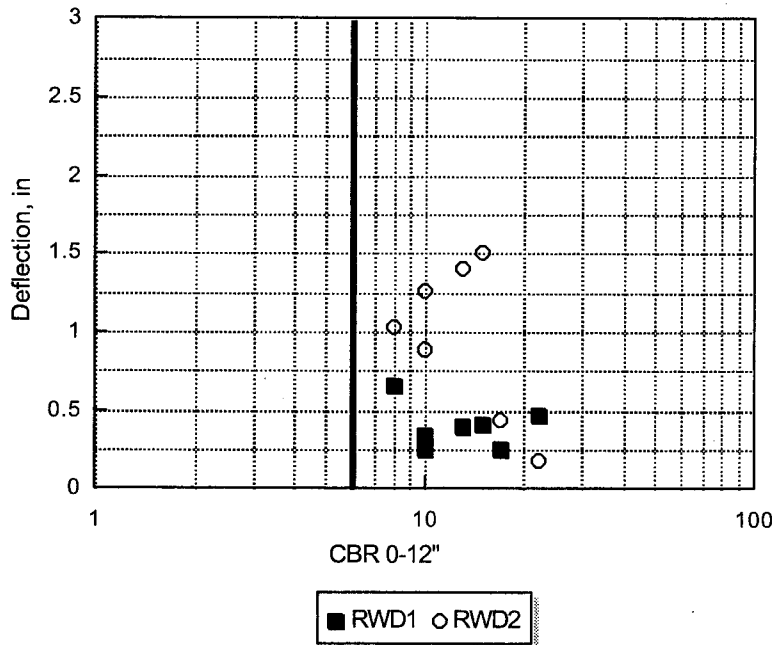
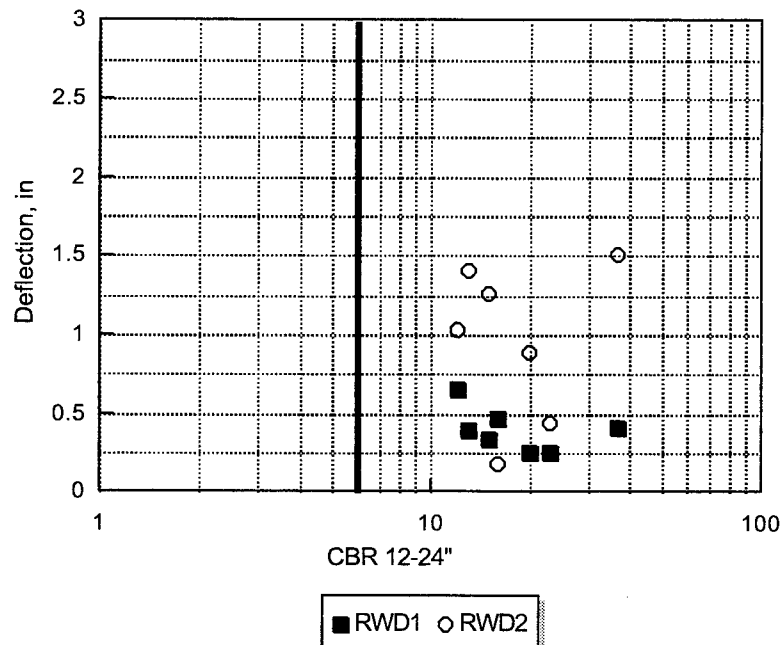
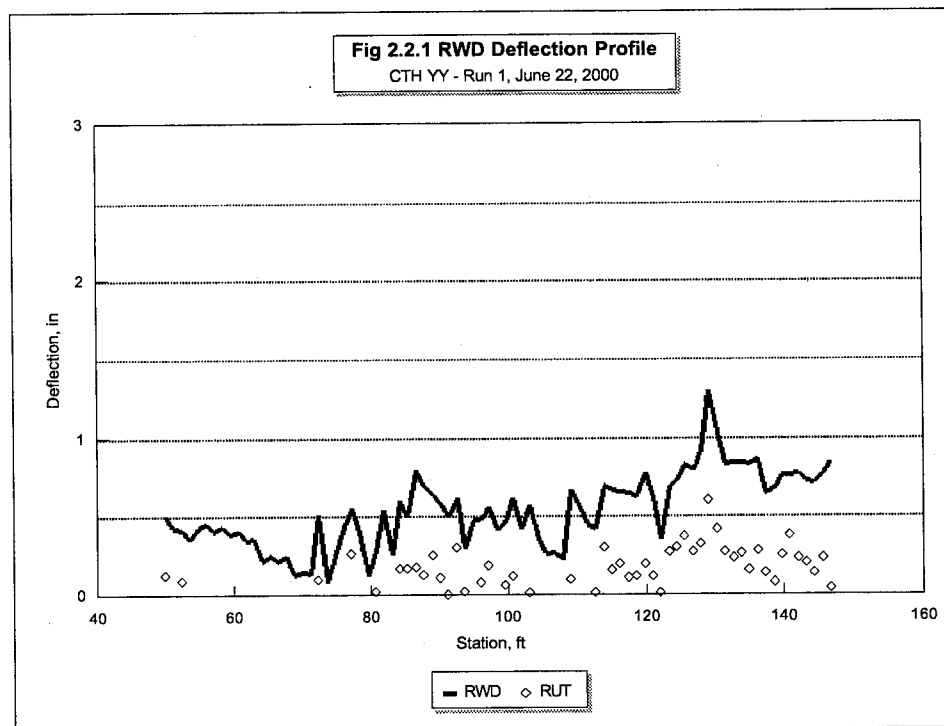
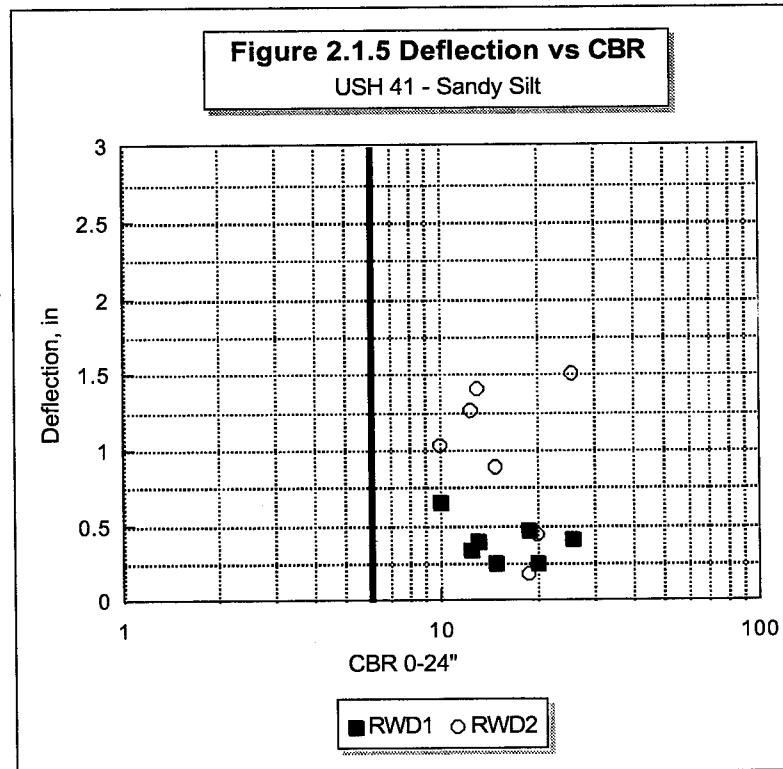
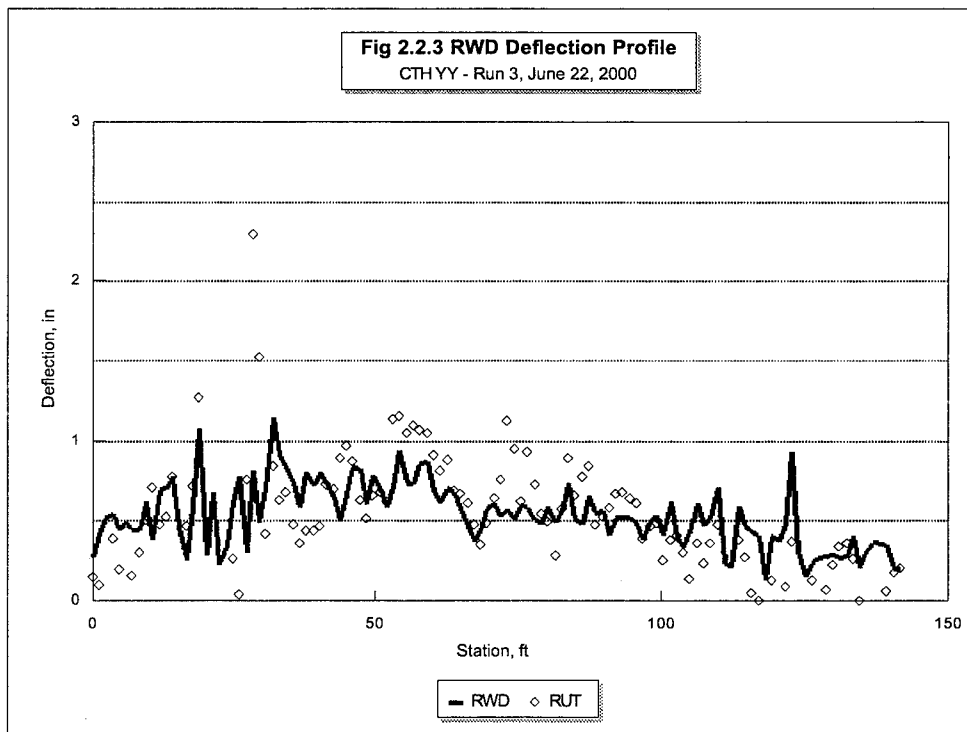
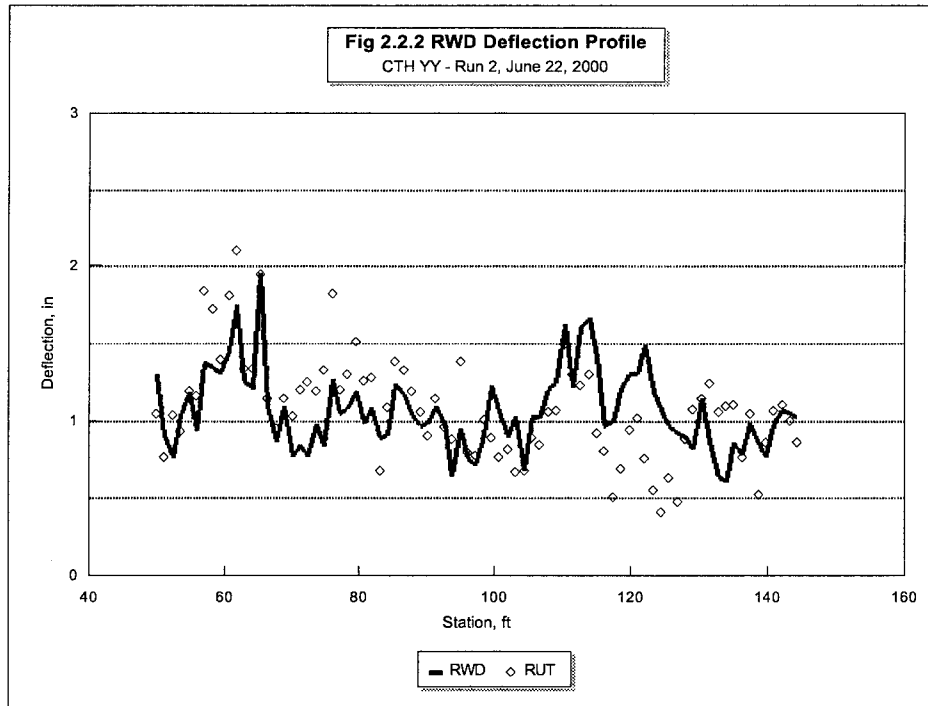


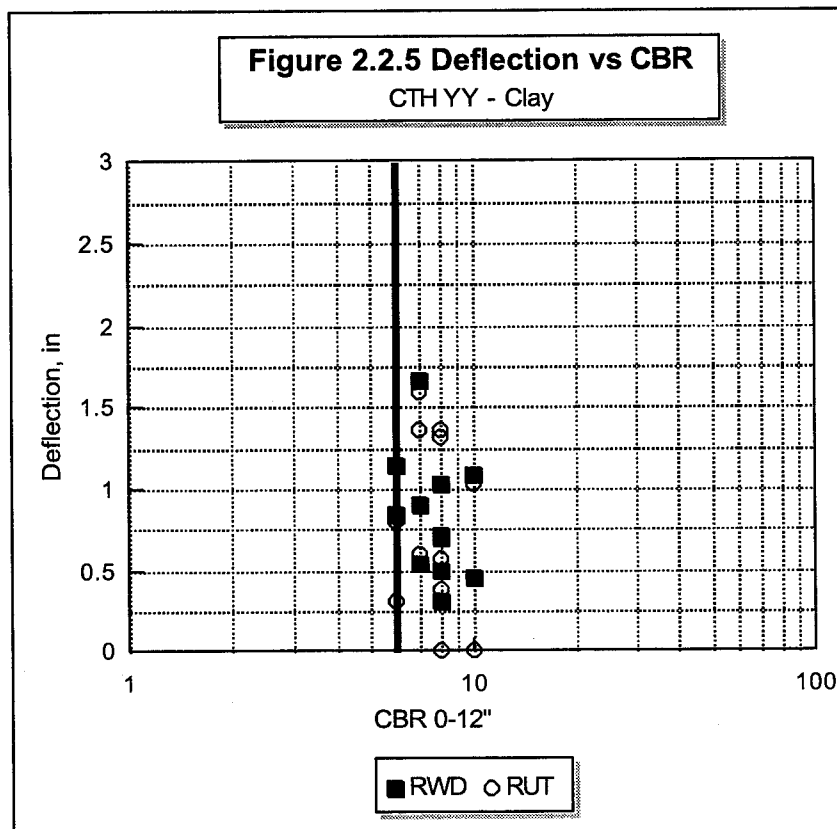
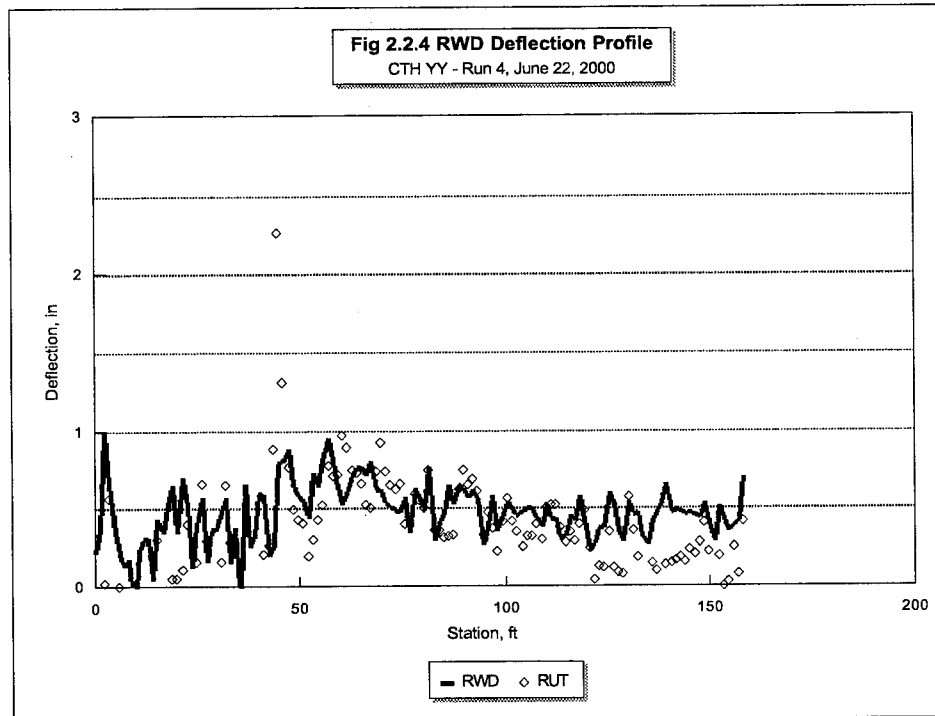
Figure 2.1.4 Deflection vs CBR

USH 41 - Sandy Silt

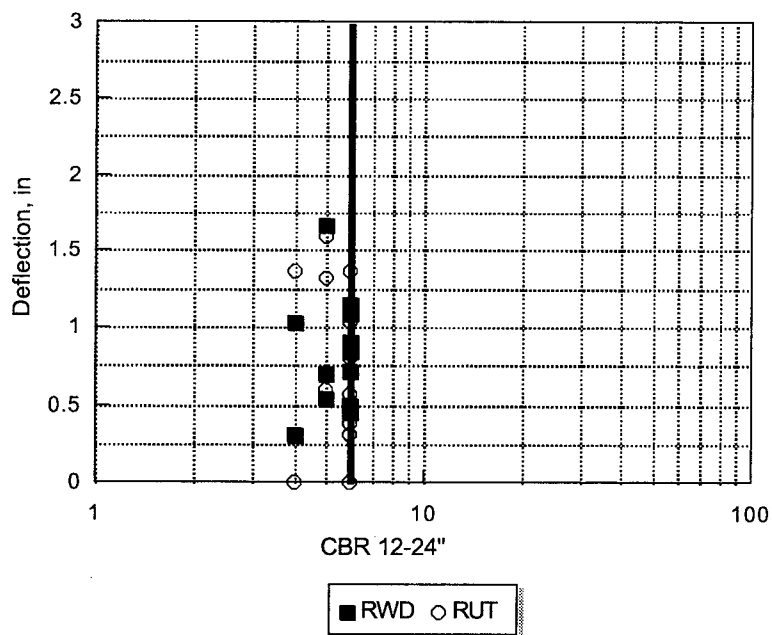




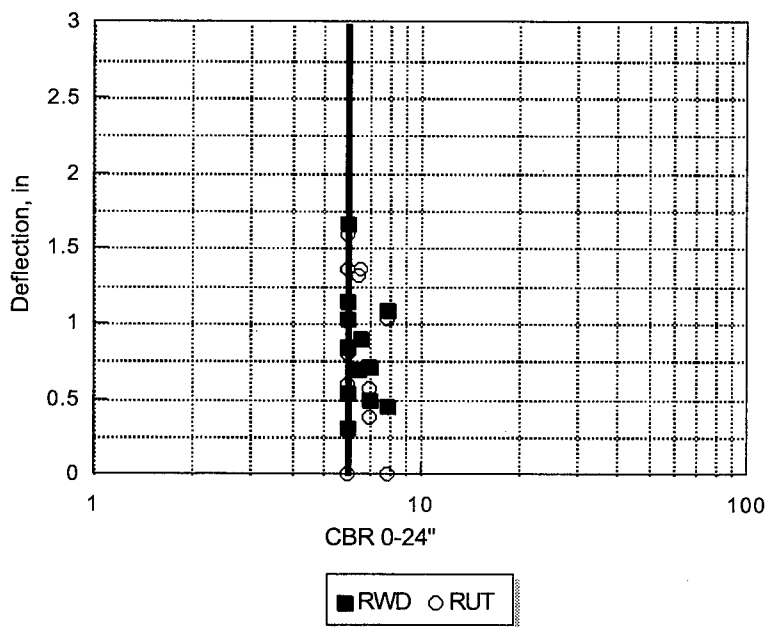


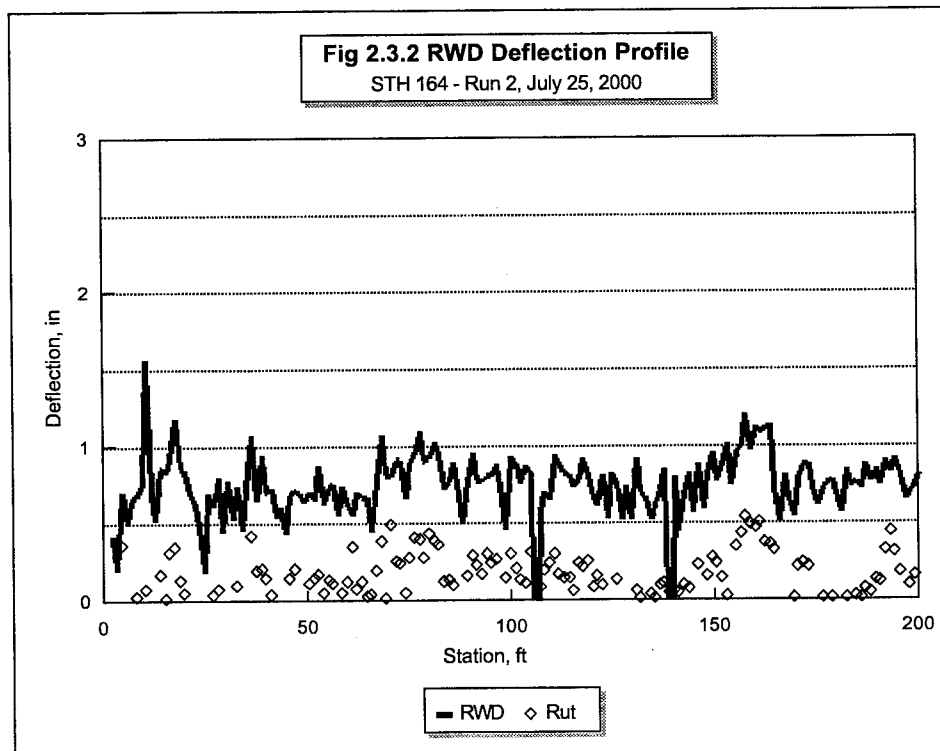
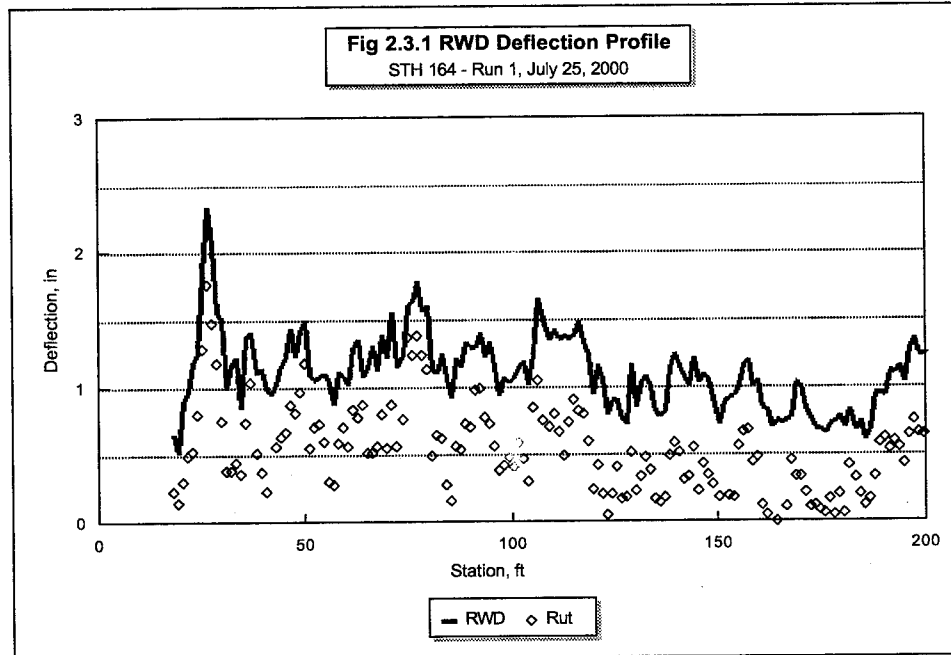


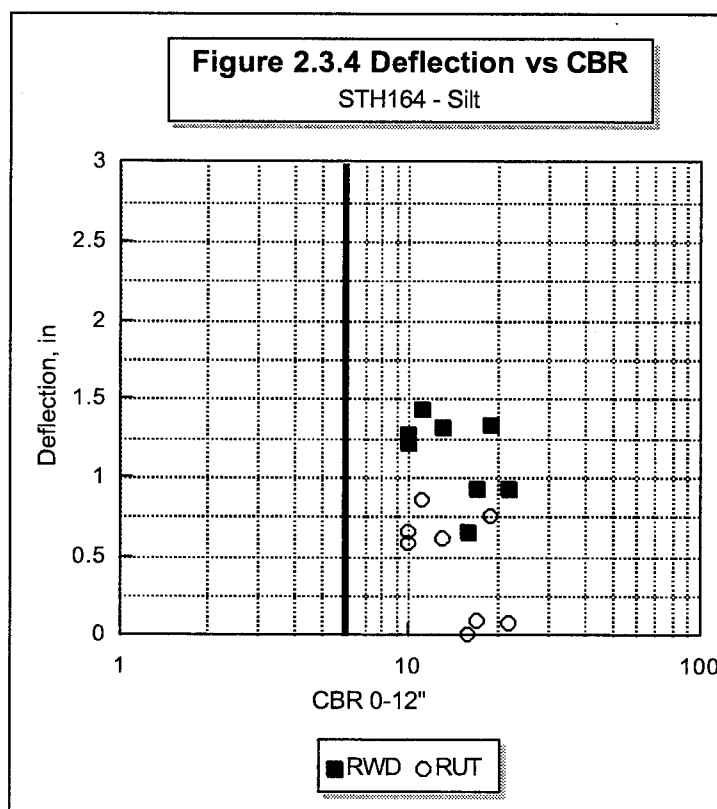
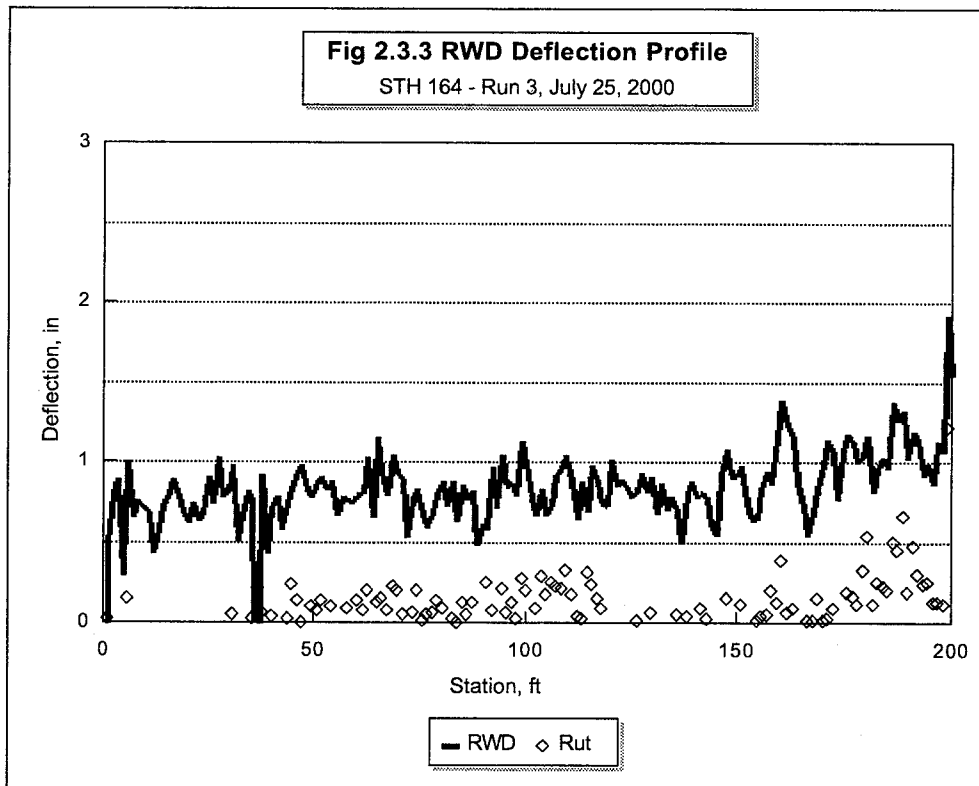
CTH YY - Clay

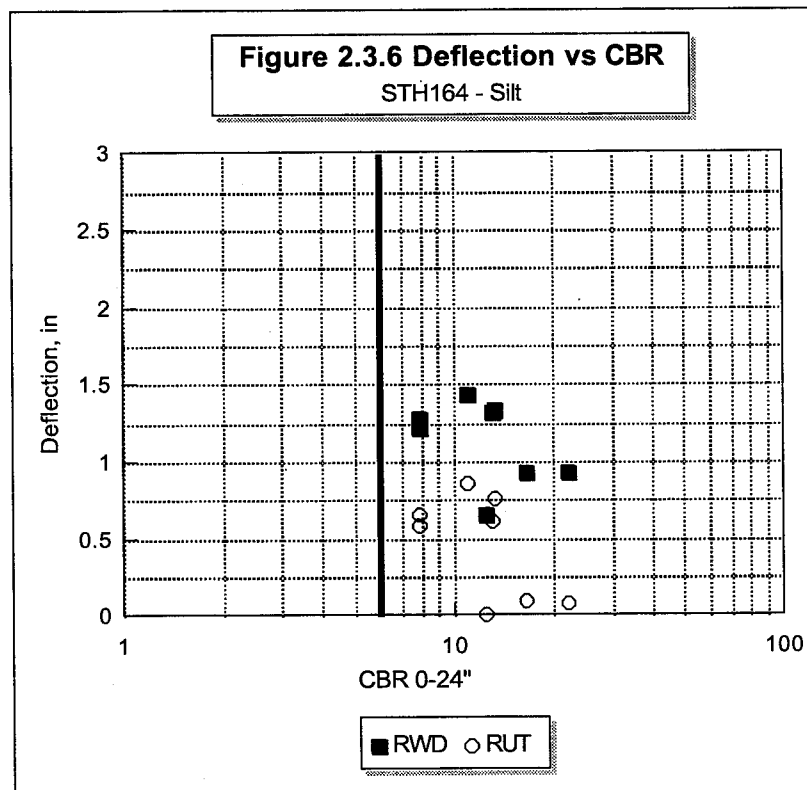
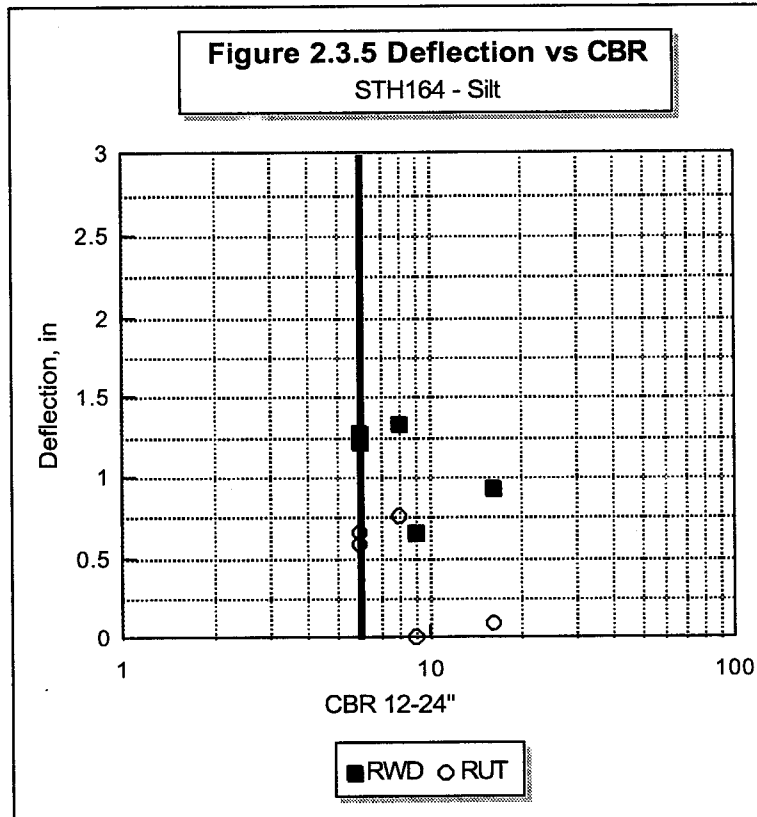


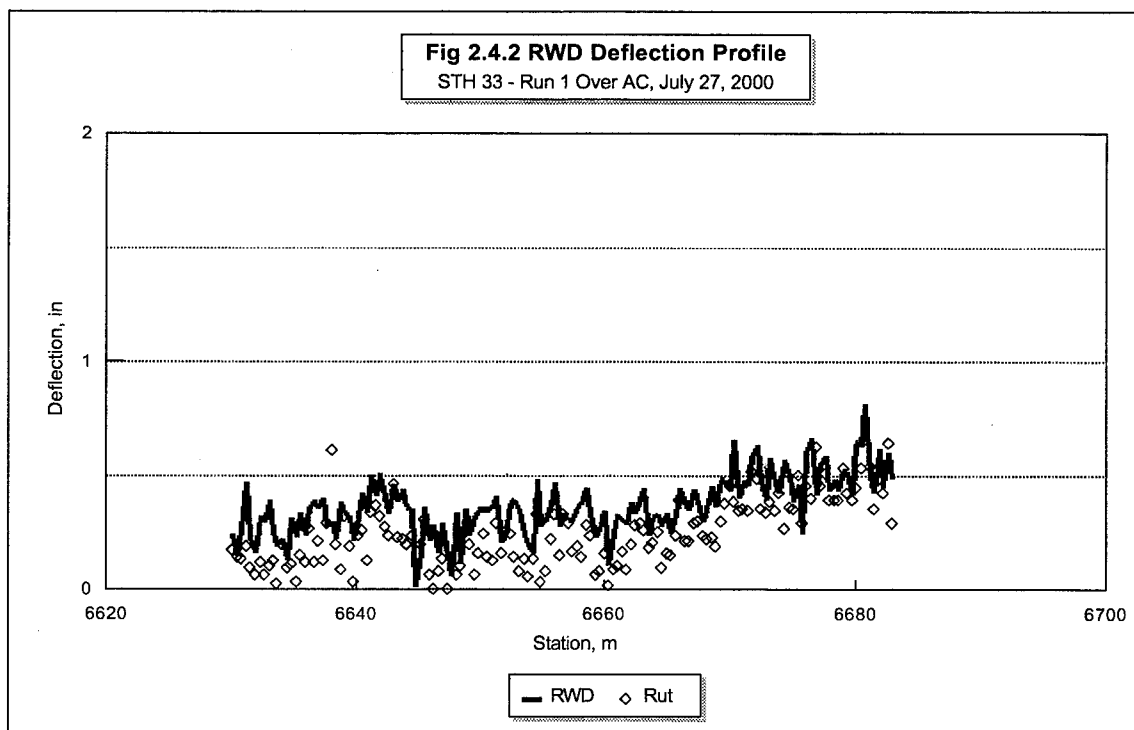
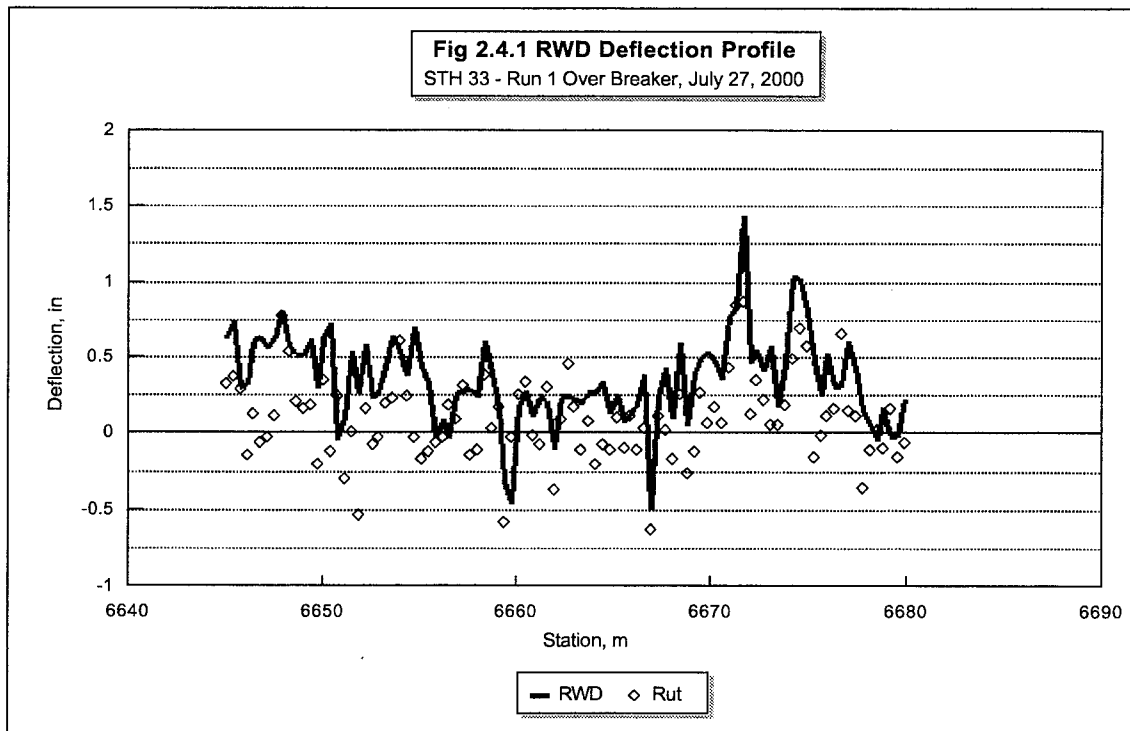
CTH YY - Clay

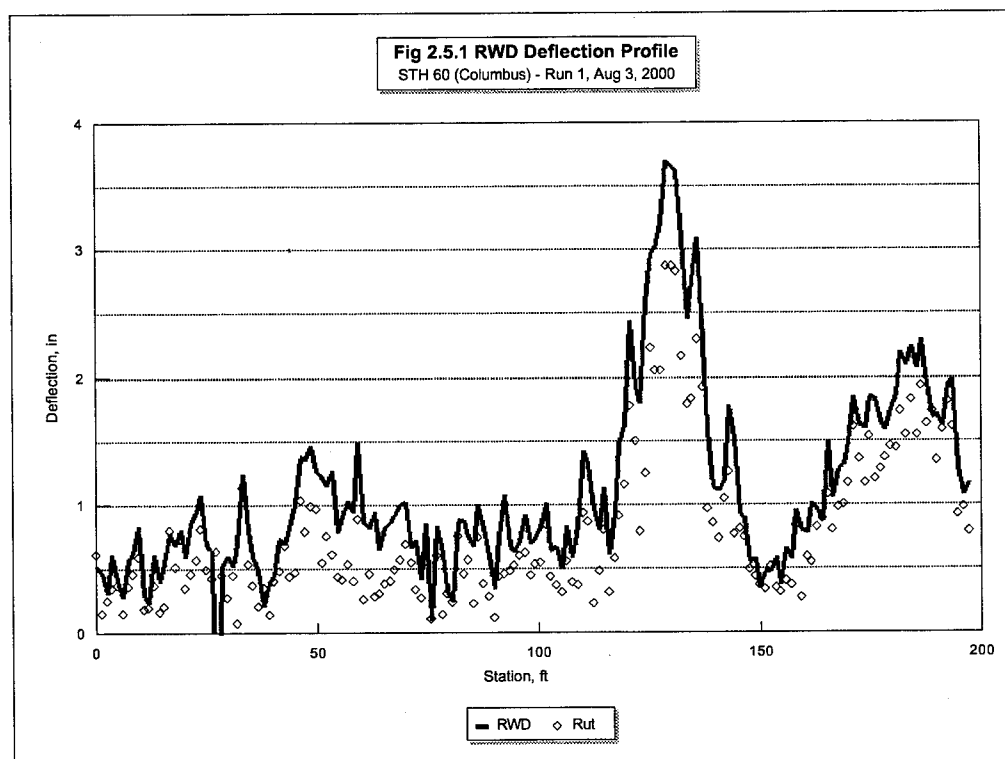
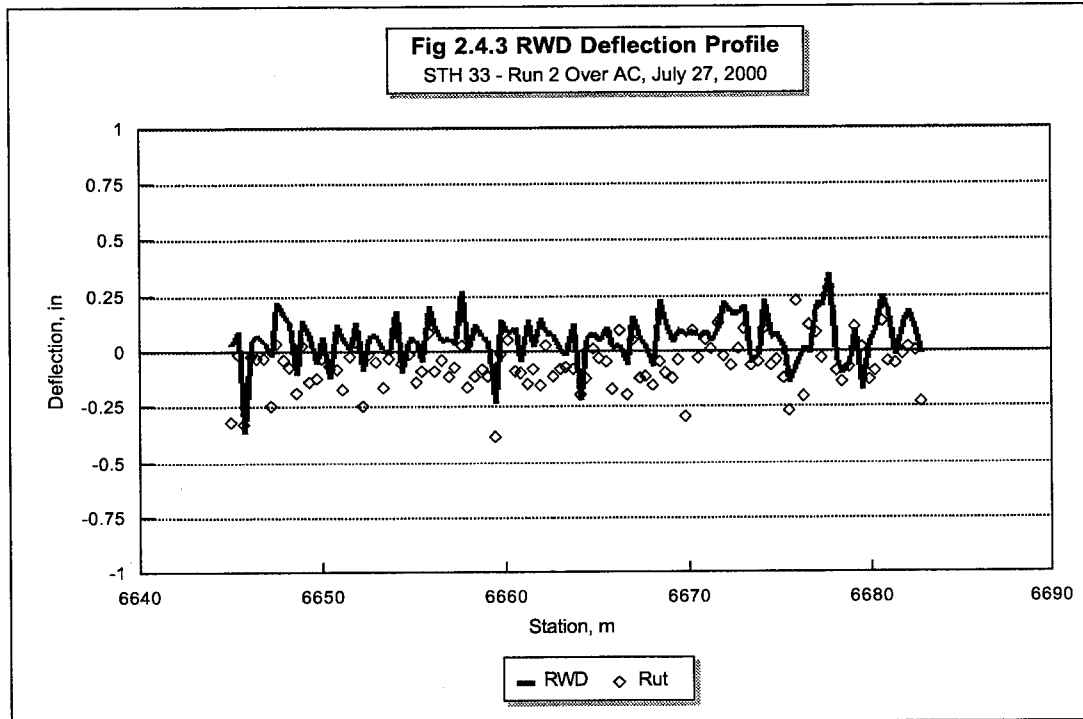












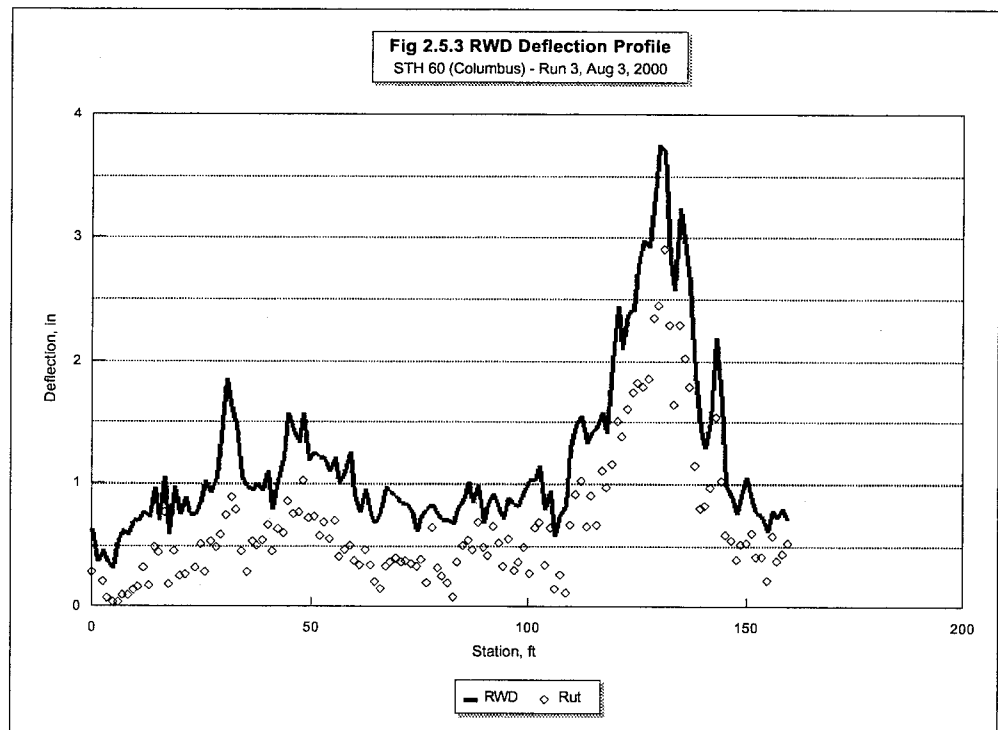
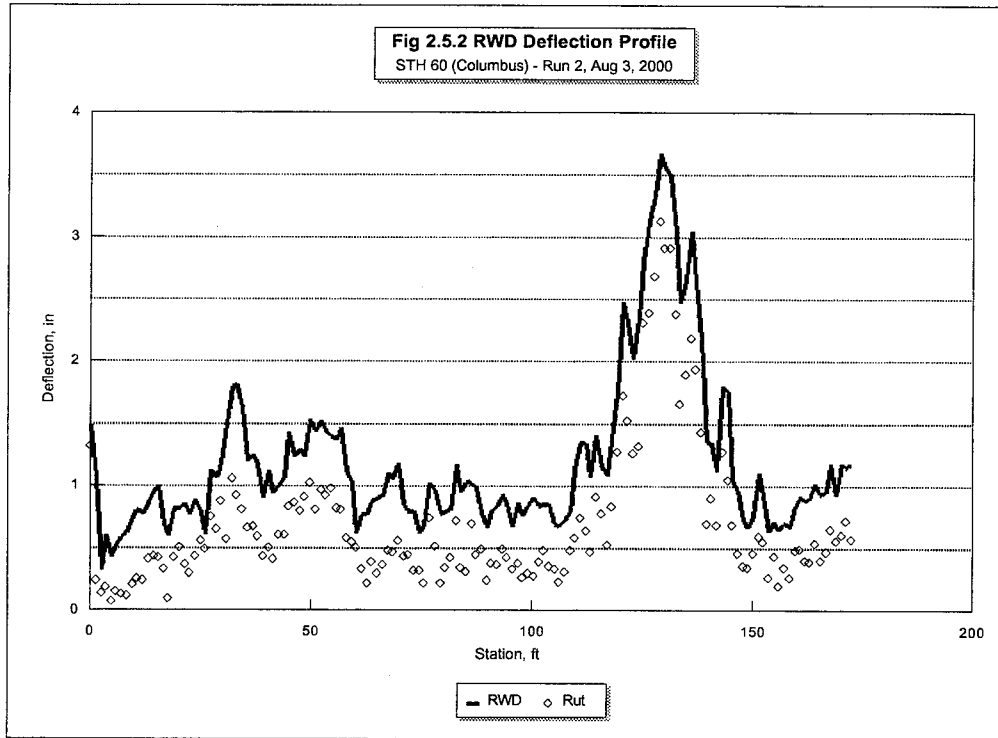


Figure 2.5.4 Deflection vs CBR
 STH 60 Columbus - Mixed

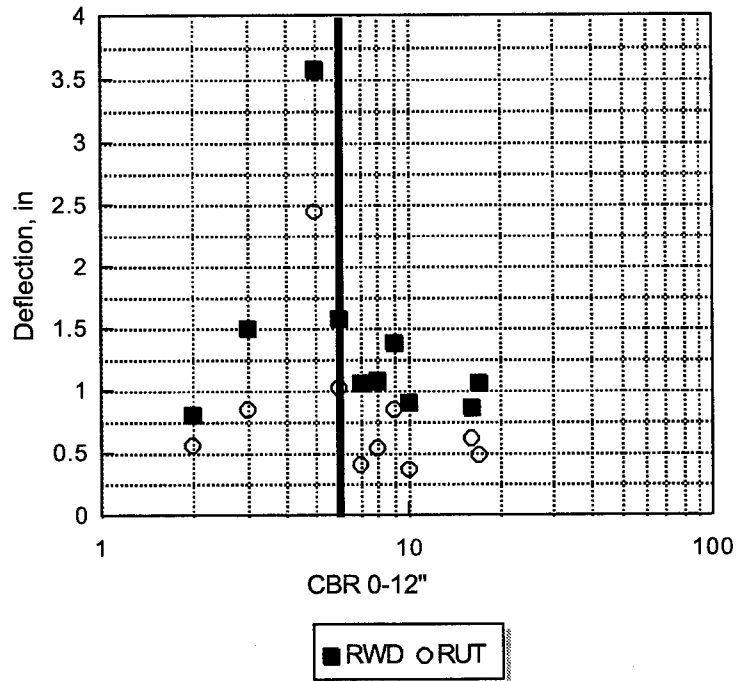
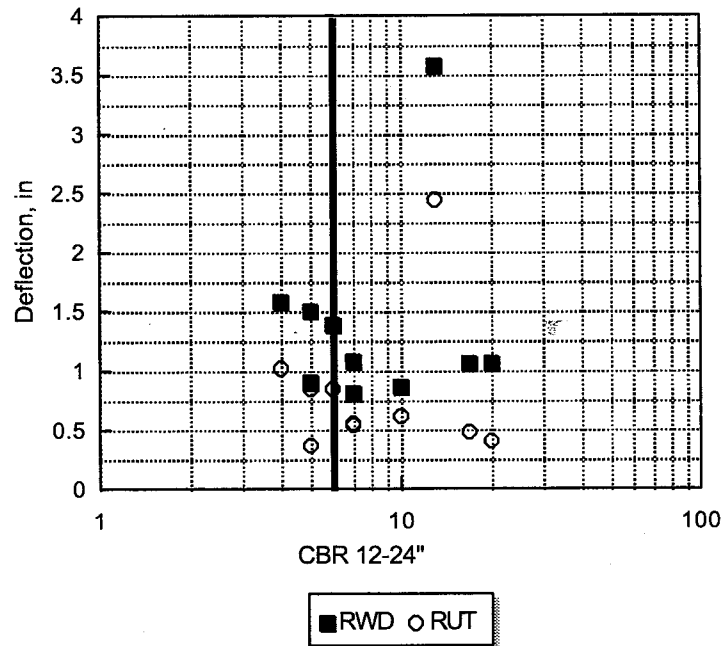
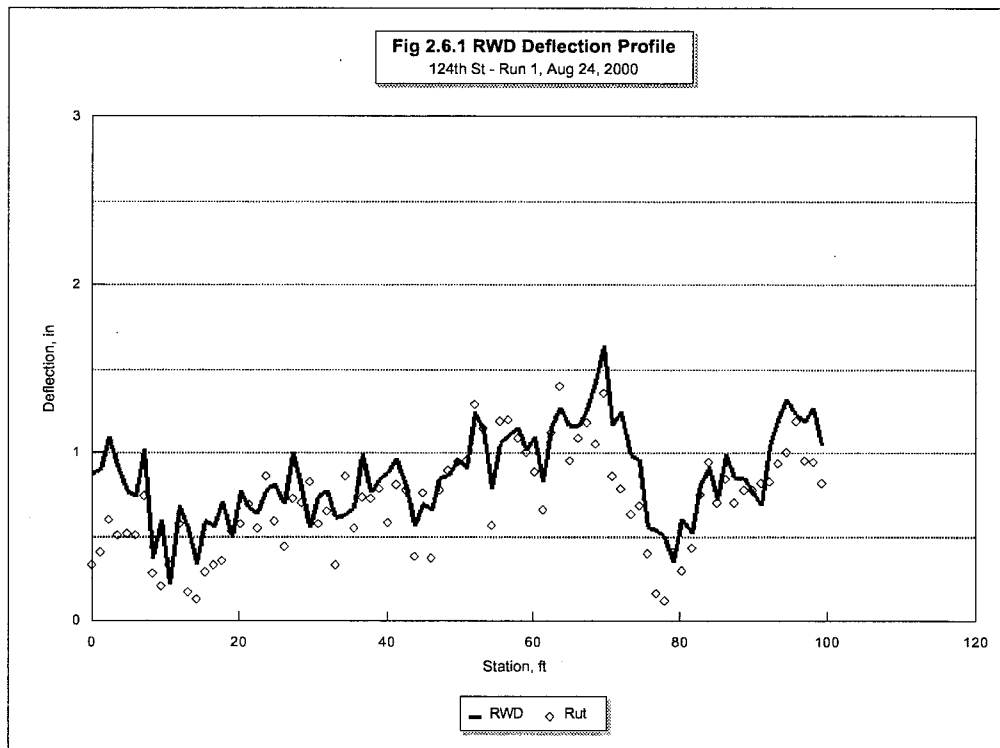
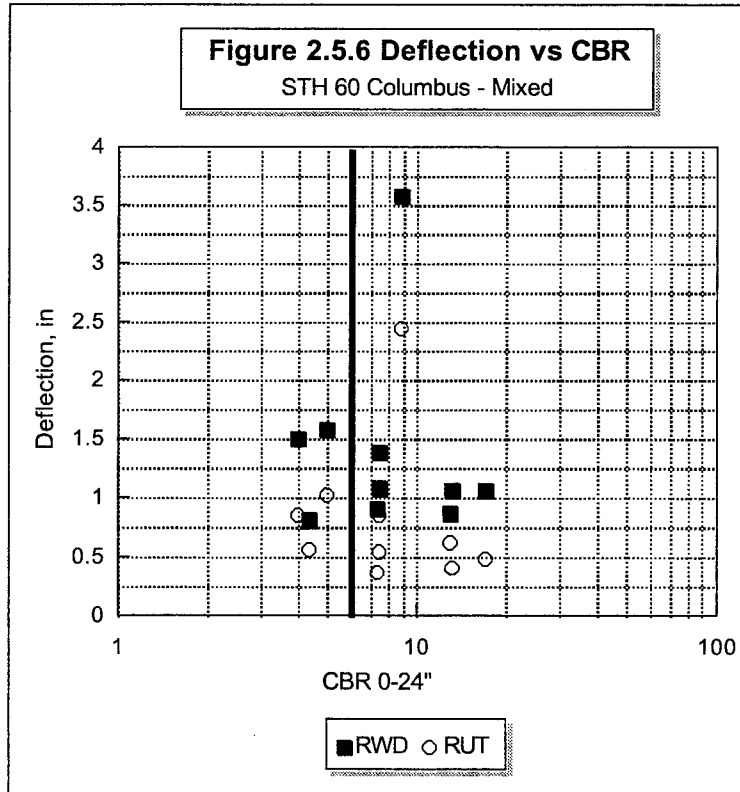


Figure 2.5.5 Deflection vs CBR
 STH 60 Columbus - Mixed





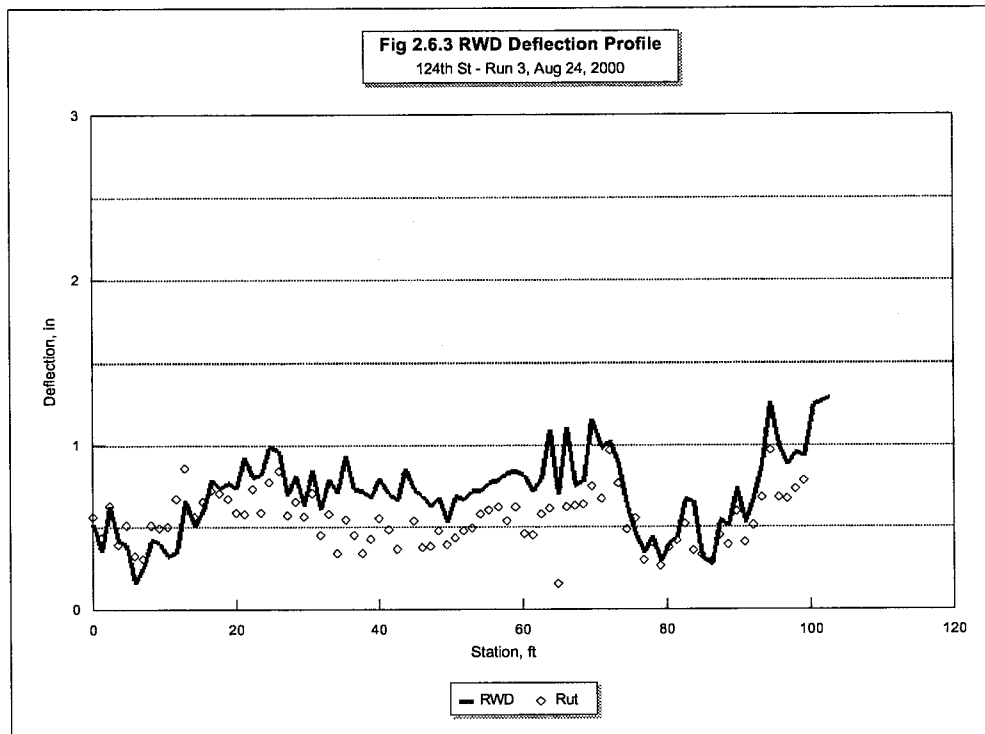
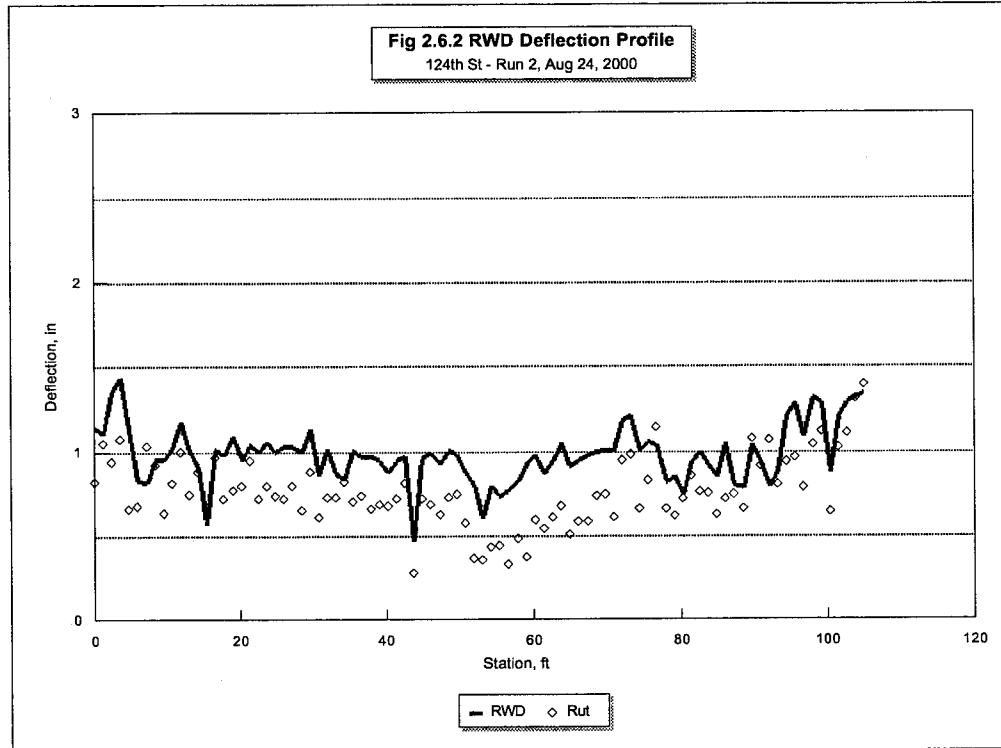


Figure 2.6.4 Deflection vs CBR

124th St - Clay

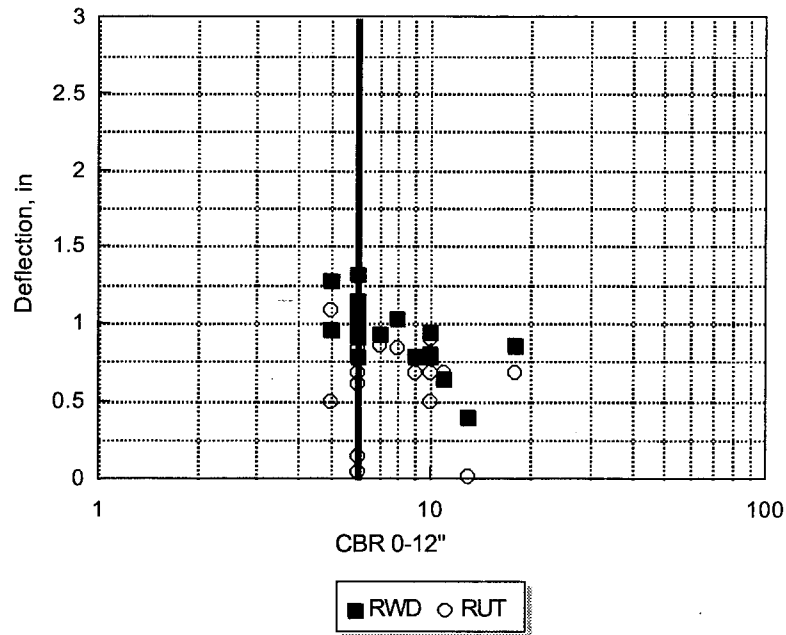
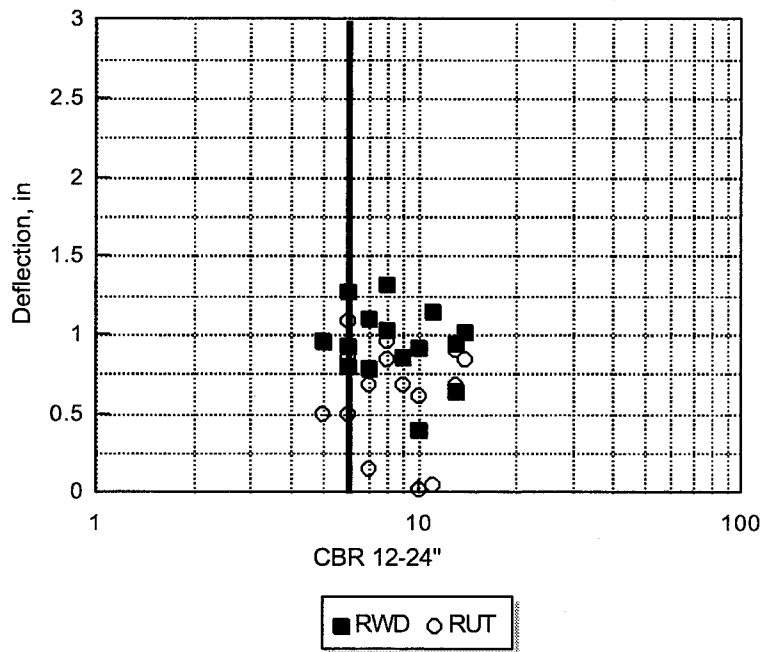
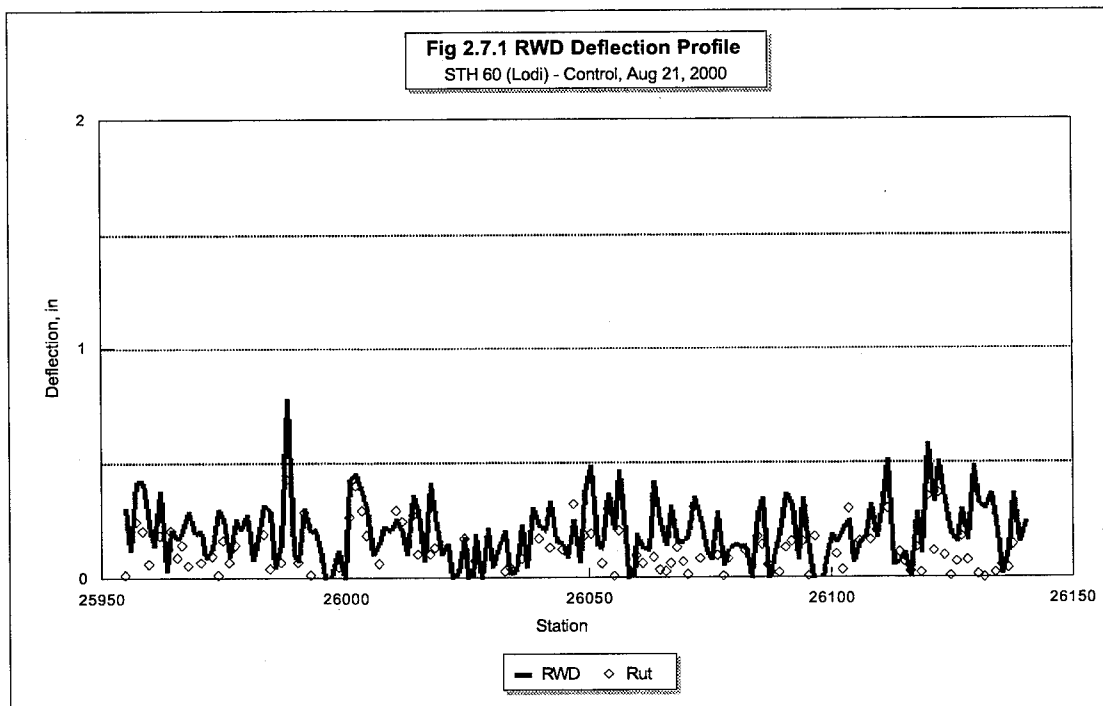
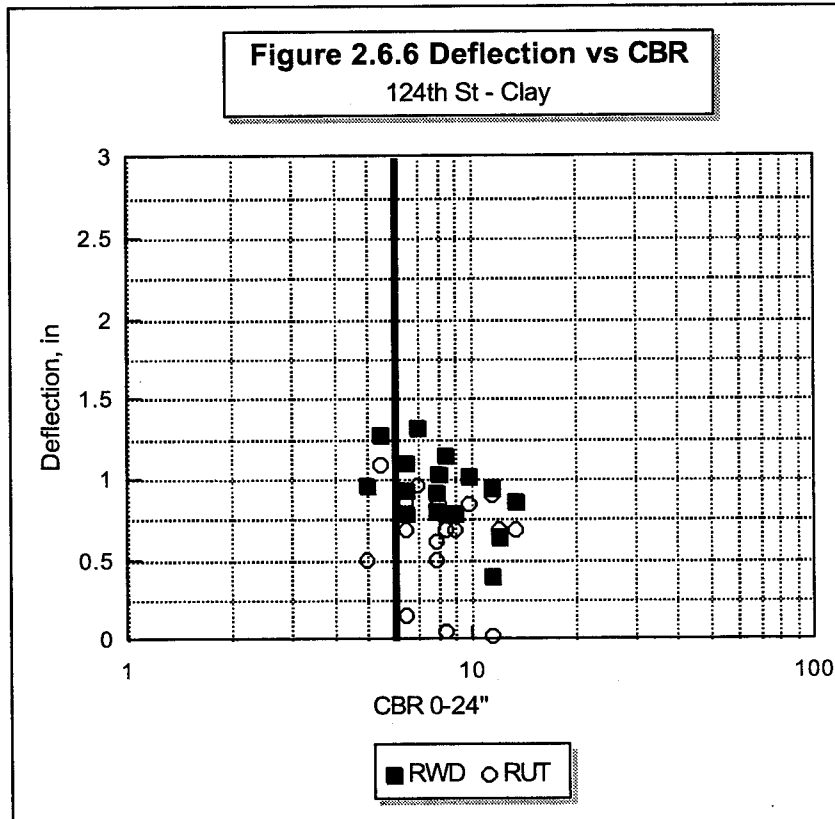


Figure 2.6.5 Deflection vs CBR

124th St - Clay





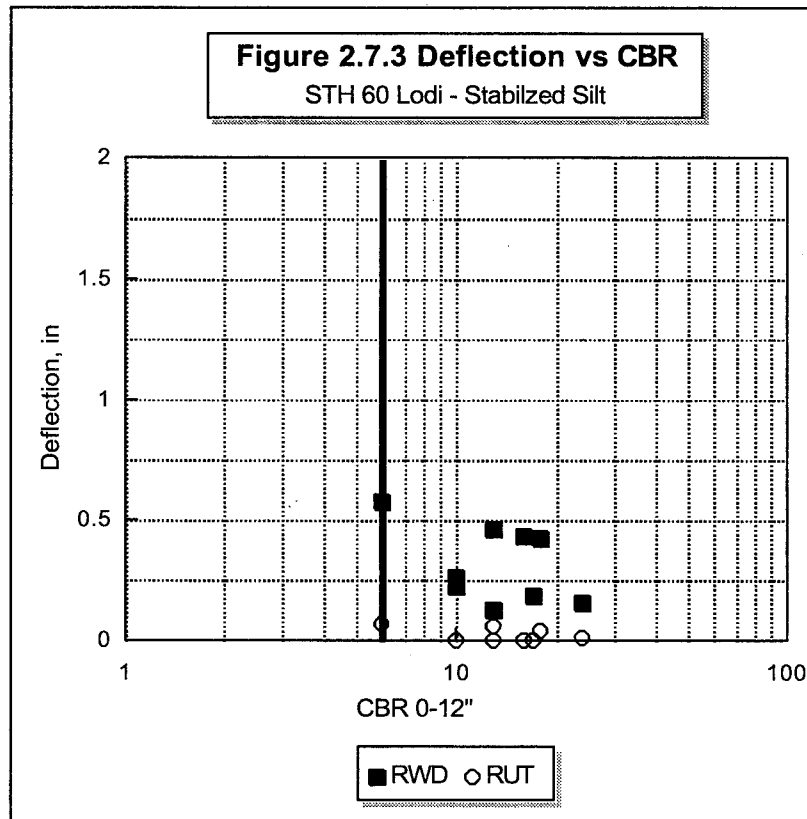
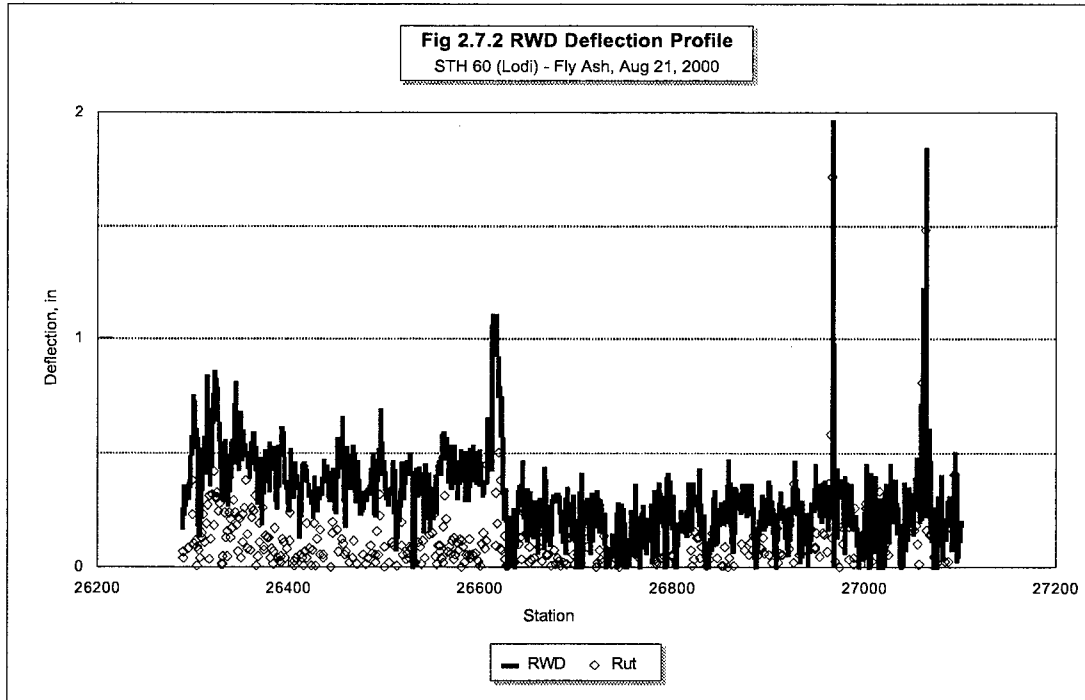


Figure 2.7.4 Deflection vs CBR

STH 60 Lodi - Stabilized Silt

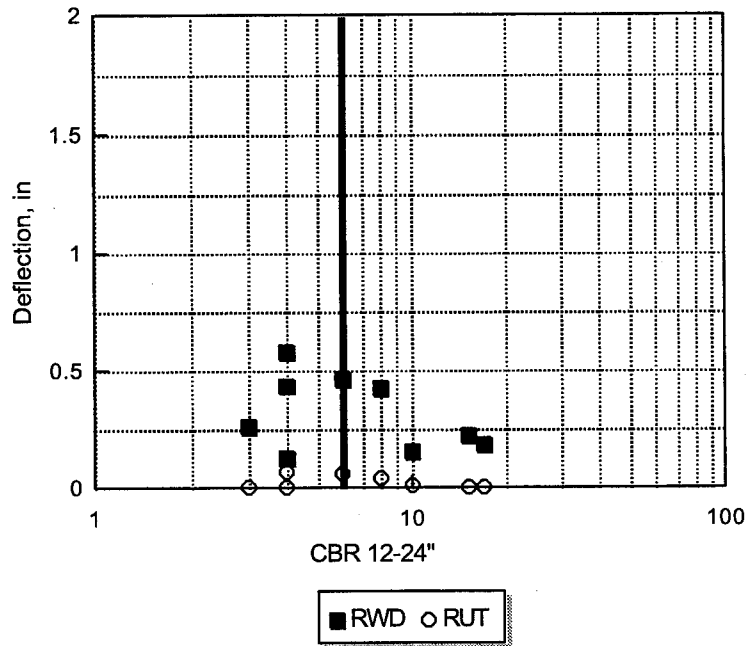
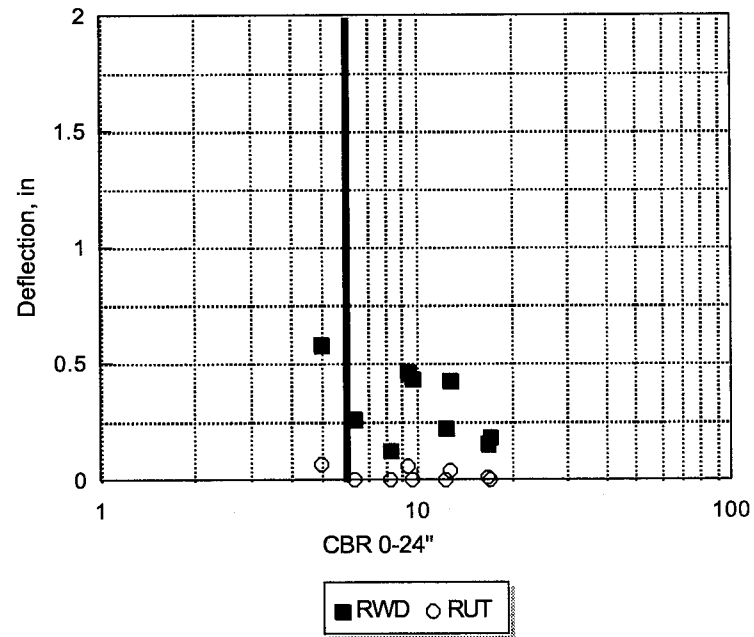


Figure 2.7.5 Deflection vs CBR

STH 60 Lodi - Stabilized Silt



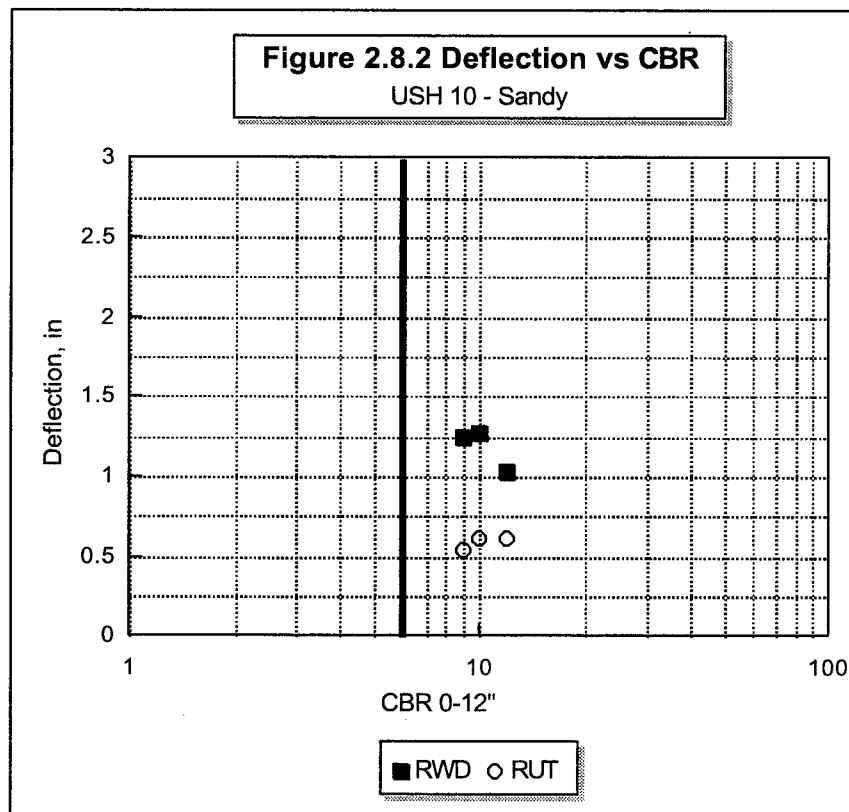
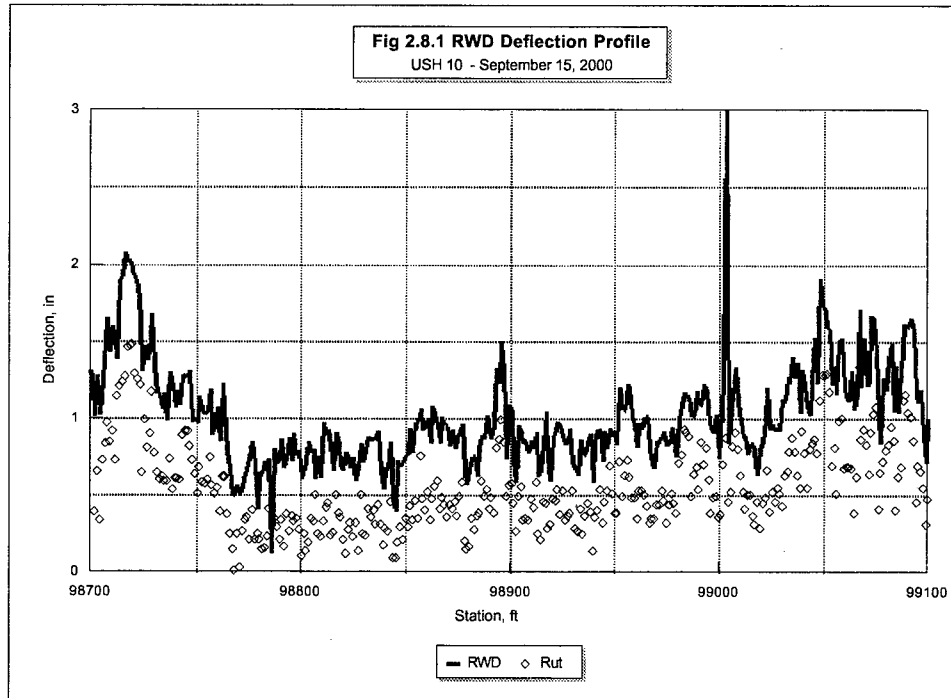


Figure 2.8.3 Deflection vs CBR
USH 10 - Sandy

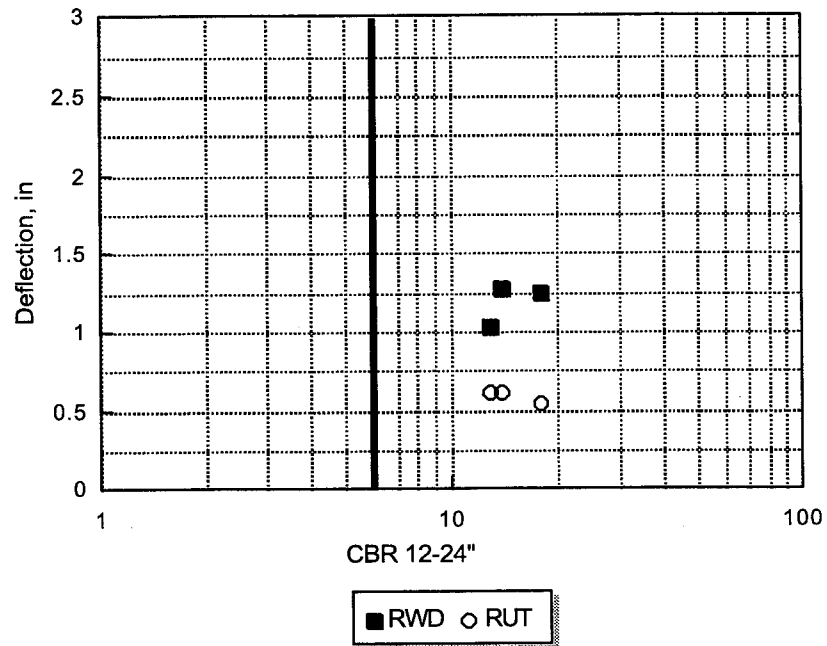
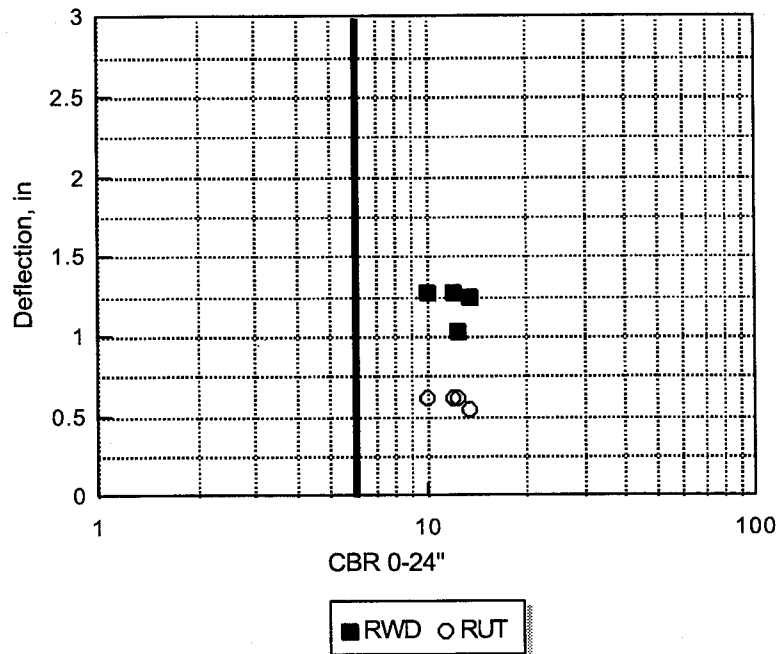


Figure 2.8.4 Deflection vs CBR
USH 10 - Sandy



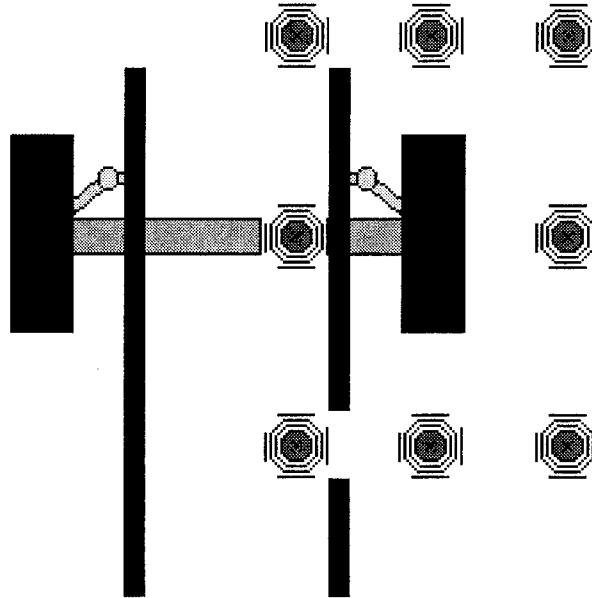
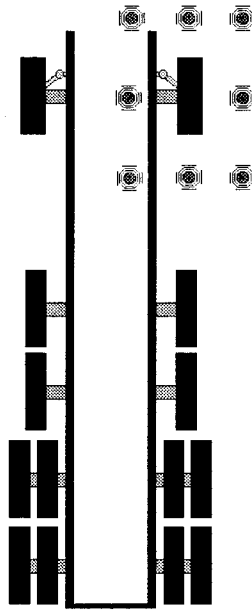
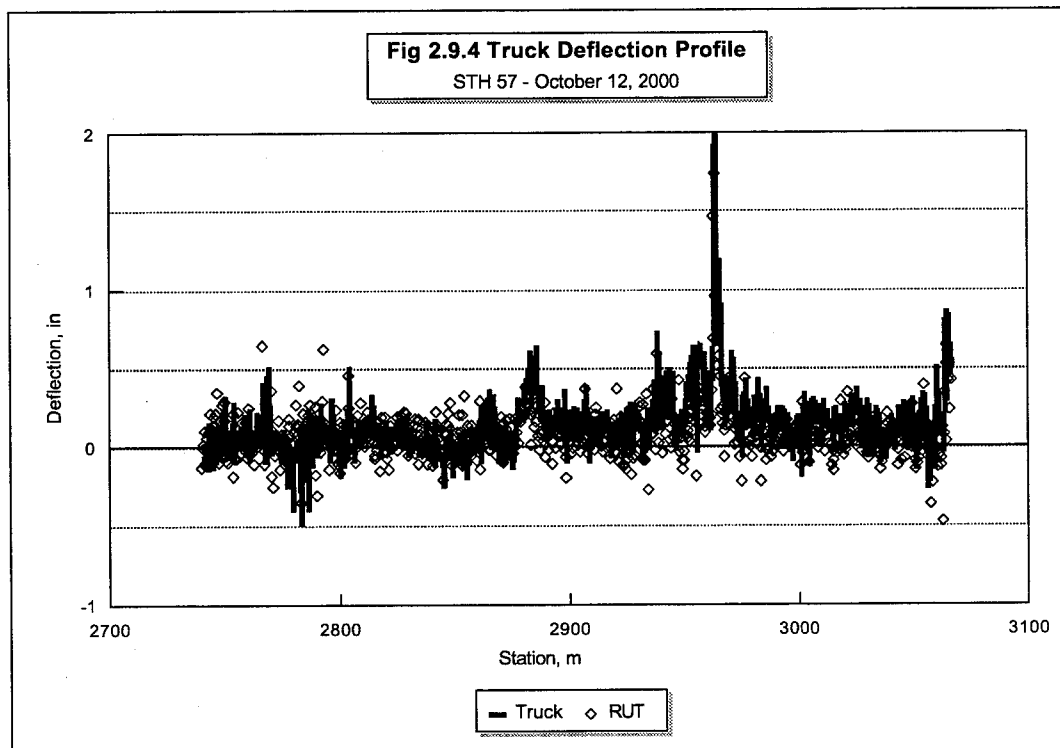
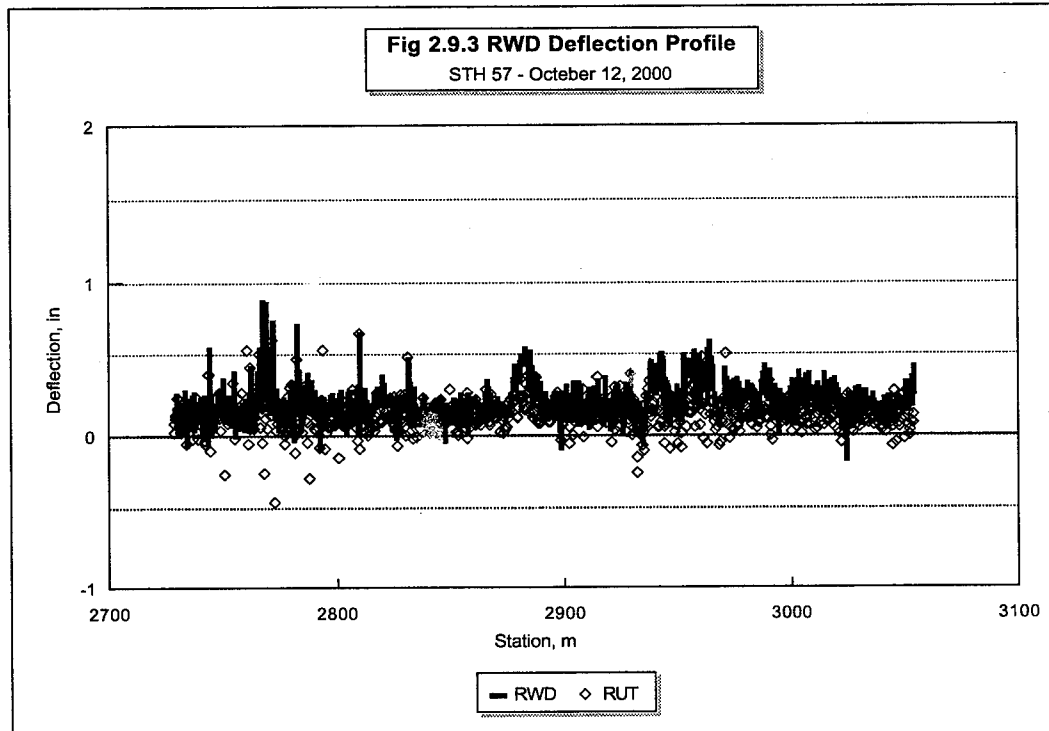


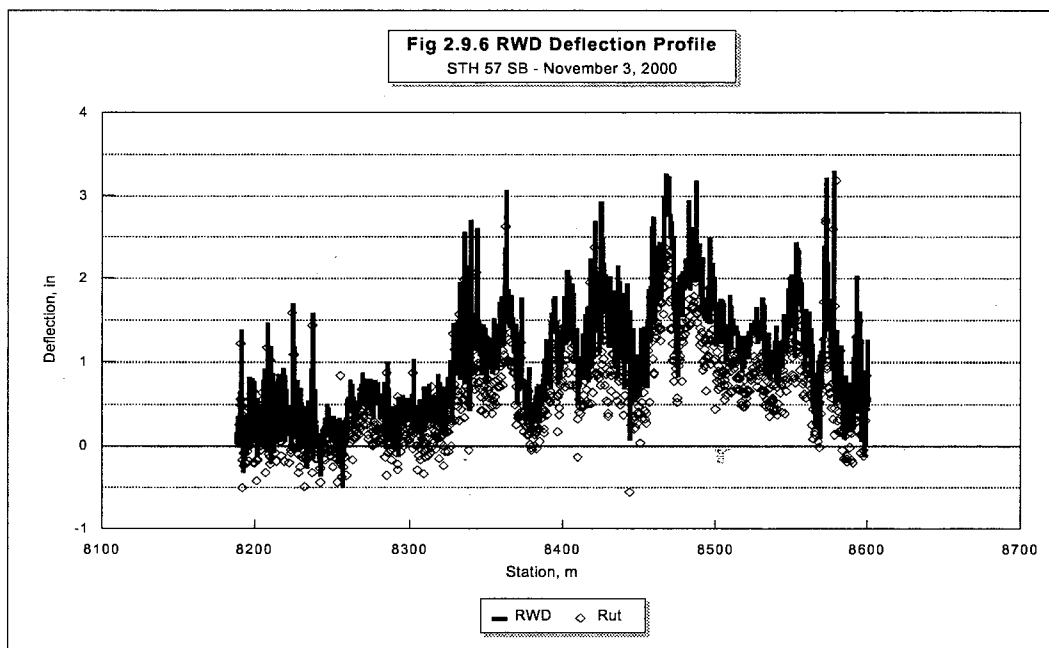
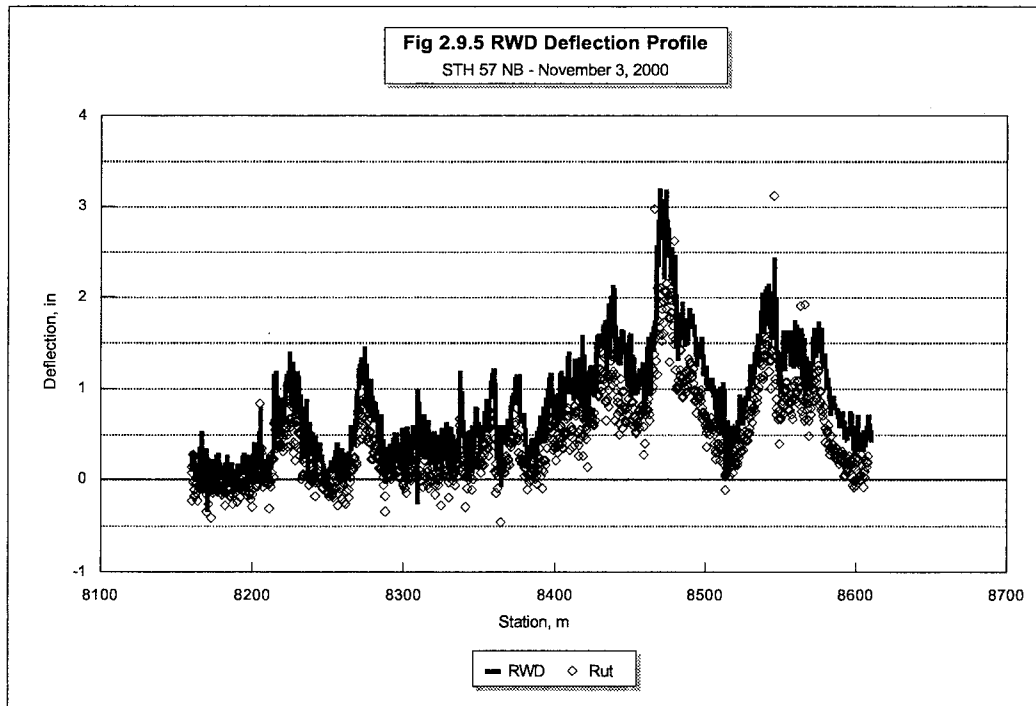
Figure 2.9.1 Sensor Array on Instrumented Truck

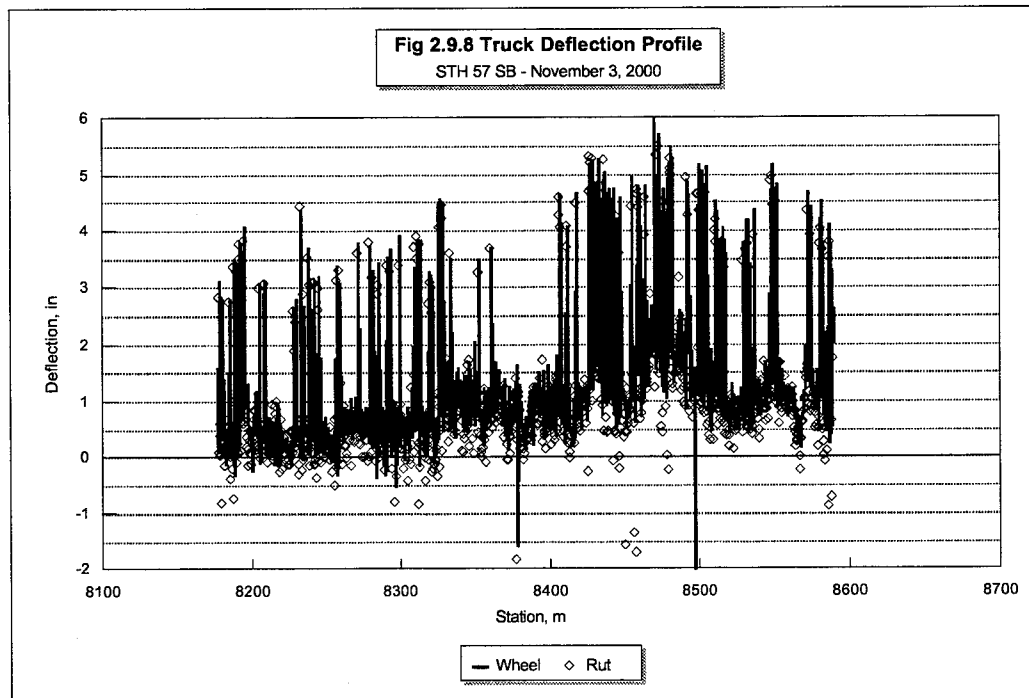
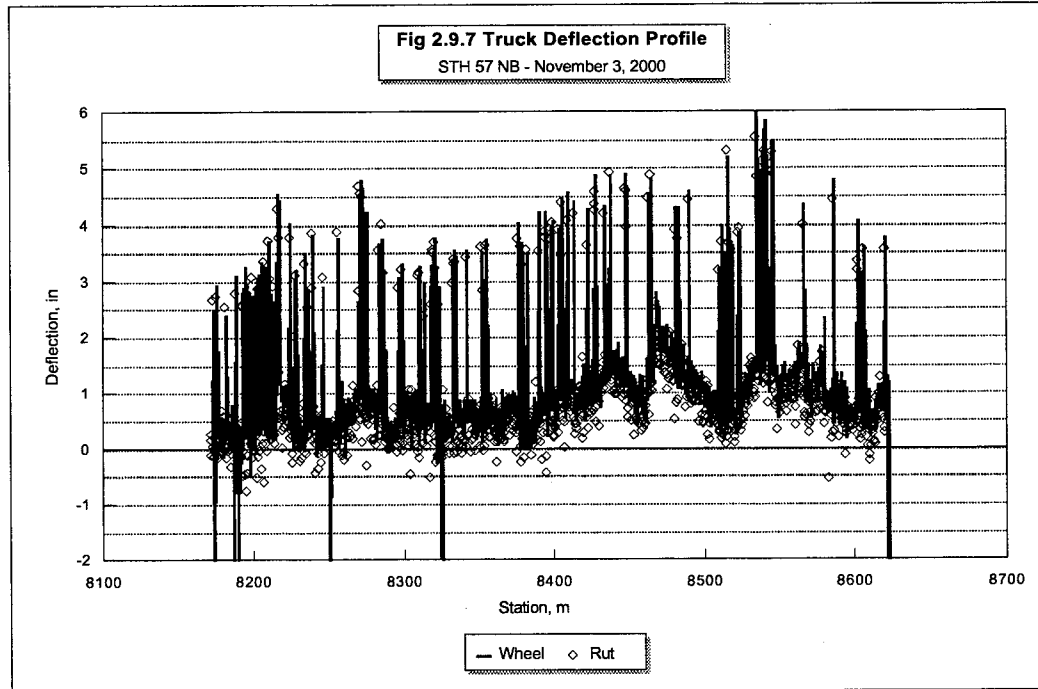


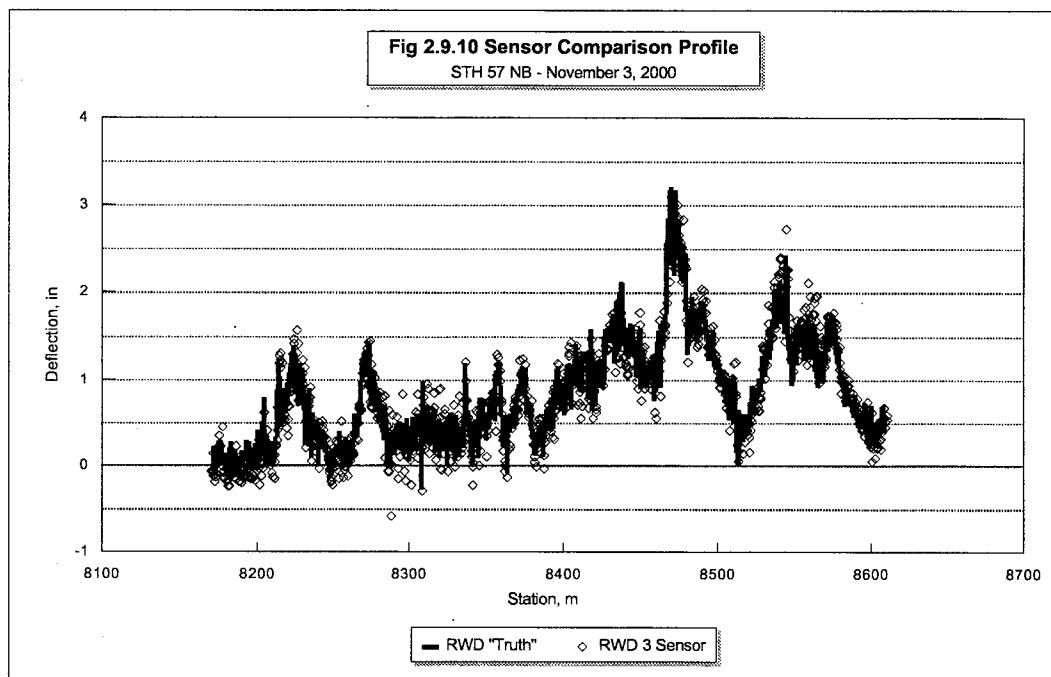
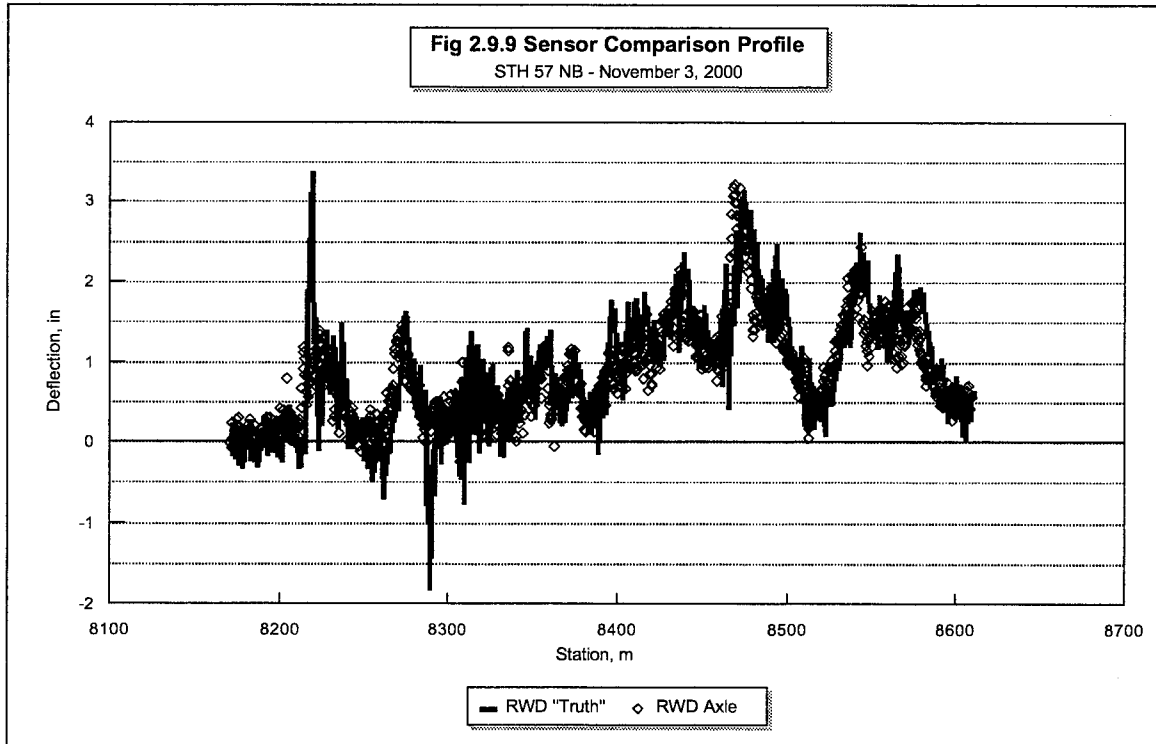
 Distance Transducer

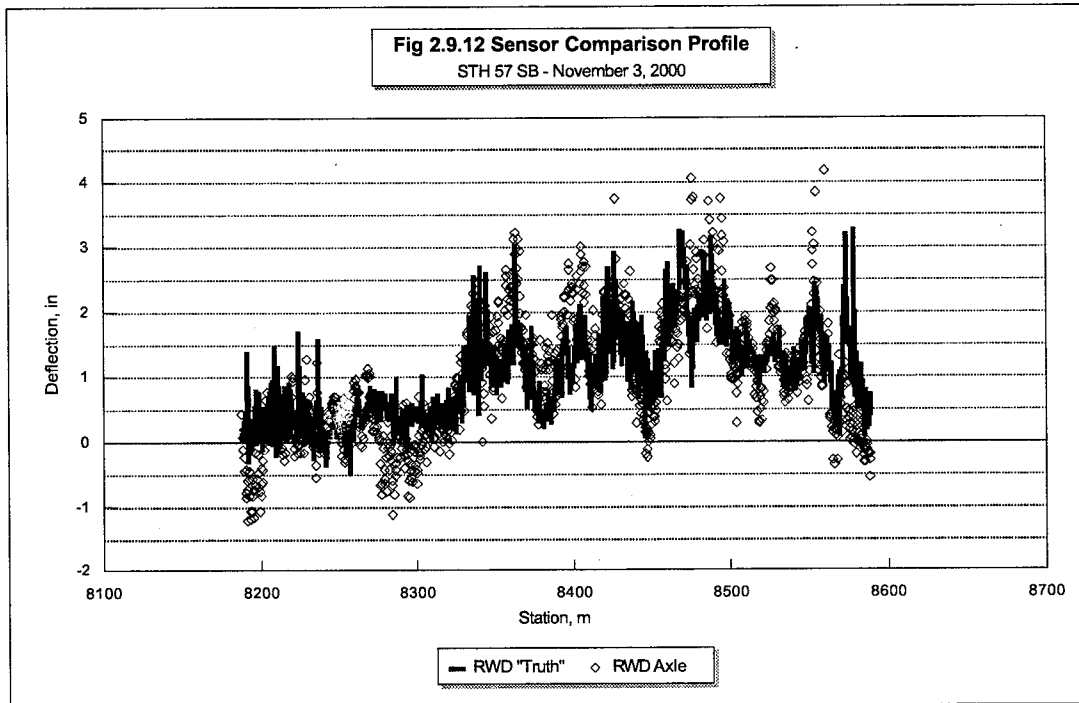
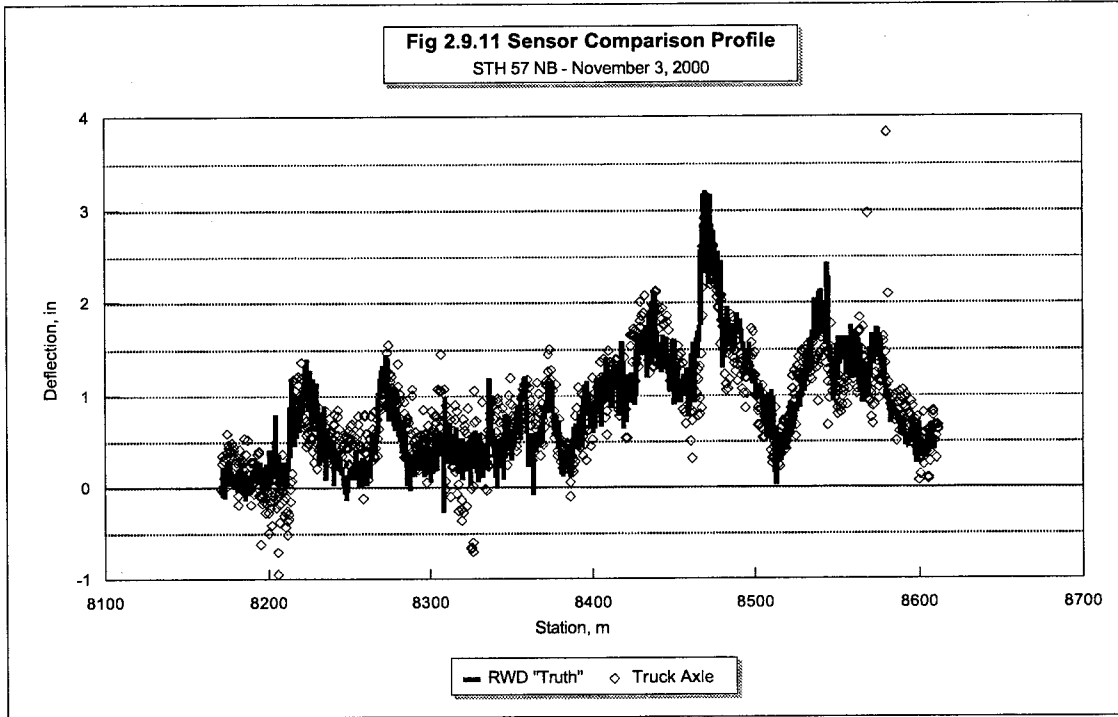
Figure 2.9.2 Sensor Array on Instrumented Truck











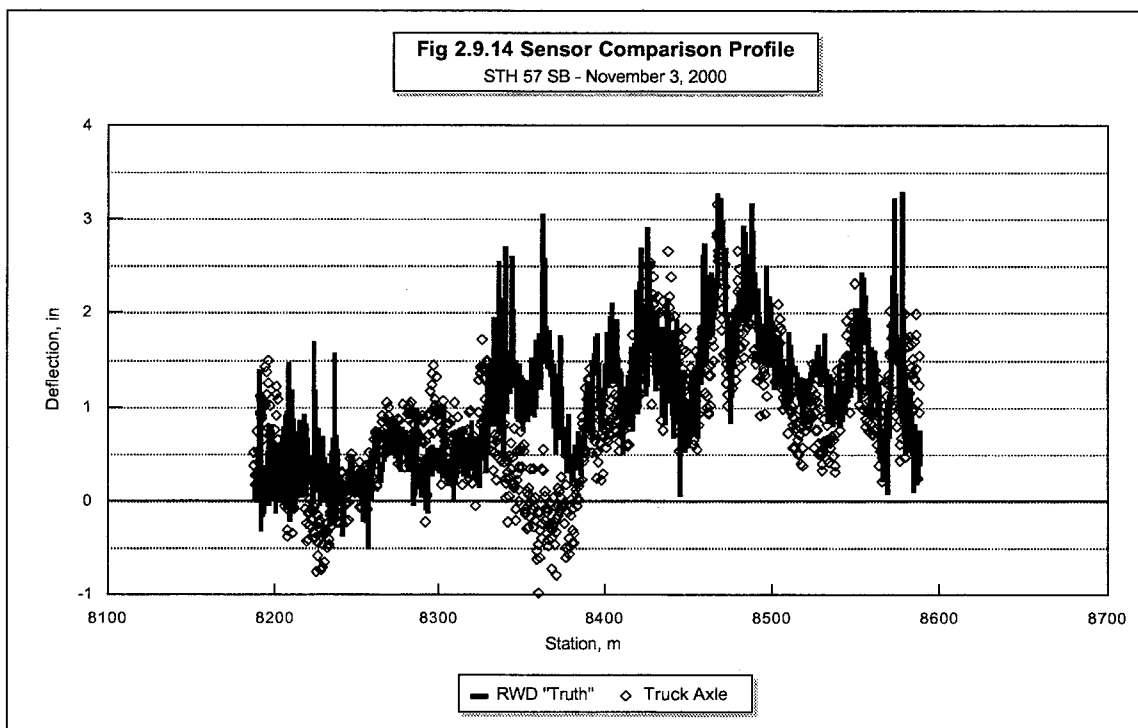
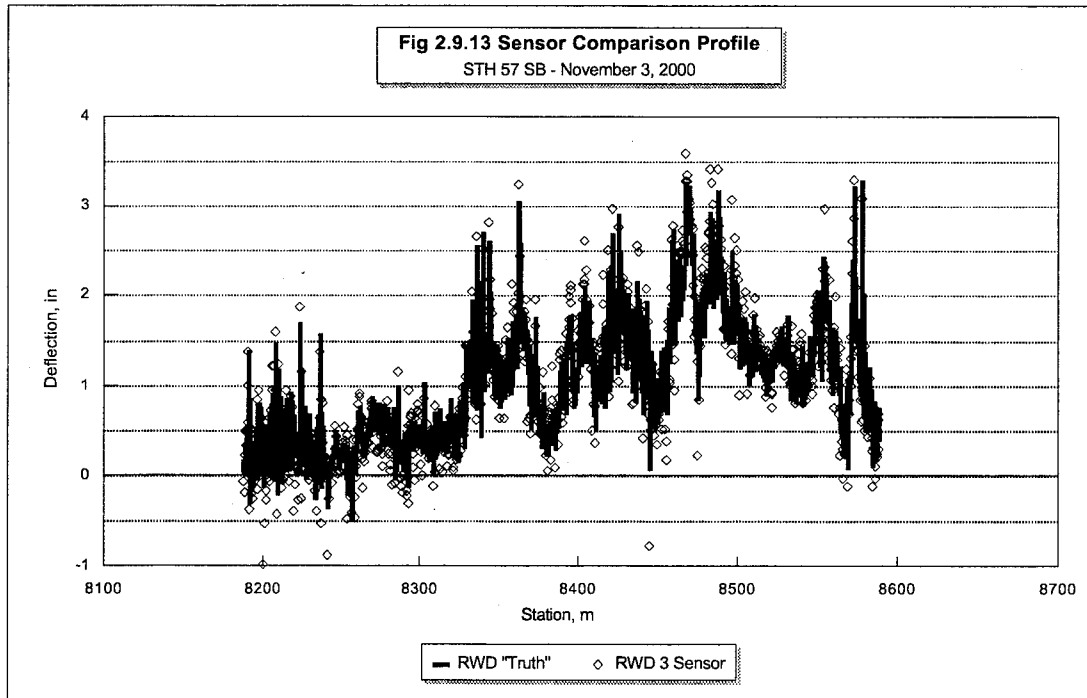


Figure 2.9.15 Deflection vs CBR
STH 57 - Red Clay

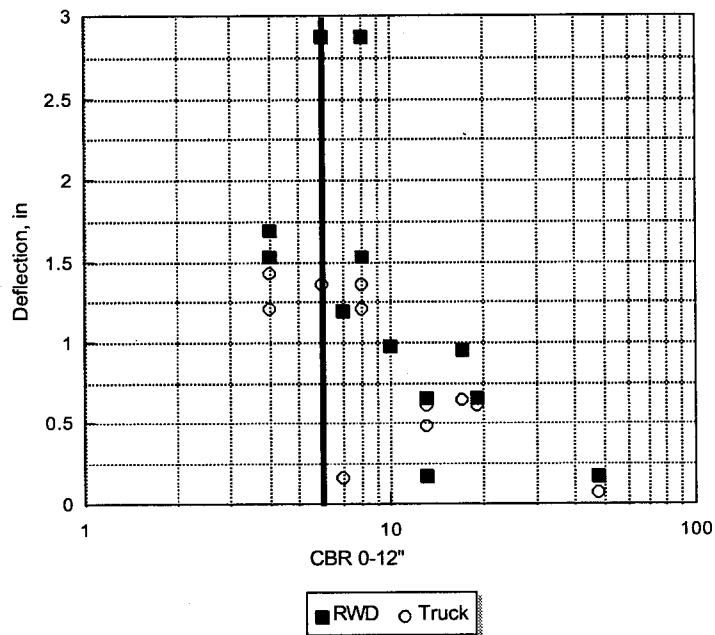
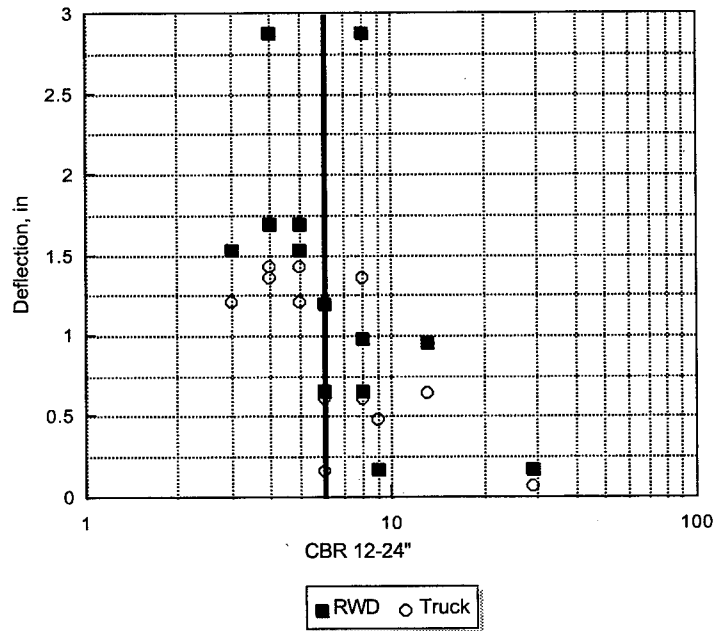


Figure 2.9.16 Deflection vs CBR
STH 57 - Red Clay



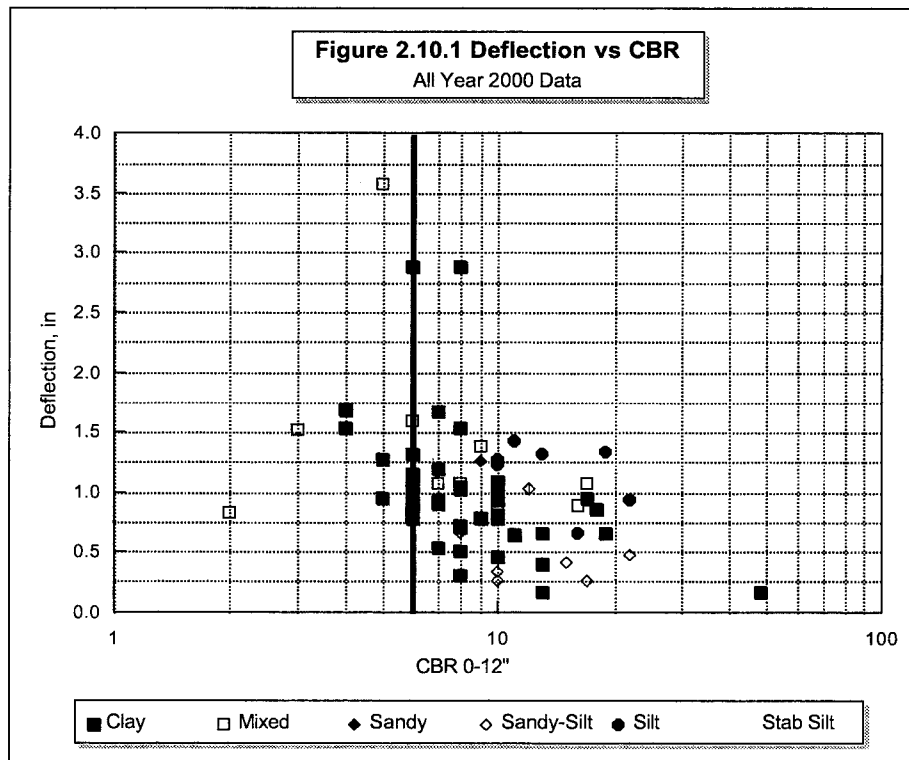
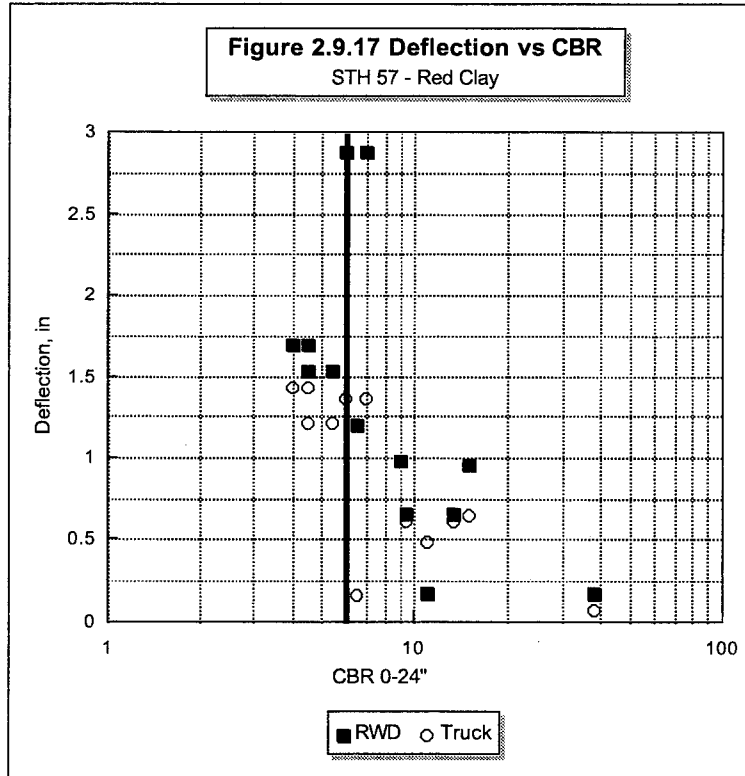


Figure 2.10.2 Deflection vs CBR
All Year 2000 Data

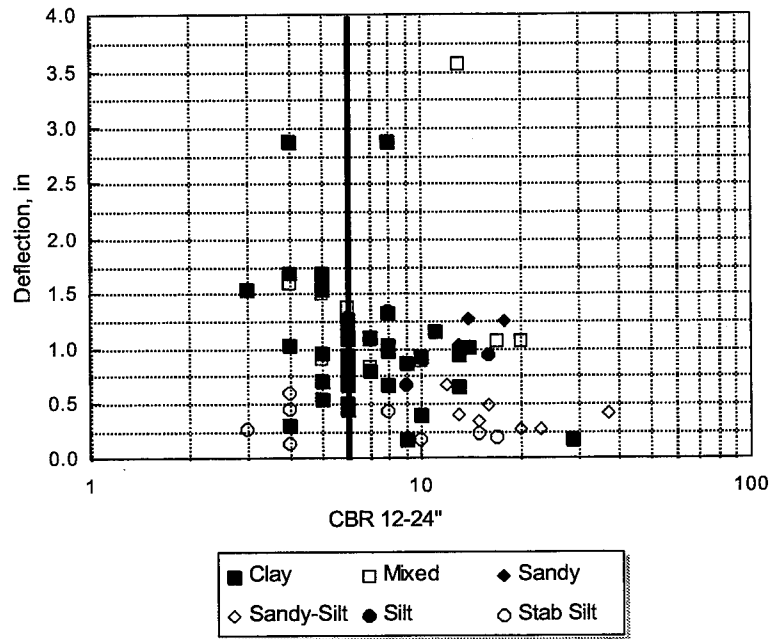
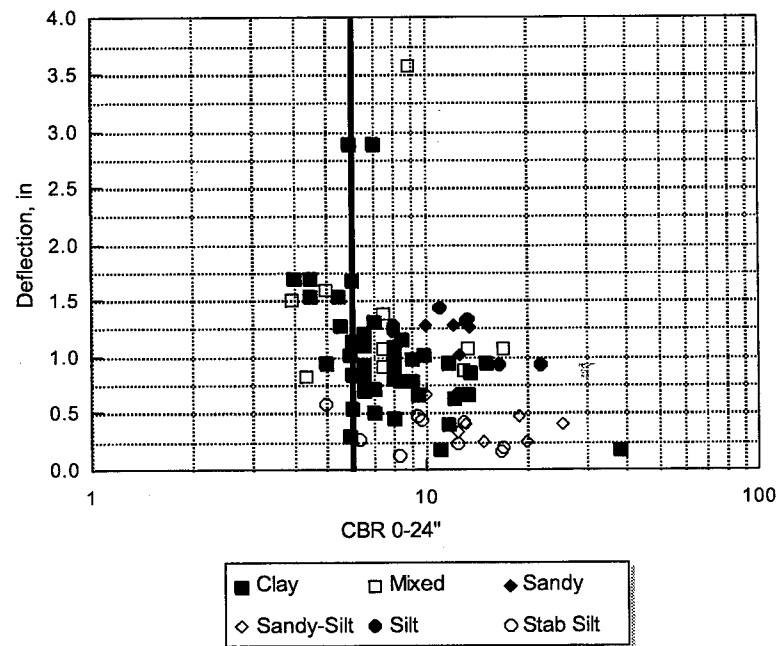


Figure 2.10.3 Deflection vs CBR
All Year 2000 Data



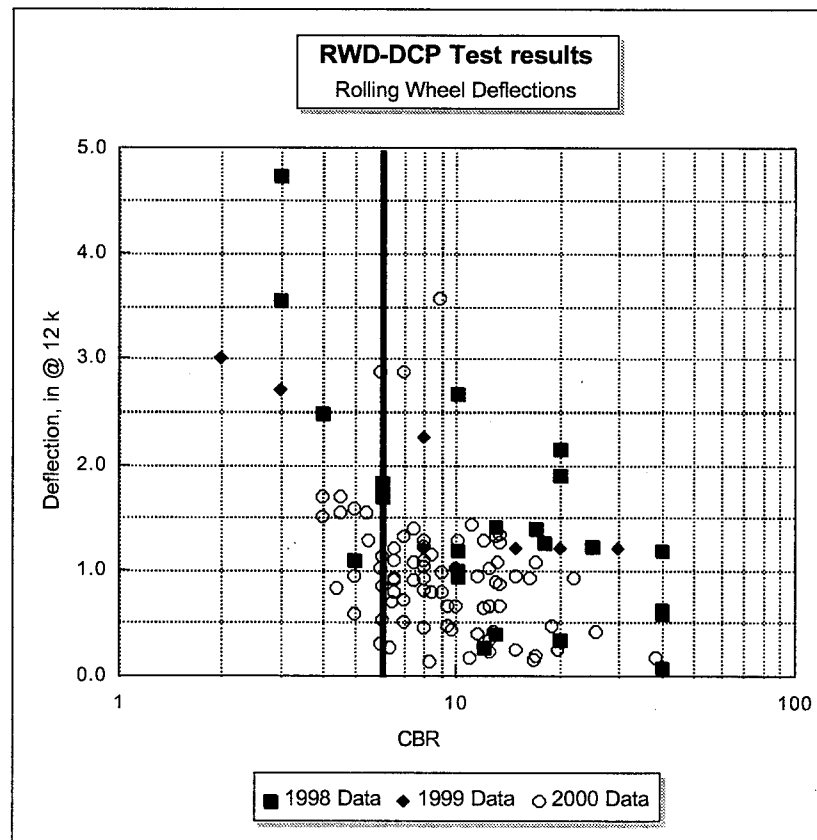
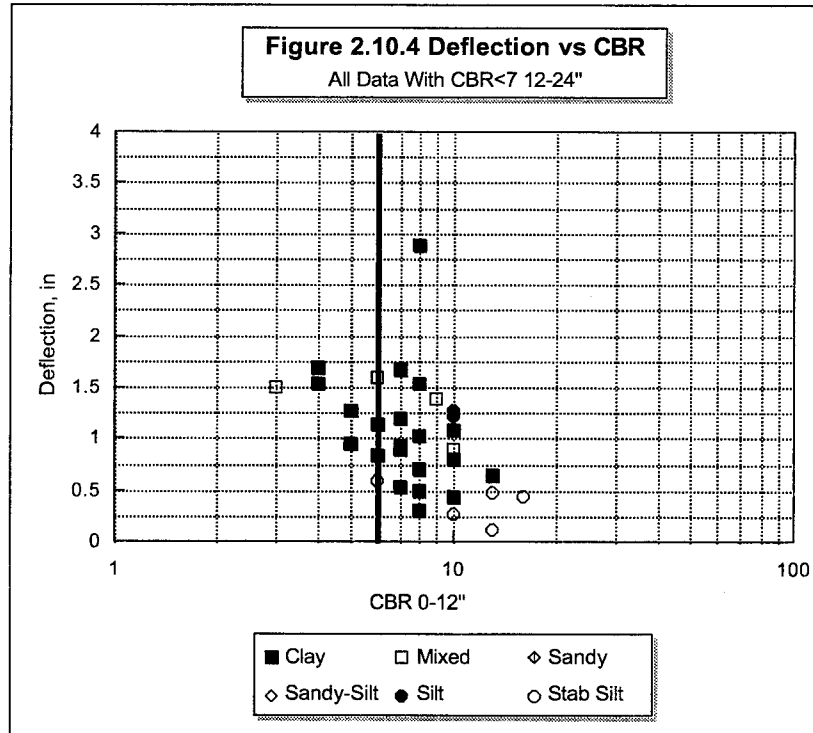


Fig 3.1.1 Proctor/CBR Results

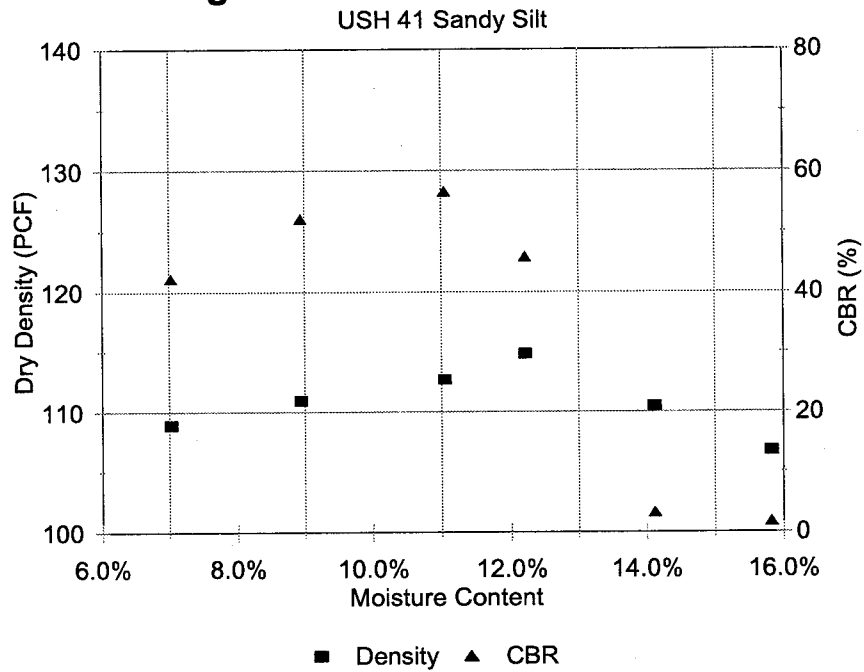


Fig 3.1.2 Proctor/CBR Results

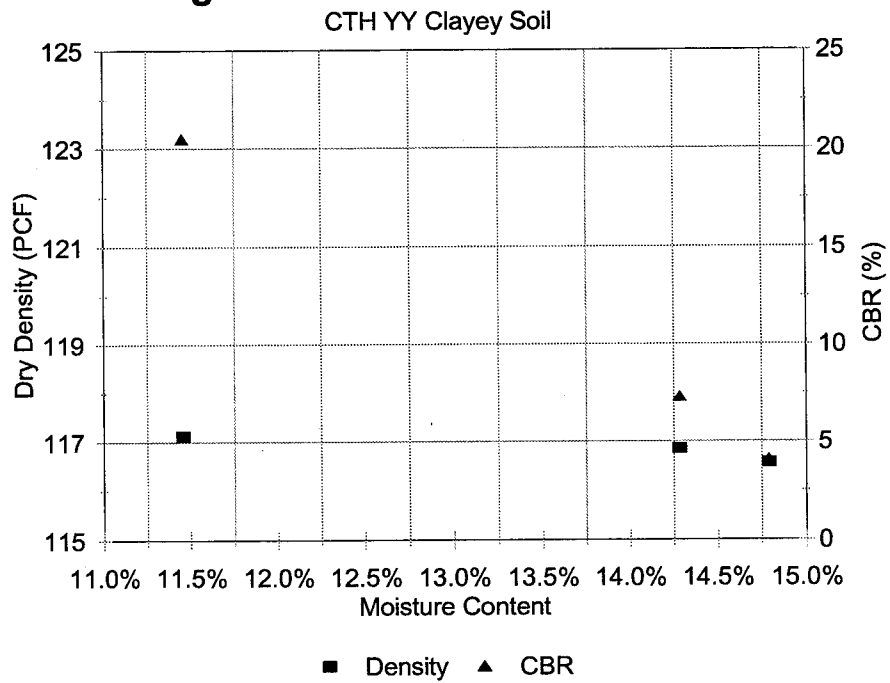


Fig 3.1.3 Proctor/CBR Results

STH 164 Silty Soil

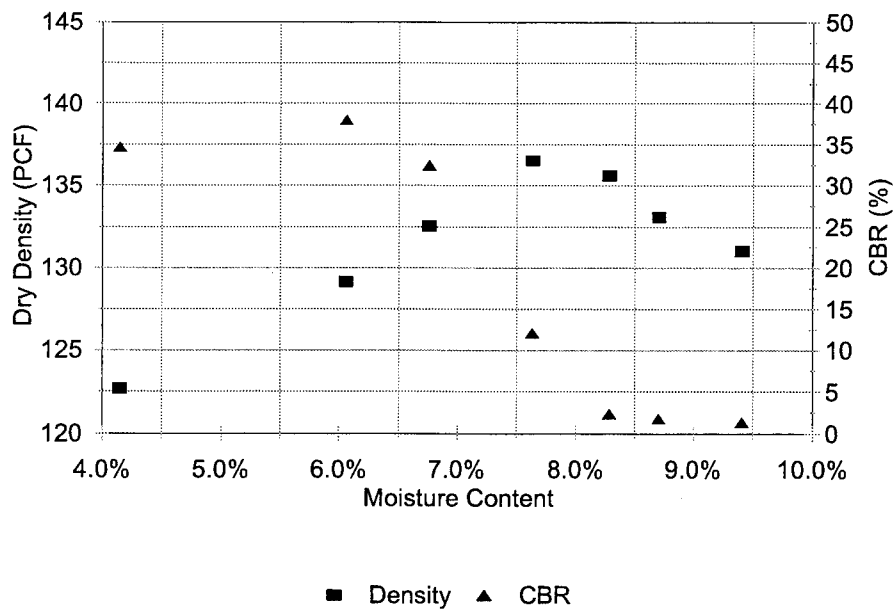


Fig 3.1.4 Proctor/CBR Results

STH 33 Silt

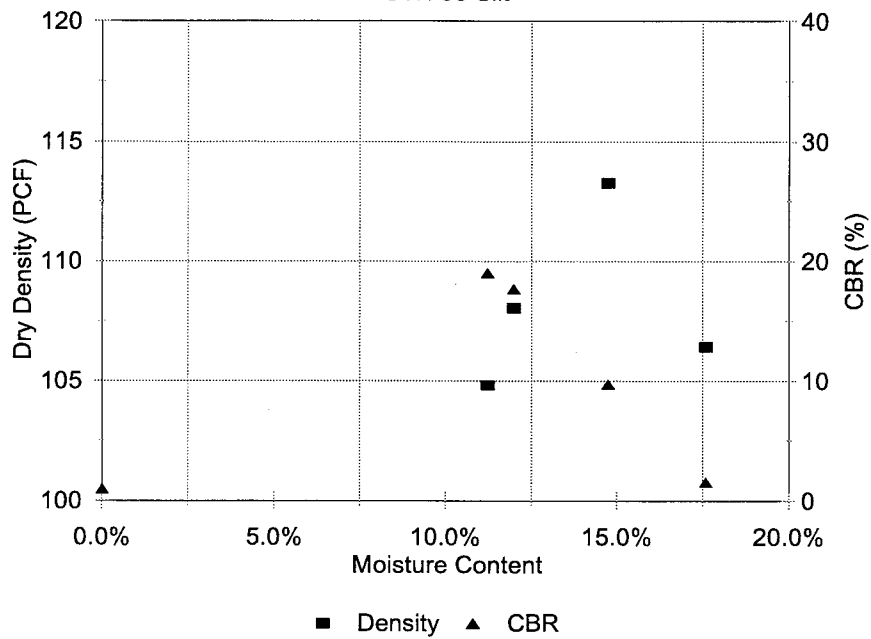


Fig 3.1.5 Proctor/CBR Results

STH 60 Mixed Soil

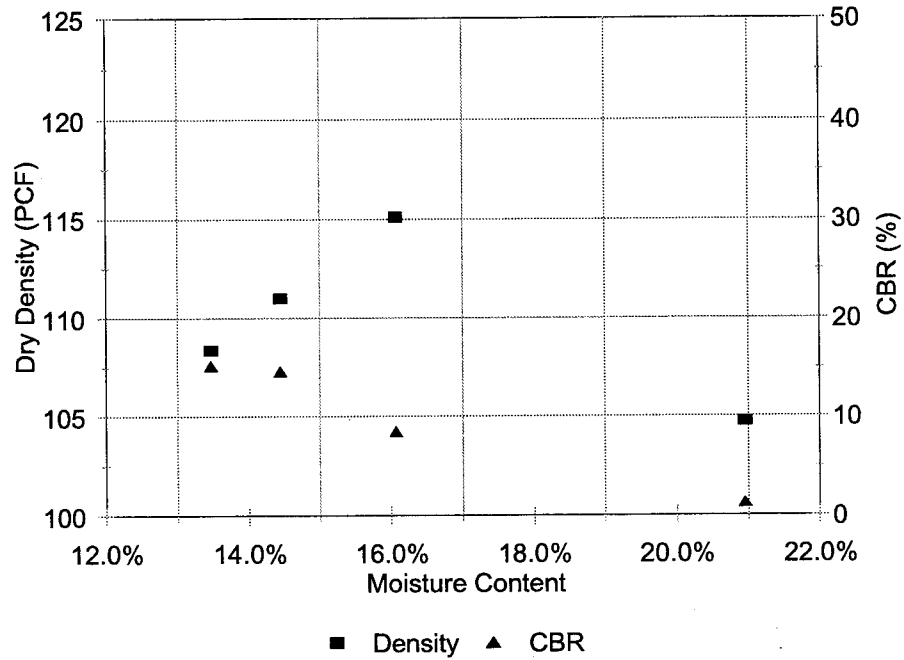


Fig 3.1.6 Proctor/CBR Results

124th St Clay

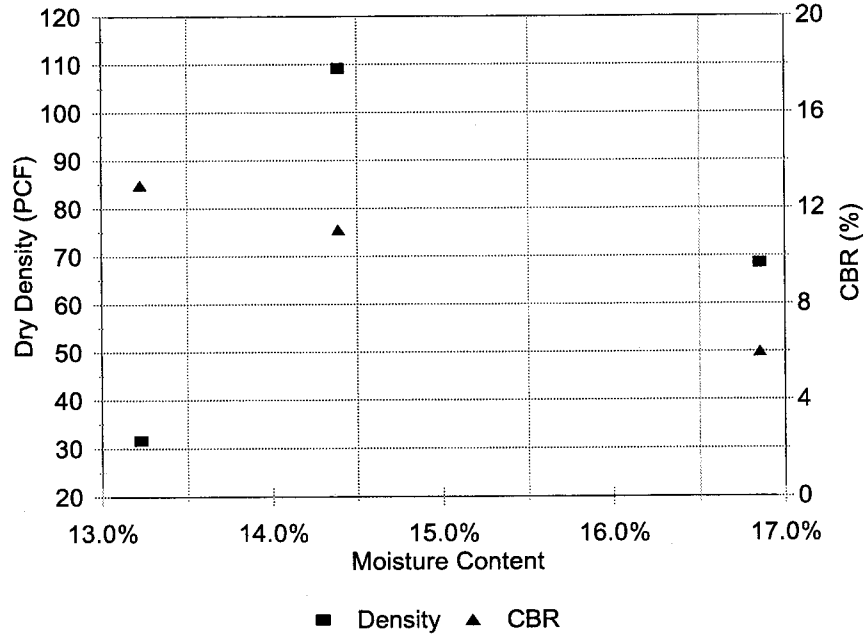


Fig 3.1.7 Proctor/CBR Results

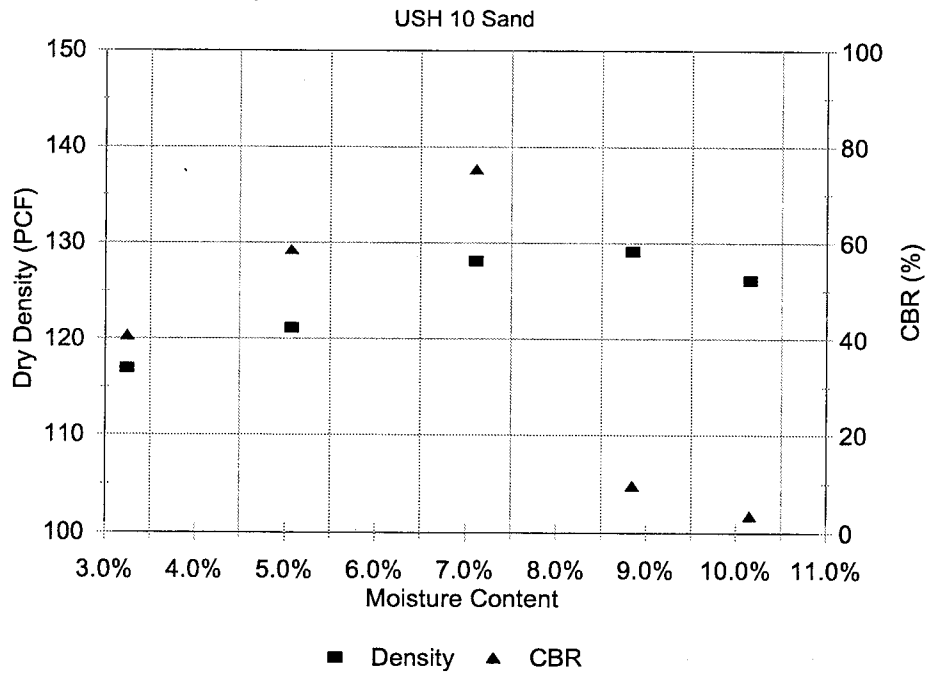
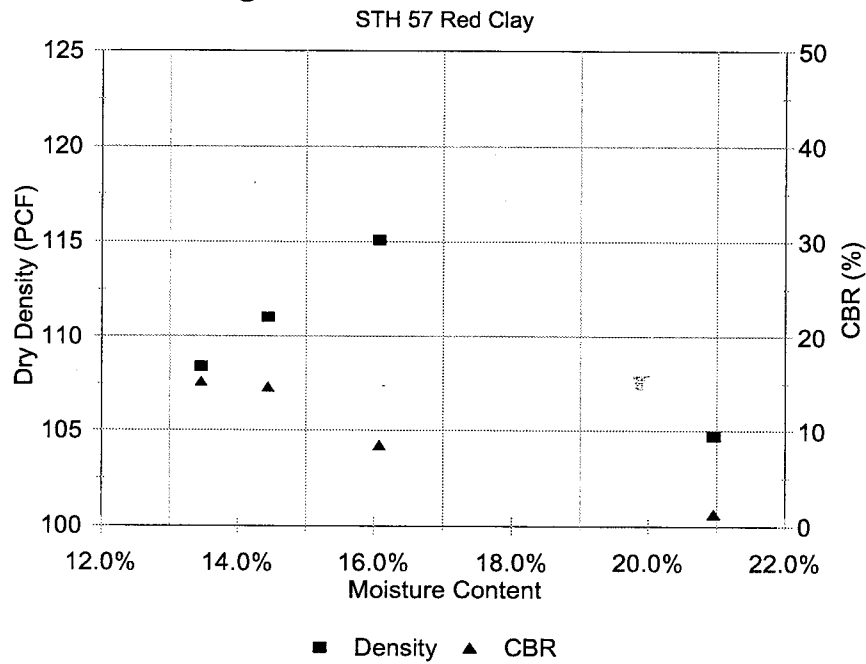
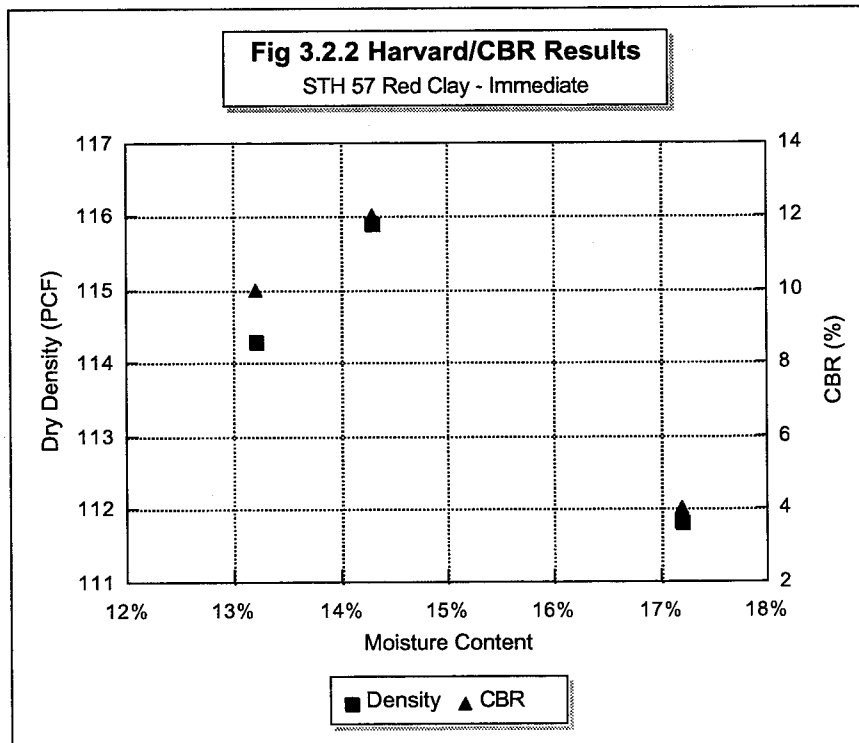
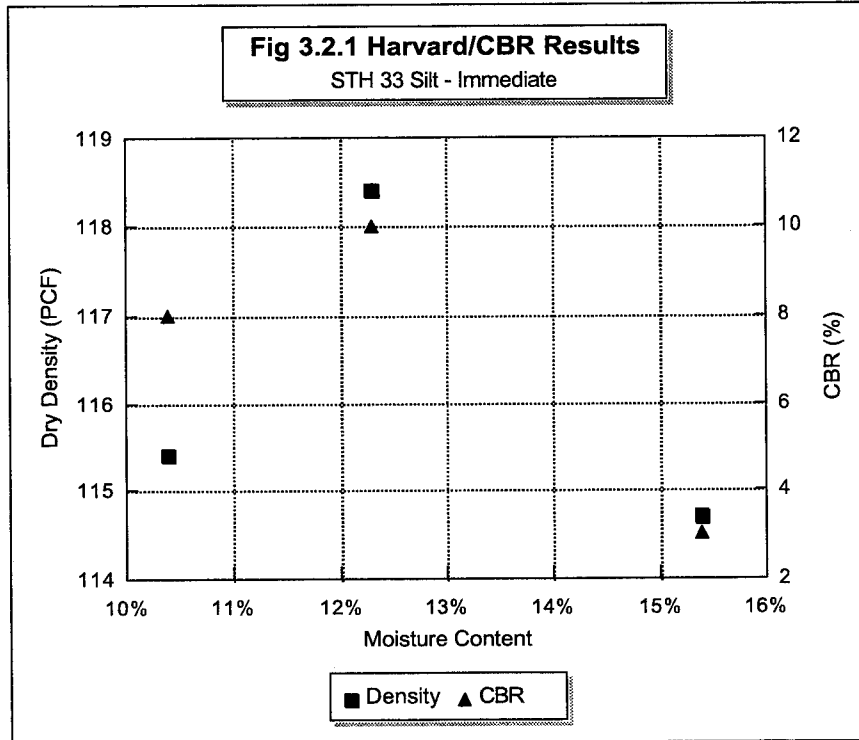
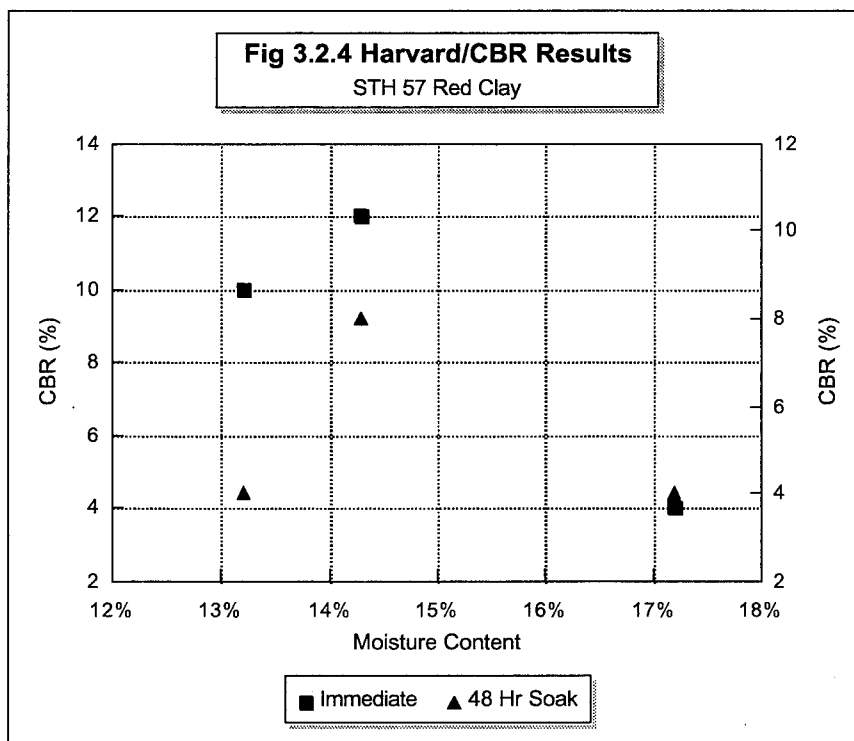
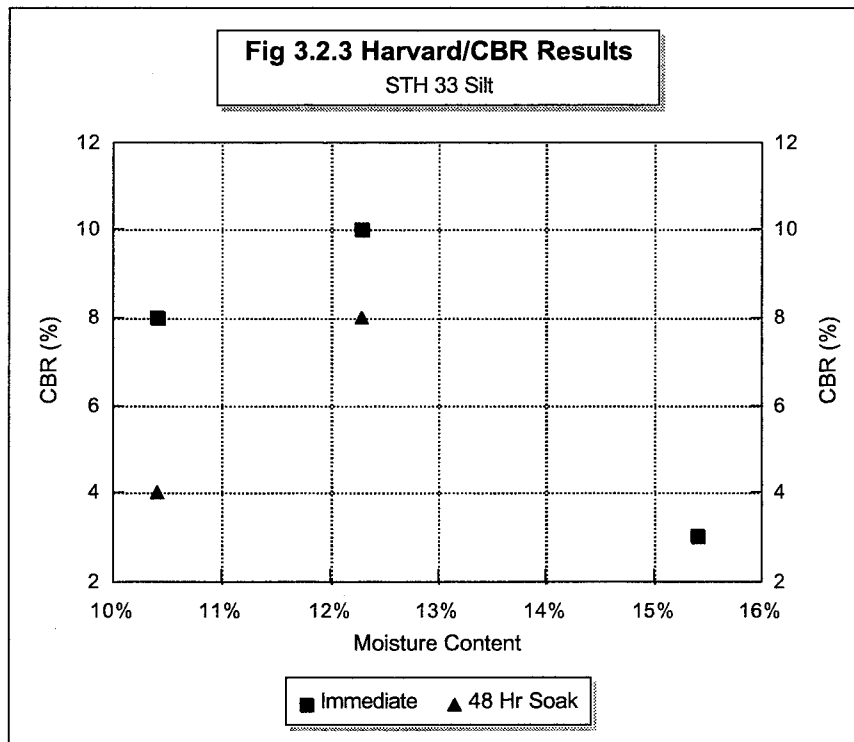
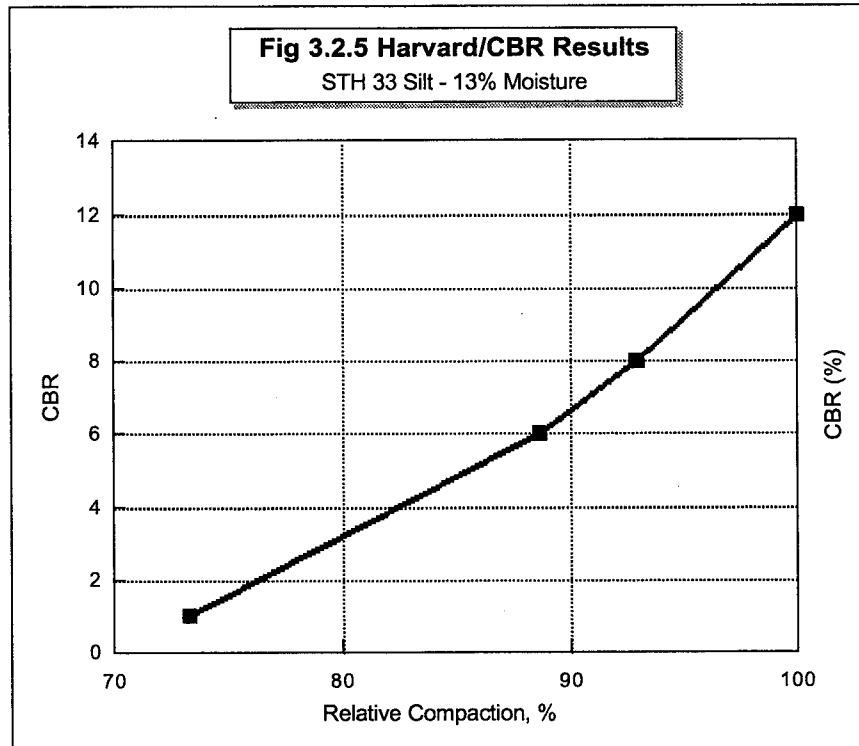


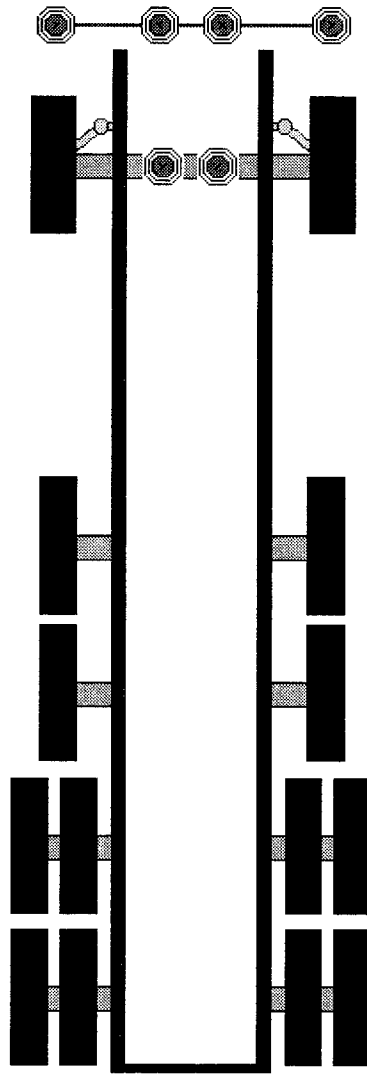
Fig 3.1.8 Proctor/CBR Results











 Distance Transducer

Figure 4.1.1 Proposed Six Sensor Array for Truck Instrumentation

