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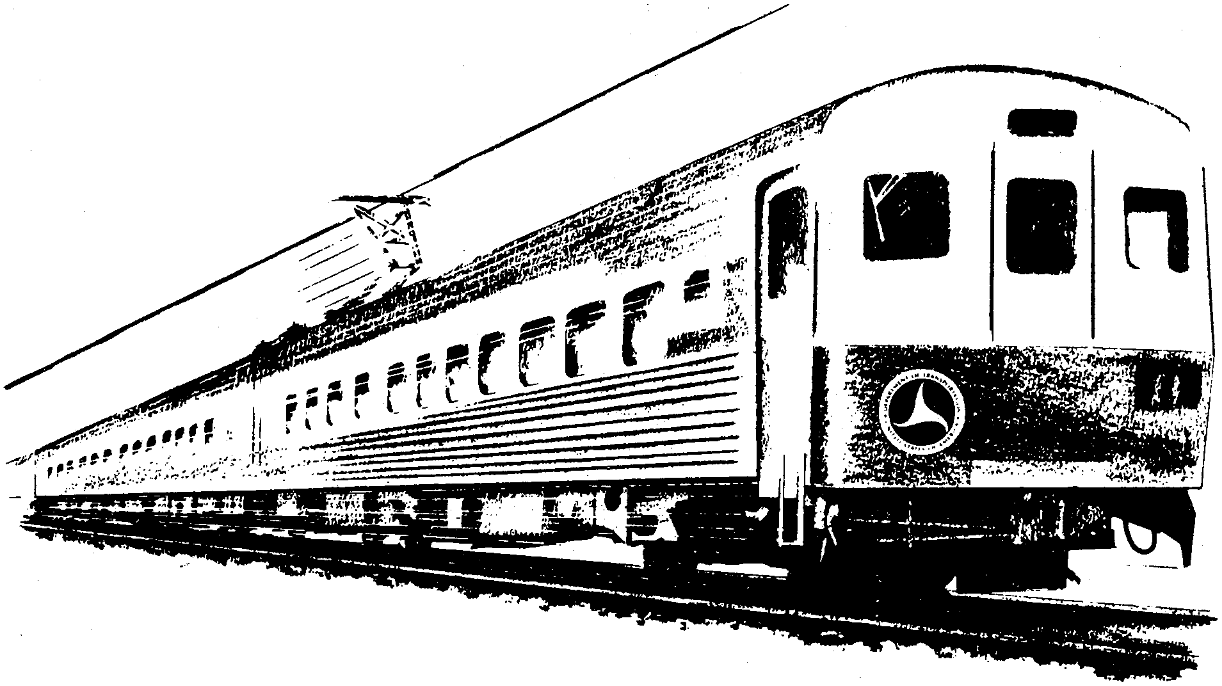
ACQUISITION AND USE OF TRACK GEOMETRY DATA IN MAINTENANCE-OF-WAY PLANNING



U.S. DEPARTMENT OF TRANSPORTATION

FEDERAL RAILROAD ADMINISTRATION

OFFICE OF RESEARCH, DEVELOPMENT AND DEMONSTRATIONS

The contents of this report reflect the comments and views of the B&LE Railroad, the D&RGW Railroad, and ENSCO, Inc., which are responsible for the facts and the accuracy of the data presented herein.

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1.0
INTRODUCTION AND OVERVIEW

Since 1971, the Federal Railroad Administration (FRA), the Denver and Rio Grande Western Railroad (D&RGW), and the Bessemer and Lake Erie Railroad (B&LE) have engaged in a program involving a joint study of the application of track geometry data to maintenance-of-way planning. The objectives of this program are to develop methods that can produce quantitative track rating information, to develop measures of track quality changes, and to utilize these techniques to establish a mathematical basis for long-range track maintenance planning.

Anticipated benefits of such a program for the railroad industry and the government include:

- Improved information for long-range maintenance planning.
- Improved control of certain maintenance-of-way budget allocations (cost to maintain track at a given set of standards can be computed better).
- Establishment of quality control measures of track maintenance (which maintenance equipment or process produces a higher or a more permanent improvement in track quality).
- Improved track safety through the application of automated track geometry inspection.
- Development of computer data processing programs to process data collected by track geometry cars and to display the results in user-oriented formats tailored for different management levels.
- Provide the government with an opportunity for testing developmental track geometry measurement equipment in the railroad environment and for receiving railroad personnel evaluation of the data produced by this equipment.

In support of the above objectives, track geometry data collection runs have been made since 1971 on an annual basis (fall) on the D&RGW and on a semiannual basis (spring and fall) on the B&LE. The railroads have utilized the data collected during these test runs to make near-term track repairs and to plan certain long-range maintenance activities. In addition, D&RGW and B&LE personnel have provided invaluable recommendations for the design of new track geometry measurement instrumentation, the development and modification of data processing programs, the generation of user oriented output formats, and the establishment of measures of track quality in support of the FRA track geometry measurement car program.

The key to this program is the track geometry measurement car which FRA supplies as part of its contribution to the effort. The FRA, through its instrumentation and data collection contractor, ENSCO, Inc., supplies the measurement car personnel, computer programming capability to process the geometry data, computerized data reduction and report generation capabilities, and development of analytic techniques to evaluate track quality and the effects of various maintenance practices. The D&RGW and B&LE furnishes the locomotive power to move the measurement cars over their property, train crews, car maintenance facilities, track maintenance records, and operational and maintenance-of-way expertise for application and evaluation of track geometry data necessary for achieving the objectives of the program.

It is estimated that periodically collected track geometry covering a minimum of 3 years is needed to complete the development of rating indices for the various parameters of track geometry and to gain practical experience with the use of these techniques in long-range maintenance planning. This includes development of specific computer programs and output formats, collection of historical data, application of the processed output in the railroad environment, evaluation of track measurement accuracy, and modification of existing and development of new instrumentation systems.

This development cycle is well underway for certain track geometry parameters (such as profile), but has not been started for other parameters (such as alignment).

The introduction of automated track geometry exception data and rating values provides much additional information for the maintenance-of-way officer. However, none of these data are designed to eliminate the track man or supervisor. The reports merely furnish more and better information to assist the track maintenance personnel in making better judgments.

The railroads involved in this project are both using the FRA track car measurement data for immediate identification and correction of geometry exceptions, and each has also initiated selected maintenance planning applications. For example, the B&LE, because of the length of its line and working season and the time of year of the survey, is able to use certain data reports to plan short-range maintenance before the winter freeze. The D&RGW is surveyed once a year in the fall and uses the reports mainly to review the quality of its maintenance program, to monitor the annual degradation of unworked track, and to help plan the next year's maintenance-of-way program. As a result, the geometry cars already produce data that is useful for a variety of planning purposes, in addition to exception identification.

There are several types of track geometry measurement cars operating in North America. In general, they measure the same basic parameters of track, although they do not necessarily use the same methods. This report is based on experience with the FRA Track Geometry Measurement Cars developed for the Northeast Corridor.

Operation of the FRA measurement cars on the D&RGW is the same as that on the B&LE, except that a business car is added on the end of the train. A 6-channel strip chart recorder is mounted in the rear of the business car and the roadmaster or division engineer acts as a rear observer. On the B&LE, the 6-channel recorder is mounted in the rear vestibule of the measurement car. Any measured defects in track geometry or rough spots felt in the car are marked on the strip chart which the roadmaster may take with him at the end of his territory.

When the length of time between detection and repair is extended, as in planning large-scale maintenance programs, considerably more data must be analyzed. If the rate of track degradation is to be studied and comparisons of maintenance methods are to be made, all of the data must be examined and compared to previous surveys. This can be as many as 100 million individual data samples for one measurement run on the D&RGW. Electronic data processing and statistical analysis are indispensable tools, and the application of these tools to track geometry data analysis has been the major goal of this project. Without clear, concise, and accurate methods of presenting this information, the planner is inundated with computer printouts. Several computer programs have been written under this effort to reduce the data to manageable size. All are useful, but none are perfect.

Chapter 2 of this report describes the work that has been done in the project, the current uses of the data, and the future thrust of the study. The remaining chapters of this report are included as backup for Chapter 2. Chapter 3 summarizes and explains the different types of information reports which can be generated for maintenance-of-way personnel. Samples of the output formats are also included.

Chapter 4 summarizes an extensive testing program that was conducted to validate the FRA track geometry measurement system. The tests were performed to establish the accuracy and repeatability of measurements made with the electronic measurement and digital computer data collection systems onboard the cars. The results are discussed along with a study designed to examine the relationship of track geometry generated ride quality indices to the riding quality of track.

Finally, Chapter 5 provides a brief description of the track geometry measurement system installed onboard the FRA measurement cars. While this particular measurement system was used for this research effort, it is important to realize that other types of equipment could also be used.

2.0

DEVELOPMENT OF TRACK MAINTENANCE PLANNING CAPABILITIES

2.1 CHRONOLOGY

In the late 1960's, the FRA developed and built track geometry measurement cars to monitor Northeast Corridor tracks. The cars were designed to measure track gage, profile, and crosslevel using noncontact capacitive sensors at speeds up to 150 mph. Initial operational experience indicated that valuable track exception information could be provided to cooperating railroads through the analysis of strip chart recordings and computer printouts.

In early 1971, the D&RGW, the B&LE, and the FRA entered into a long-term research effort to develop ways of utilizing track geometry data for maintenance-of-way planning, track degradation studies, and track maintenance quality control evaluation.

During the early track geometry development period, the strip chart recording was considered an important analysis tool, because it provided an integrated picture of the major track geometry measures. Figure 2-1 shows a portion of an 8-channel strip chart produced in real time on the FRA measurement cars. It shows nearly three-fourths of a mile of track. From the top, the profile of each rail, the short chord alignment of each rail, the crosslevel of the track, the track curvature, the track gage, and track location references are displayed.

Figure 2-2 shows a location trace. Midtrack anomalies, such as road crossings, turnouts, location monuments, and even high ballast or weeds, are automatically sensed and accurately entered in the data stream by a detector located under the measurement car. Selected turnouts and road crossings have been established as reference

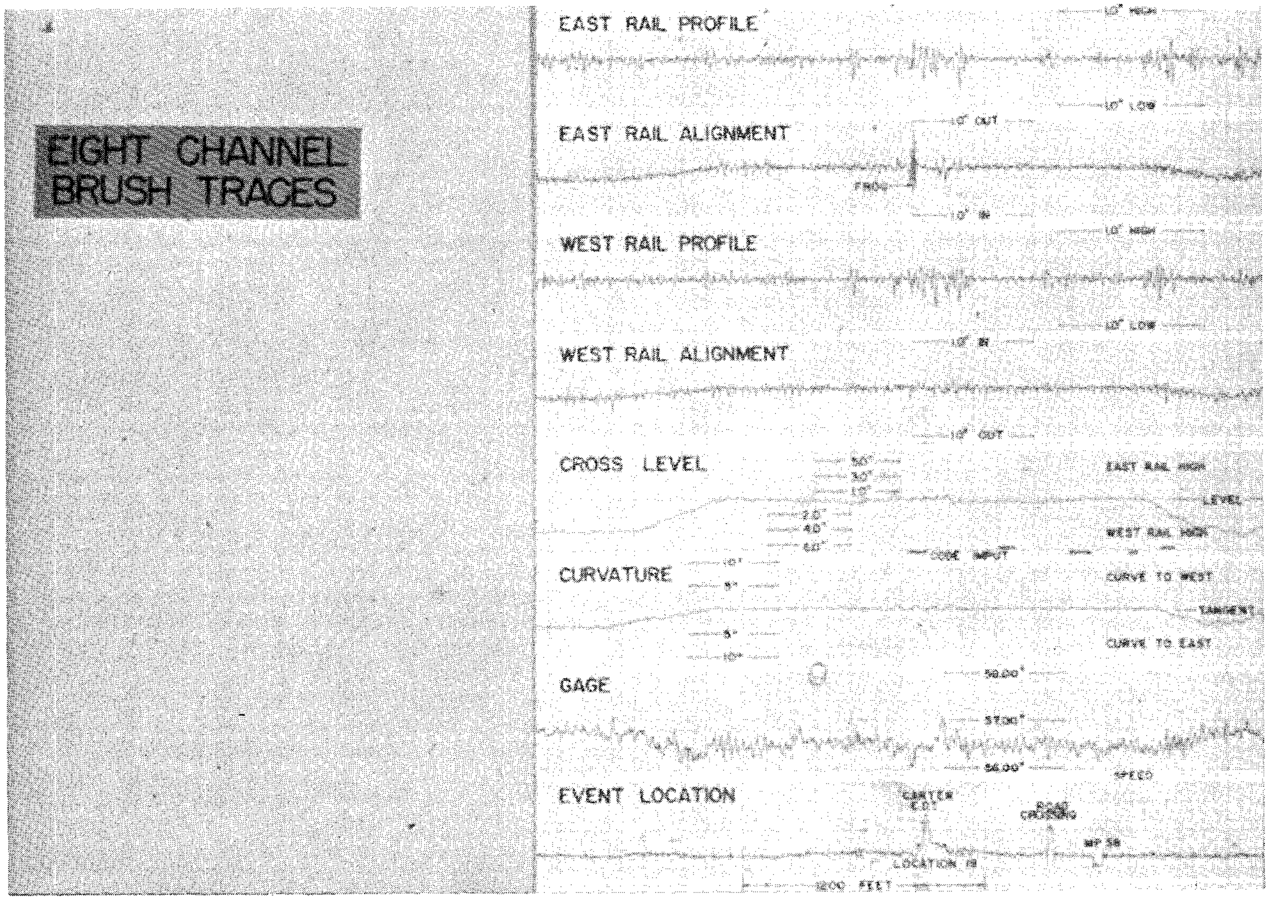


Figure 2-1. Typical 8-Channel Strip Chart Recording

locations and have been programmed into the computer as reference stations. The B&LE is thus divided into nearly 100 track segments of from 2 to 8 miles in length for comparison purposes. For example, the end of double track at Carter is one of these and is coded as location 19; Pine Street crossing in Grove City is coded as location 20. Pine Street is 3.91 miles north of Carter. The D&RGW has been similarly divided into track segments; but, because of the length of its lines, many more locations are required. Some of these are as much as 10 miles long where general track conditions permit homogeneous sections. By processing the data between adjacent locations, the same piece of track can be examined for comparison of one measurement run with another.

In an effort to refine the data reporting techniques and to get away from reading squiggly lines on roll after roll of paper, an off-line gage exception program was developed. Figure 2-3 is an example. The initial program output was cumbersome since, as can be seen, it noted the beginning point of a defect, each change in the severity threshold (usually every 1/4 inch), the maximum value recorded, each descending change in threshold, and the end point. Often this could mean six to 12 lines for one defect, with the report running to several hundred pages.

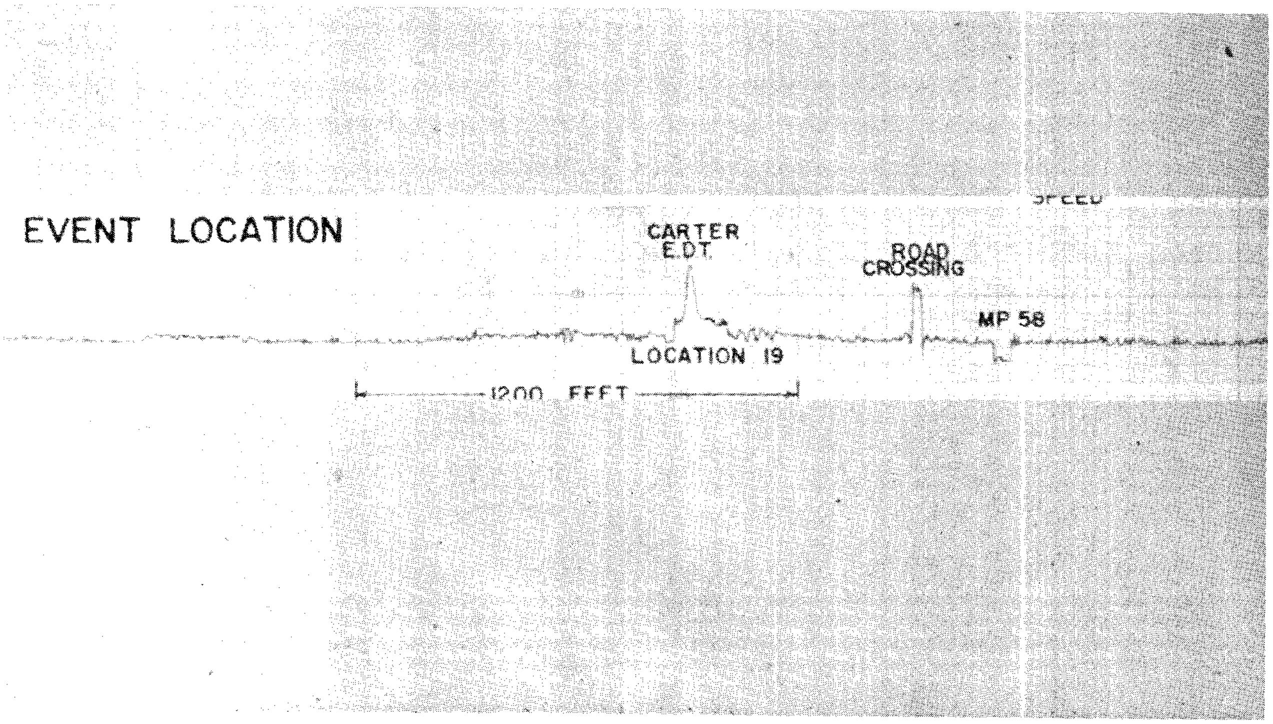


Figure 2-2. Example of Event Location Trace From 8-channel Strip Chart Recording

```
  WIDE GAGE EXCEPTIONS                      ACQUISITION  21031-1N1            PROCESSED  11/07/72                       PAGE    9
LOC X62                                           STANDARDS   57.00        57.25*       57.50**      57.75***      58.00****

   MP     FEET        TRK/LOC       MILE        FEET       GAGE        O/A DIST      ALD    COMMENTS      EXC.INDEX        AVG. GAGE

 * 138     500          1   62        2         2176       57.02                              START
 * 138     550          1   62        2         2198       57.09                              MAX
 * 138     550          1   62        2         2200       57.01           24                 END               8             57.03


 * 138     600          1   62        2         2229       57.02                              START
 * 138     600          1   62        2         2234       57.14                              MAX
 * 138     600          1   62        2         2246       57.03           17                 END              20     C      57.08


 * 138     700          1   62        2         2374       57.02            2                                   1             57.02


 * 138     900          1   62        2         2565       57.01                              START
 * 138    1050          1   62        2         2698       57.26 *
 * 138    1050          1   62        2         2700       57.33 *                            MAX
 * 138    1050          1   62        2         2705       57.25 *
 * 138    1050          1   62        2         2717       57.01          152                 END             123             57.07


 * 138    1250          1   62        2         2881       57.10                              START
 * 138    1250          1   62        2         2881       57.10                              MAX
 * 138    1250          1   62        2         2886       57.05            5                 END               7             57.08


 * 138    1250          1   62        2         2913       57.08                              START
 * 138    1350          1   62        2         2993       57.35 *
 * 138    1350          1   62        2         3024       57.52 **
 * 138    1400          1   62        2         3036       57.81 ***
 * 138    1400          1   62        2         3036       57.81 ***                          MAX
 * 138    1400          1   62        2         3036       57.81 ***
 * 138    1400          1   62        2         3041       57.62 **
 * 138    1400          1   62        2         3048       57.34 *
 * 138    1800          1   62        2         3466       57.06          553                 END            1715             57.26


 * 138    1900          1   62        2         3532       57.08                              START
 * 138    1900          1   62        2         3534       57.14                              MAX
 * 138    1900          1   62        2         3539       57.05            7                 END              12             57.10
```

Figure 2-3. Original Off-line Gage Report

The data contained in the strip chart can be partially read and understood. For example, a short, sharp dip in the profile trace is easily seen as a low rail joint. When the gage trace exceeds 57.25 inches for the track or 57.50 inches for curved track, the roadmaster can visualize what he will find in the field. Changes in the crosslevel or curvature traces may also have some meaning to the experienced eye, however. Except for the absolute value of a low joint in profile or a wide spot in gage, the interpretation of individual traces is a function of judgment and experience. Such defects as warp, even though requiring the reading of only one trace, become more difficult and time consuming to detect. Locating areas of rock and roll in profile or areas of significant mismatch in curvature and superelevation again is a difficult process. At the same time, a meaningful comparison of one strip chart trace with another is impractical.

Computerized profile data exception reports were also under development at this time. Both profile and gage exception reports were designed to ignore good track and print out exceptions in digital form by location and severity. Figure 2-4 shows an early form of such a profile report. On the left are four columns which locate the defect. The first column designates the track being measured. The second column shows the code number of the last referenced location. The third and fourth columns show the distance in miles and feet from that location. Note that this figure is a one-page computer printout that covers 2-1/2 miles of track profile.

Columns five through eight list the defects by rail as referenced to the cars, the overall length (or distance) of the defect from cutoff threshold to cutoff threshold, and a "fact" column. An X in this last column indicates that the defect is related to a road crossing or turnout.

The cutoff threshold in this report was 3/8 inch low. More severe defects were flagged by stars, with one star indicating 1/2 inch low, two stars indicating 5/8 inch low, and so forth. The computer

```
PROFILE EVALUATION              ACQUISITION  11108-2N4          PROCESSED  12/09/71              PAGE   9
                                                   STANDARDS (INCHES)   -.375      -.500*      -.625**      -.750***

                         - - EXCEPTIONS - -                LEFT  - - SEGMENT SUMMARY ( 1320 FEET) - -    RIGHT
  TRK/LOC  MILE FEET       LEFT     RIGHT     DIST FACT    INDEX  SLOPES    MEAN     VAR    INDEX  SLOPES    MEAN     VAR

  1  13    2    3536                -.417
  1  13    2    3558      -.459                 22
  1  13    2    3565                -.391       07
  1  13    2    3954                                         856       2    .011   .0058     1020       6    .016   .0083

  1  13    2    4025      -.377
  1  13    2    5274                                         981       3    .016   .0066     1210       6    .024   .0097

  1  13    3    1313                                         914       0    .024   .0048     1183       4    .017   .0087

  1  13    3    1645                -.766***
  1  13    3    1705      -.445                 60
  1  13    3    1756                -.388       51
  1  13    3    2633                                        1054       4    .013   .0077     1286      11    .020   .0123

  1  13    3    3754      -.439
  1  13    3    3952                                         798       3    .016   .0044     1078       0    .018   .0069

  1  13    3    4470                -.451
  1  13    3    5134                -.445
  1  13    3    5137      -.385                 02
  1  13    3    5272                                         863       2    .010   .0054     1187       7    .032   .0086

  1  13    4      23                -.387
  1  13    4    1311                                         917       5    .008   .0061     1210       3    .035   .0087

  1  13    4    1891      -.390
  1  13    4    2237                -.486
  1  13    4    2631                                        1036       3    .010   .0079     1306      12    .033   .0111

  1  13    4    2645                -.399
  1  13    4    2706                -.443       60
  1  13    4    3950                                         985       2    .005   .0069     1221      12    .033   .0093

  1  13    4    5270                                         749       1    .006   .0040     1090       5    .037   .0067

  1  13    5     212                -.476             G
  1  13    5     236      -.495                 24
  1  13    5    1309                                        1187       4    .005   .0102     1494       5    .037   .0128

  1  13    5    1677                -.398
  1  13    5    2266                -.392
  1  13    5    2629                                         853       0    .007   .0047     1071       4    .031   .0068
```

Figure 2-4. Original Off-line Profile Report program was written to give the user the option of varying these thresholds. The right-hand half of Figure 2-4 gives various profile rating values. These were the earliest attempts at rating track quality. This program output information was the first designed for different levels of management. The supervisor or roadmaster, who is primarily concerned with defects, used the left portion, while the planner or middle management maintenance-of-way officer was concerned with the right half. From a user's standpoint, it was realized that separate reports were needed. As a result, consolidated defect summaries were developed to meet the track supervisor's needs.

The computer was programmed to sort the profile defects in a given territory by severity and print them in a sorted table. Such a listing (Figure 2-5) can include all spots above a given severity level, or can display the worst 50, 100, or even 200 exception locations. Such a printout can give a first-line maintenance supervisor all the information he needs to locate and repair the more severe profile defects. The listing eliminates the need to scan numerous pages of a more detailed report.

Profile rating summaries (Figure 2-6) were also developed for quarter-mile sections of track. These were oriented toward middle management and planning personnel. The four columns on the left of the figure define the quarter-mile track section by the location of its end point in miles and feet, either from a milepost or from a permanent location. The quarter-mile section was selected for several reasons. While one can argue that tangents and curves should be separated, neither a measurement car nor an experienced surveyor can accurately locate a point of curve to the nearest foot on the track. Some sort of permanent monument would be required at each end of each curve as an absolute minimum. The FRA measurement car can measure a mile of track with a maximum error of 5 feet (0.1 percent). The computer can accurately divide this mile into quarters. By selecting turnouts and road crossings located generally

```
****************************************   MOST SEVERE EXCEPTIONS - CHORD OFFSET   ****************************************
*                                                  LOC X03 - LOC X13                                                       *
*                                          WEST             *                                          EAST                *
*  MP    FEET   TRK/LOC  MILE   FEET   PROFILE  FACT  PAGE  *  MP    FEET   TRK/LOC  MILE   FEET   PROFILE  FACT  PAGE  *
*                                                           *                                                           *
*                                                           *                                                           *
*   8    1850   1    04     2   1714      -.76           4  *  35    2400   1    11     2   4858      -.80          19  *
*  26     900   1    08     1   4089      -.71     X    13  *  32    4400   1    11     0   1469      -.76   G X    18  *
*  32    4450   1    11     0   1549      -.71     X    18  *  20    3200   2    06     3   4549      -.73          10  *
*  40    1150   1    12     2   3681      -.70          20  *  23     400   2    06     6   1771      -.71          11  *
*   9     750   1    04     3    497      -.70     G     4  *  35    2350   1    11     2   4798      -.71          19  *
*  24    2950   1    08     0    855      -.69          13  *   9    1000   1    04     3    762      -.69     C     4  *
*  20     150   2    06     3   1475      -.68          10  *  22    2800   2    06     5   4371      -.68     C    11  *
*   8    4250   1    04     2   4126      -.67           4  *  23    4000   2    06     7     46      -.68          11  *
*   9    3550   1    04     3   3269      -.67     X     4  *   4     150   1    03     2   1410      -.68           1  *
*  33    4800   1    11     1   1999      -.66          18  *   9    2500   1    04     3   2246      -.67     C     4  *
*  20    2500   2    06     3   3851      -.64          10  *  20     150   2    06     3   1475      -.65          10  *
*  23     400   2    06     6   1771      -.64          11  *   4    1600   1    03     2   2889      -.64           2  *
*  26    1750   1    08     1   4916      -.64     C    13  *  40    1150   1    12     2   3703      -.64          20  *
*  35    3550   1    11     3    729      -.64     X    19  *   3    4450   1    03     2    433      -.61           1  *
*  27     600   1    09     0    210      -.62     X    15  *   4    2150   1    03     2   3430      -.61           2  *
*  17    5000   2    06     1   1015      -.62           9  *  32    1150   1    10     1   3164      -.61          17  *
*  17     150   2    06     0   1435      -.62   GCX     9  *  25    3100   1    08     1   1023      -.60          13  *
*  22    4250   2    06     6    537      -.62          11  *  27     550   1    09     0    167      -.60     X    15  *
*  39    4900   1    12     2   2149      -.60          20  *  20    4700   2    06     4    782      -.59          10  *
*  30    1250   1    09     3    668      -.60          15  *  17     150   2    06     0   1450      -.58     C     9  *
*  27     550   1    09     0    133      -.60     X    15  *  36    1300   1    11     3   3783      -.58   G X    19  *
*   3    4450   1    03     2    433      -.59           1  *   8     300   1    04     2    153      -.58     X     3  *
*   4     450   1    03     2   1746      -.59           1  *   8     950   1    04     2    810      -.57           3  *
*   7    2400   1    04     1   2209      -.59    GC     3  *   6     400   1    04     0    295      -.57     C     3  *
*  20    4000   2    06     4     89      -.59          10  *  22    5000   2    06     6   1252      -.57          11  *
*  11    5200   1    04     5   4918      -.57           5  *   4    1400   1    03     2   2703      -.57     G     1  *
*   9    4550   1    04     3   4281      -.56   G X     4  *  31    1200   1    10     0   3115      -.57          17  *
*  30    3800   1    10     0    459      -.56          17  *  10    3750   1    04     4   3465      -.56           5  *
*  23    2600   2    06     6   3951      -.56          11  *  30    1250   1    09     3    646      -.56     X    15  *
*  24     750   2    06     7   2079      -.55          11  *  39    4950   1    12     2   2173      -.56          20  *
*  16    3150   1    05     3   4313      -.55     X     7  *  27      50   1    08     2   3251      -.56          14  *
*  16    4300   1    06     0    147      -.55   G X     9  *   4     550   1    03     2   1850      -.55     X     1  *
*  24     100   2    06     7   1419      -.55          11  *  31    3800   1    10     1    418      -.55     X    17  *
*   7    3850   1    04     1   3679      -.55     C     3  *  24     100   2    06     7   1402      -.55          11  *
*  16    3250   1    05     3   4390      -.54     X     7  *  23    1250   2    06     6   2608      -.54     C    11  *
*  19    3250   2    06     2   4578      -.54          10  *   5     150   1    03     3   1444      -.53     C     2  *
*  12    4300   1    05     0    179      -.54     X     7  *  23    3950   2    06     7     15      -.53          11  *
*  24    2850   1    08     0    737      -.54     X    13  *  26     900   1    08     1   4075      -.53          13  *
*  38     650   1    12     0   3146      -.53          20  *  10    3650   1    04     4   3361      -.53           5  *
*  23     700   2    06     6   2025      -.53          11  *  18    3600   2    06     1   4928      -.52           9  *
*   6    4650   1    04     0   4538      -.53           3  *  33    1350   1    11     0   3840      -.52     C    18  *
*   2     800   1    03     0   2144      -.53     X     1  *   4    2950   1    03     2   4232      -.52     G     2  *
*  37    4800   1    12     0   2035      -.53          20  *  17    1000   2    06     0   2289      -.52     C     9  *
*  21    5200   2    06     5   1288      -.53          10  *  22    1500   2    06     5   3047      -.52          11  *
*  24    2250   2    08     0    135      -.53          13  *  36    2950   1    11     4    135      -.52          19  *
*  16    4500   2    06     0    343      -.52           9  *  37     450   1    11     4   2897      -.51    CX    19  *
*  21    1750   2    06     4   3124      -.51          10  *  33    2400   1    11     0   4882      -.51          18  *
*  27     550   1    09     0    172      -.51     X    15  *  16    5150   2    06     0   1039      -.51    CX     9  *
*   9    3400   1    04     3   3143      -.51     X     4  *  43     650   2    13     1   2494      -.51     X    22  *
*   1    4450   1    03     0    524      -.50           1  *   6    4800   1    04     0   4676      -.51           3  *
*                                                           *                                                           *
***************************************************************************************************************************
```

Figure 2-5. Priority Profile Defect List (Chord Offset)

```
********************  TRACK SEGMENT SUMMARY FOR LOCATION : LOC X04                6.0-12.8                     ********************
*                                      I                                                                                          *
*     TRACK SEGMENT =  1320 FEET       I EXCEPTION THRESHOLD LEVELS : 1 =  .375,  2 =  .500,  3 =  .625,  4 =  .750,  5 =  .875   *
*                                      I                                                                                          *
*                                      I                                  .50     I             NUMBER OF EXCEPTIONS              *
*          SEGMENT LOCATION    % DATA  I   TRACK   TRACK        CUM.   PERCENT.   I               ABOVE THRESHOLDS :              *
*     MP     FEET  MILE  FEET  IN SEG  I   INDEX   SLOPES      SLOPE    VALUE     I      1   2   3   4  5  I   1   2   3  4   5   *
*                                      I                                          I        ( WEST RAIL)    I      ( EAST RAIL)    *
*                                      I                                          I                        I                      *
*      10     2900   4    2631    100  I    1703     115          3.45    -.371   I                        I   3                  *
*      10     4200   4    3950    100  I    1624     107          3.06    -.483   I      6                 I   3   2              *
*       6     1450   0    1319    100  I    1561      95          3.02    -.447   I      4                 I   3   2              *
*       9     4200   3    3952    100  I    1401      83          2.79    -.394   I      2   1   1         I                      *
*      12      200   5    5268    100  I    1399      74          2.71    -.406   I      2   1             I   1                  *
*      10      250   3    5272    100  I    1354      85          2.46    -.400   I      1   1             I   3                  *
*       6     2750   0    2639    100  I    1246      61          2.44    -.357   I      1                 I   1                  *
*       9     2900   3    2633    100  I    1246      51          2.51    -.383   I      2                 I           1          *
*      10     1600   4    1311    100  I    1223      53          2.14    -.407   I      2                 I   2                  *
*      11     2900   5    2629    100  I    1201      50          2.17    -.391   I      2                 I   1                  *
*       7     4150   1    3956    100  I    1183      56          2.13    -.393   I          1             I   3                  *
*       8      100   1    5276    100  I    1181      59          2.24    -.306   I      2                 I                      *
*      11     1550   5    1309    100  I    1149      56          2.20    -.277   I                        I                      *
*       7     1500   1    1317    100  I    1140      45          2.10    -.393   I      1                 I   2                  *
*       9      250   2    5274    100  I    1131      50          2.11    -.434   I      2       1         I   2                  *
*      11      250   4    5270    100  I    1131      41          2.32    -.259   I                        I   1                  *
*       9     1550   3    1313    100  I    1097      32          2.13    -.503   I              1         I           1          *
*      12     1500   6    1307    100  I    1090      32          2.30    -.270   I                        I   1                  *
* *    12     4100   6    3884     95  I    1085      38          1.94    -.285   I                        I   1                  *
*      12     2850   6    2627    100  I    1072      40          1.96    -.254   I                        I                      *
*      11     4200   5    3948    100  I    1067      43          1.95    -.246   I                        I                      *
*       7     2800   1    2637    100  I    1049      42          1.95    -.378   I      1   1             I                      *
*       8     4050   2    3954    100  I     971      36          2.00    -.295   I                        I   1                  *
*       6     4050   0    3958    100  I     931      26          1.68    -.337   I                        I   1                  *
*       7      200   0    5278    100  I     907      27          1.63    -.388   I          1             I       1              *
*       8     2750   2    2635    100  I     780      13          1.48    -.260   I                  1     I                      *
*       8     1450   2    1315    100  I     773      20          1.39    -.408   I      1                 I       2              *
*                                      I                                          I                        I                      *
***********************************************************************************************************************************

    *  =  SEGMENT IS LESS THAN FULL TRACK SEGMENT
```

Figure 2-6. Profile Exception Track Segment Summary Report

3 to 5 miles apart as permanent monuments, highly repeatable quarter-mile sections can be output for each test run. At the same time, these sections are then short enough that limited changes in the data do not become masked by the sheer mass of data.

The last column on the left quarter of the page shows the percentage of data accounted for in the section. Each quarter mile of track should have 1092 samples of profile data. If some of these samples have been lost or are not included for some reason, the rating values for that section lose their validity and cannot be used for comparative purposes unless there is compensation for this loss of data.

The first profile rating value shown is "track index." This is defined as the area between a measured profile curve and a theoretically perfect track. The numerical value for each sample of profile data is multiplied by the 2.4-foot sampling interval (converted to inches), and these products are then summed for each rail. Although individual defects are related to a particular rail, track profile quality is related to both rails. In present practice, therefore, the index values for the two rails are averaged to determine track index.

As in defect reporting, the computer can be programmed to sort the quarter-mile sections by index value for longer stretches of track. These are then printed out in order of severity so that the worst track can receive immediate attention. Figure 2-7, for example, covers nearly 50 miles of track.

A second method being studied to rate track is the "top of rail slope" changes per quarter mile. These are shown as "Track Slopes" in the column to the right of "Track Index" in Figure 2-6. If two consecutive data point values on either rail differ by more than 0.1 inch, the slope of the top of the rail is considered to have changed, and one slope, or slope change, is counted. The number of such changes per quarter mile is printed as a measure of surface quality.

```
****************************     MOST SEVERE EXCEPTIONS - TRACK SEGMENT SUMMARY     **************************************
*                                                   LOC X03 - LOC X13                                                     *
*                                                                                                                         *
*                                                BASED ON SEVERITY OF INDEX                                               *
*                                                                                                        .50              *
*    MP       FEET        TRK/LOC          MILE       FEET      INDEX      SLOPES     MEAN    VARIANCE      CUM.      PERCENT.    PAGE *
*                                                                                                   SLOPE      VALUE           *
*                                                                                                                         *
*    24       3400        1    08            0        1319      1809        156       .001     .0183      3.5556     -.5151      13 *
*    17         50        2    06            0        1319      1736        112       .003     .0155      3.2893     -.5024       9 *
*    10       2900        1    04            4        2631      1703        115       .007     .0167      3.4510     -.3712       5 *
*    10       4200        1    04            4        3950      1624        107       .010     .0141      3.0632     -.4828       5 *
*    19       3950        2    06            2        5274      1583         93      -.007     .0134      3.3931     -.4094      10 *
*     6       1450        1    04            0        1319      1561         95      -.006     .0148      3.0208     -.4470       3 *
*    19       5250        2    06            3        1313      1535         71      -.011     .0132      3.1407     -.3550      10 *
*    13        100        1    05            0        1319      1500         90       .011     .0118      2.9687     -.3658       7 *
*    17       5300        2    06            1        1317      1498         75       .003     .0121      3.0490     -.3561       9 *
*     4       1350        1    03            2        2635      1485         92       .005     .0122      2.4840     -.4973       1 *
*    20       3900        2    06            3        5272      1483         78      -.007     .0147      2.7022     -.4103      10 *
*    27       1700        1    09            0        1319      1466         84       .008     .0134      2.6606     -.5087      15 *
*    37        200        1    11            4        2631      1450         94       .016     .0106      3.0545     -.2928      19 *
*    30       1900        1    09            3        1313      1439         90       .009     .0111      2.8621     -.4398      15 *
*    40       1400        1    12            2        3954      1433         63      -.021     .0111      2.7678     -.5380      20 *
*     4       4000        1    03            2        5274      1426         82       .014     .0104      2.6481     -.4347       2 *
*    23       1300        2    06            6        2627      1415         77      -.002     .0150      2.4329     -.5444      11 *
*     9       4200        1    04            3        3952      1401         83      -.007     .0108      2.7858     -.3938       4 *
*    37       1500        1    11            4        3950      1400         92       .014     .0099      2.6545     -.3741      19 *
*    12        200        1    04            5        5268      1399         74       .002     .0118      2.7065     -.4063       5 *
*    23       5250        2    06            7        1305      1398         94       .002     .0125      2.4286     -.4541      11 *
*     4       2650        1    03            2        3954      1391         86       .002     .0118      2.4626     -.5309       2 *
*    32       4250        1    11            0        1319      1386         73       .006     .0105      2.6993     -.3518      18 *
*     4         50        1    03            2        1315      1380         73      -.001     .0080      2.7274     -.3823       1 *
*    20       1300        2    06            3        2633      1379         61      -.002     .0124      2.8605     -.5482      10 *
*    23       2600        2    06            6        3946      1370         73      -.005     .0119      2.4966     -.4395      11 *
*    10        250        1    04            3        5272      1354         85      -.005     .0108      2.4605     -.4004       4 *
*    24       1300        2    06            7        2625      1336         65       .001     .0111      2.4665     -.5014      11 *
*    18       1300        2    06            1        2637      1325         45       .008     .0081      2.6993     -.2575       9 *
*    18       2650        2    06            1        3956      1317         39      -.002     .0096      2.5455     -.3669       9 *
*    29       1900        1    09            2        1315      1307         82       .018     .0093      2.5103     -.2737      15 *
*    20       5250        2    06            4        1311      1301         54      -.000     .0108      2.4863     -.4428      10 *
*    26       2100        1    08            1        5276      1297         67       .004     .0104      2.4049     -.5213      13 *
*     3       4000        1    03            1        5276      1296         52       .009     .0065      2.8364     -.2882       1 *
*    24       4750        1    08            0        2639      1286         75      -.005     .0093      2.4706     -.3665      13 *
*    17       1350        2    06            0        2639      1285         52       .010     .0090      2.5518     -.4825       9 *
*    33        150        1    11            0        2639      1284         82       .006     .0093      2.2635     -.4544      18 *
*    41        100        1    12            3        2633      1280         42      -.019     .0084      2.4762     -.3504      21 *
*    29       4550        1    09            2        3954      1276         61       .002     .0089      2.6170     -.2918      15 *
*    38       1450        1    12            0        3958      1261         45      -.024     .0082      2.3490     -.3776      20 *
*     2       1300        1    03            0        2639      1255         63      -.001     .0079      2.4462     -.3912       1 *
*     6       2750        1    04            0        2639      1246         61       .001     .0089      2.4430     -.3565       3 *
*     9       2900        1    04            3        2633      1246         51      -.015     .0081      2.5092     -.3831       4 *
*     1       5250        1    03            0        1319      1244         61      -.004     .0093      2.2438     -.4539       1 *
*    38        100        1    12            0        2639      1241         57      -.015     .0082      2.5491     -.3183      20 *
*    29       3250        1    09            2        2635      1239         66       .015     .0077      2.6517     -.2514      15 *
*     5          0        1    03            3        1313      1237         76       .011     .0083      2.3179     -.2935       2 *
*    26       3400        1    08            2        1315      1236         61       .004     .0089      2.4088     -.2802      13 *
*    27       3050        1    09            0        2639      1236         52       .017     .0088      2.4106     -.3191      15 *
*    20       2600        2    06            3        3952      1235         46      -.008     .0091      2.4342     -.3858      10 *
*                                                                                                                         *
***************************************************************************************************************************
```

Figure 2-7. Priority Profile Defect List (Track Segment Summary-Index)

A third profile rating technique is printed near the center of Figure 2-6 and is denoted as "Cumulative Slope." To define this concept graphically, the cumulative histogram (Figure 2-8) of all the profile data points in a quarter-mile section of track is constructed by the computer. The X-axis shows the profile values, while the Y-axis shows the sum of all the data readings equal to or less than that profile reading as a percentage of the total samples.

Mathematically the slope of a line is described as the tangent function which is equal to the difference in Y-values divided by the corresponding difference in X-values. By reading across the constructed graph at the 70 percentile level to the curve and then down to the X-axis, the corresponding profile value can be determined. The same can be done at the 30 percentile level. The change in Y-values is 70 percent minus 30 percent, or 40 percent. The change in X-values is the algebraic difference of the two X-axis readings. The slope value can therefore be calculated by division.

If the track section is smooth, the data points will tend to group tightly together; the change in X-value will tend to be smaller, and the slope value will tend to be larger. If the track section is rough, the data points will spread more across the graph; the change in X-value will be larger, and the slope will tend to be smaller.

These rating methods are concerned with the overall condition of a quarter-mile section. However, it is possible that only a few isolated spots may begin to deteriorate. These could be at road crossings, at insulated joints, or at turnouts. It is also desirable to flag this type of change. The 0.5 percent value shown in Figure 2-9 is an attempt to note this type of change. This can be described as that value of the profile data which is less than 99.5 percent of all the values in the section. The figure shows the lower end of the cumulative distribution curve,

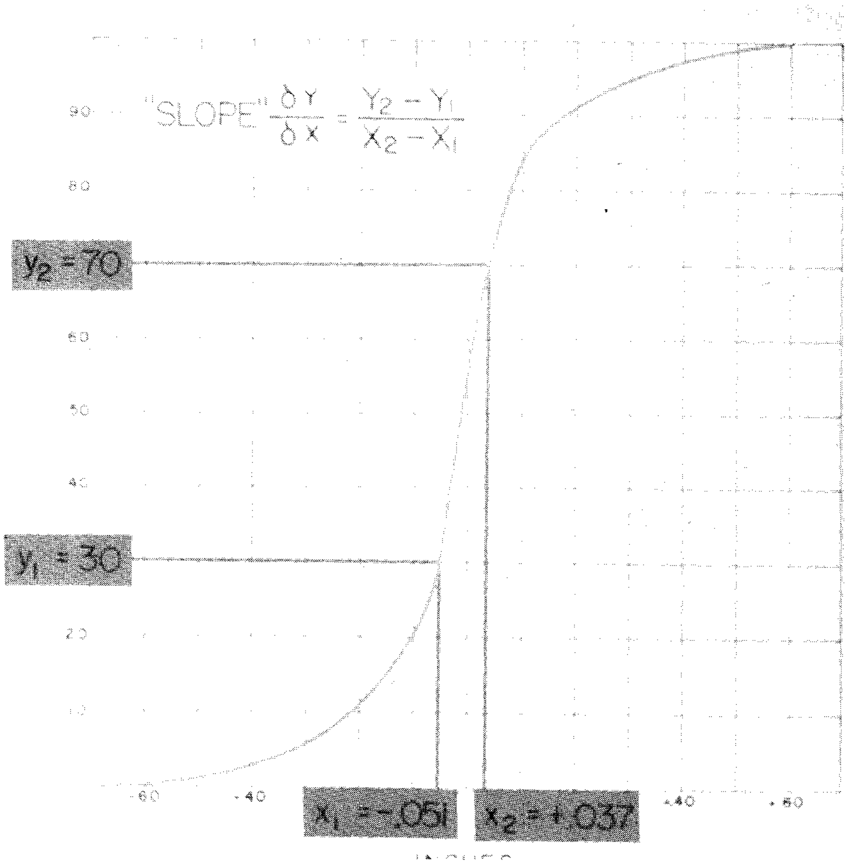


Figure 2-8. Cumulative Slope Value Calculation

with the cumulative percentage of the data as the ordinate and the profile value as the abscissa. The computer, in effect, reads up to the 0.5 percentile level and then over to the curve to find an intercept value. This is the 0.5 percent value and is printed out in the summary data.

The calculation of the 0.5 percent value normally utilizes five data samples, or 12 feet of track. If these samples represented a "critical" defect, they might be corrected before the computerized data analysis was complete. For future comparative purposes it would, as a result of corrective actions, lose its meaning.

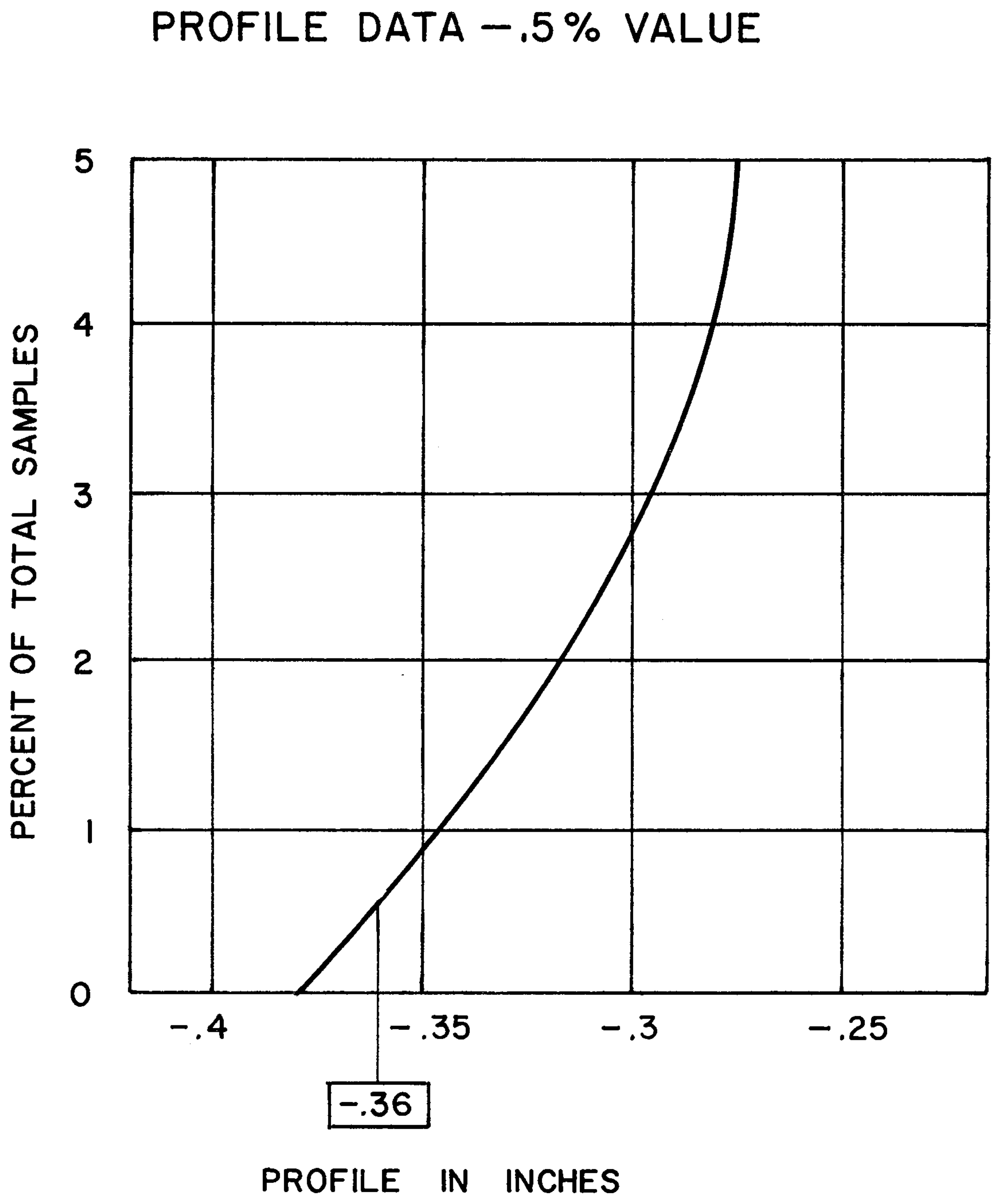
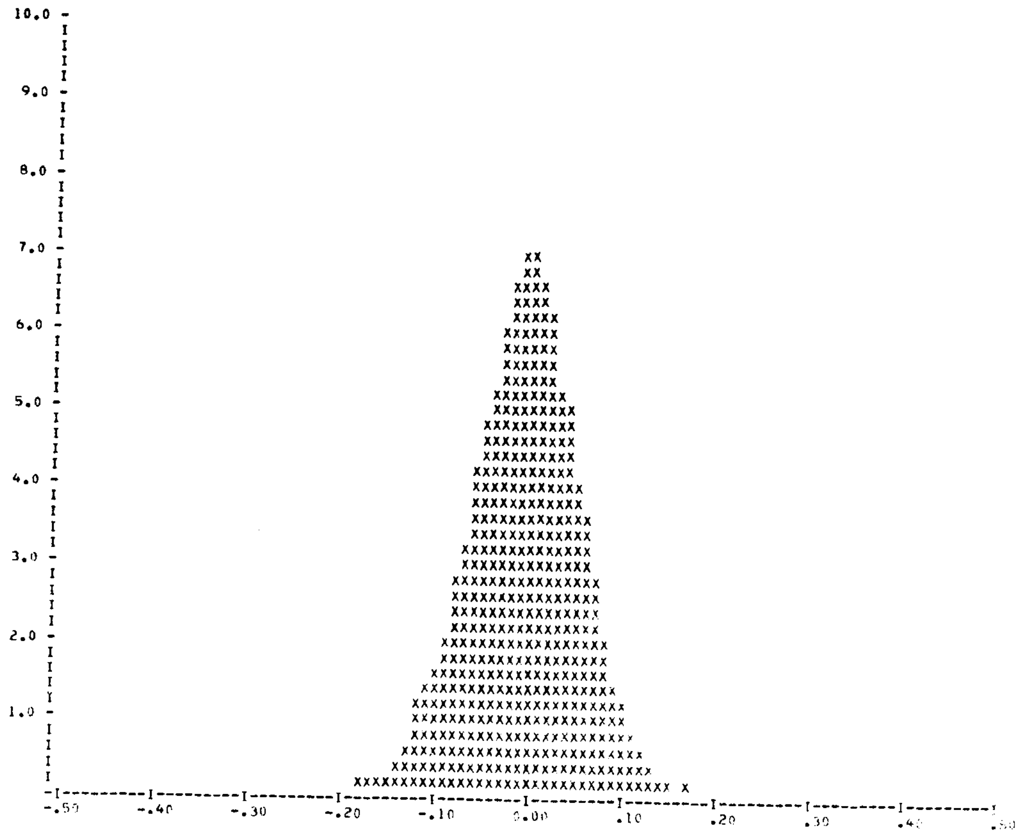


Figure 2-9. 0.5 Percent Profile Value Calculation

Pictorial representations of the data can be made by the computer through the use of the histogram. In Figure 2-10, the percentage of profile data points in each cell, shown on the Y-axis, is plotted against the profile value for the cell, shown on the X-axis. The histogram can be an effective technique for displaying data for longer stretches of track.

As with the study of track profile, it became necessary to develop gage rating techniques and to output them in a separate user-oriented report. Figure 2-11 shows gage rating techniques used to evaluate approximately four miles of track.



```
PROFILE DATA HISTOGRAM

PERCENT OCCURRENCE OF CHORD OFFSETS          CHORD OFFSET :  MINIMUM VALUE =  -.58
LOC X13                                                      MAXIMUM VALUE =   .25
RIGHT RAIL
```

Figure 2-10. Typical Profile Histogram

```
    TRACK SEGMENT SUMMARIES           ACQUISITION  41124-1N1             PROCESSED  12/15/74                         PAGE   3
                                                    PERCENTAGE LEVELS : 1 = BELOW 57.25      2 = 57.25 - 57.50
                                                                        3 = 57.50 - 57.75      4 = 57.75 - 58.00
  TRACK SEGMENT LENGTH =  1320 FEET (   546 SAMPLES)                    5 = 58.00 - 58.25      6 = ABOVE 58.25

   MP     FEET         TRK/LOC        MILE        FEET      MEAN     VARIANCE            PERCENTAGE LEVELS           NO.     I    PERCENTAGE VALUES
                                                                                1     2     3     4     5      6 SAMPLES I     95%     97%     99%
                                                                                                                         I
*  13      100          1  05           0         1319     56.43      .0241     98     2     0     0     0     0    546   I   56.66   56.72   56.83
*  13     1400          1  05           0         2639     56.50      .0121     97     3     0     0     0     0    546   I   56.70   56.77   56.87
*  13     2750          1  05           0         3958     56.58      .0191     87    13     0     0     0     0    546   I   56.80   56.85   56.94
*  13     4050          1  05           0         5278     56.51      .0292     92     8     0     0     0     0    546   I   56.82   56.86   56.91
*  14      150          1  05           1         1317     56.50      .0147     96     3     1     0     0     0    546   I   56.71   56.80   56.98
*  14     1500          1  05           1         2637     56.42      .0475     93     7     1     0     0     0    546   I   56.79   56.88   56.98
*  14     2800          1  05           1         3956     56.32      .0166    100     0     0     0     0     0    546   I   56.57   56.65   56.74
*  14     4100          1  05           1         5276     56.53      .0587     79    20     1     0     0     0    546   I   56.87   56.90   57.07
*  15      150          1  05           2         1315     56.73      .0522     46    44    10     0     0     0    546   I   57.04   57.08   57.13
*  15     1500          1  05           2         2635     56.81      .0393     30    59    12     0     0     0    546   I   57.07   57.10   57.14
*  15     2800          1  05           2         3954     56.46      .0203     97     3     0     0     0     0    546   I   56.72   56.76   56.86
*  15     4100          1  05           2         5274     56.35      .0126    100     0     0     0     0     0    546   I   56.57   56.58   56.60
*  16      150          1  05           3         1313     56.27      .0102    100     0     0     0     0     0    546   I   56.45   56.50   56.60
*  16     1500          1  05           3         2633     56.25      .0087    100     0     0     0     0     0    546   I   56.42   56.44   56.55
*  16     2800          1  05           3         3952     56.24      .0053    100     0     0     0     0     0    546   I   56.38   56.40   56.43
*  16     4000          1  05           3         5122     56.32      .0201     98     2     0     0     0     0    484   I   56.67   56.71   56.80
```

Figure 2-11. Gage Track Segment Summary

The track has been divided into the standard quarter-mile sections during data processing. The columns on the left of the figure locate the end of the section and identify the particular track. Perhaps there is too much data displayed here merely to locate the section, but to a large extent this must be a decision of the user.

In the next column the "mean" gage is given. This is the arithmetic average of all the data points recorded in that quarter mile of track. Normally this is 546 readings. A glance at the "mean" gage readings on this figure will show that it varies from 56.24 inches to 56.81 inches. An average gage of 56.24 inches may be questioned by some track maintenance men, but this is continuous welded rail which was laid 1/4-inch tight on tangents. A "mean" gage of 56.81 inches is, however, questionable.

A second gage rating value which was developed is the gage "variance." This is the normal statistical "variance," or the square of the standard deviation, of all the data points within a quarter-mile section. Any offset of the data due to calibration is ignored by this calculation. The "variance" is shown near the center of the figure for each quarter mile of track.

Both "mean" gage and gage "variance" can be used to examine the general condition of the gage in a quarter mile of track. However, a limited number of spots where gage may be changing are also cause for concern. Just to the right of the "variance" data are six columns labeled percentage levels. These indicate the percentage of all the data samples in that quarter-mile section which fall within the gage value groupings shown at the top of the page. A number of the track sections shown have 100 percent of their values located in the first percentage level, or below 57.25 inches. Most sections fall in the first and second levels, or below 57.50 inches. All of the sections fall within the first three percentage levels, or below 57.75 inches. This is good Class 4 track.

The percentage level rating technique actually looks at both the broad trends in overall gage and the limited changes at the wide end of the distribution. As such, it could be a valuable technique.

At the right of the figure are three columns which are headed "percentage values." These are developed in the same fashion as the 0.5 percent values for profile. The computer is looking at the wide gage side of the distribution. Three different levels have been computed and printed out in an effort to determine if one is more significant than another.

In the historical development of the rail research program, the next step was the generation of a crosslevel exception program. Although a crosslevel system was operational on the measurement cars from the beginning, more than a year passed before attempts were made to write a program locating and quantifying the defects. Because an isolated crosslevel value may or may not be a defect, depending on whether the track is tangent or curve, it was necessary to provide the computer with the logic equivalent to the judgment and experience that the track maintenance personnel would use when looking at crosslevel data on a strip chart.

This was accomplished through the use of a data sample averaging technique. The values of the 60 data points immediately preceding the data point in question as well as the 20 data points immediately following are averaged. If the value of the data point in question varies more than a preset threshold amount from this average, it is considered a defect. As such it can then be output in a digital crosslevel exception report. It can be displayed as a point or as a longer exception having a beginning, a maximum, and an end The defect is also specified by its location in the track.

Figure 2-12 is an example of one of the earliest of such reports. At this time, curvature output information was attempted using the crosslevel data. This information is shown in the left center of the figure. After a small amount of field analysis, it became

```
   CROSS LEVEL ANALYSIS               ACQUISITION  11109-5N1              PROCESSED  01/13/71                    PAGE   1

LOCATION OF END OF EVENT  TANGENT       RUNOFF     SUPERELEVATION   TRANSITION          EXCEPTIONS              WARP
 TRK/LOC  MILE   FEET     AVG  LNTH   R/C LNTH  N    AVG    LNTH     IMV    FMV     TYPE  MAX  LNTH  IDX  SHORT  MAX   LONG  INDEX

   0  40     0     39     .48    39                                                                        .222  .934           147

   0  40     0     89                                                              SHORT  .88    19  154
   0  40     0    196                -.75  157 15                    .66    .52                                                 455

   0  40     0    737                              -1.03     541                                                      .014     746

   0  40     0    865                 .90  128  7                           .80                                                 314

   0  40     0    894                                                              SHORT  .65    29   65
   0  40     0   1742    -.04   877                                                                        .008 1.038  .028    1419

   0  40     0   1994                 .84  251 10                                                                               363

   0  40     0   2598                               2.53     604                                                                729

   0  40     0   2847                -.62  249  1                                                                               304

   0  40     0   4700                                                              SHORT  .68    70  160
   0  40     1    563     .24  2997                                                                        .001  .801  .019    2979

   0  40     1    626                                                              SHORT  .58    12   80
   0  40     1    858                -.92  295  3                                                                               470

   0  40     1   1187                              -2.67     329                                                                324

   0  40     1   1499                 .94  312  1                           .55                                                 321

   0  40     1   3596                                                              SHORT  .70    72  227
   0  40     2    482     .09  4263                                                                                   .029    3843

   0  40     2    661                -.46  179  0                                                                               269

   0  40     2    735                              -.96       75                                                                 62

   0  40     2    931                 .87  196  1                                                                               316

   0  40     2   1460     .26   529                                                                                   .017     460

   0  40     2   1586                 .48  126  1                                                                               222

   0  41     2   3445    -.05  1858                                                                                            1743
```

Figure 2-12. Original Off-line Crosslevel Report obvious that this portion of the report was too inaccurate to have a practical use in curve analysis or maintenance. A curvature system and a report based upon its data would be needed.

On the right third of the figure crosslevel and warp exceptions are listed. While most of the crosslevel exceptions could be verified in the field, they represent only those spots where the actual data value varies from the average. Crosslevel in tangent, reverse elevation, and improper elevation of curves were beyond the measurement capability of the system. This situation provided the motivation for developing an independent curvature measurement system and curve evaluation report.

About this time an extremely valuable tool was made operational on the measurement cars (Figure 2-13). This was the real-time digital exception printout. It furnished the maintenance-of-way supervisor with a hard copy list of "critical" defects by magnitude and location which he could take with him when he left the cars. A second copy was provided for office use or as a checklist of corrected defects reported from the field.

This list has been successfully used by track maintenance forces. There have been several instances when a track supervisor, working from such a list, corrected the "critical" defects before a formal list could be given to him from off-line data processing runs. On one occasion, when the on-line digital tape recorder malfunctioned, gage and profile corrections were made by working from the real-time digital exception printouts.

One objective during the course of this study was the simplification of reports and a reduction in the amount of generated report paper. Figure 2-14 is an example of the first attempt to develop an off-line integrated exception report showing the defects in all parameters on one page. This report eliminated the need for separate gage and profile exception reports, allowed the track man to see how defects related to each other, and did away with the cumbersome switching from data book to data book.

```
           EXCEPTION  LISTING  REPORT                                                  PAGE 010
30919 1N2

MILE                      LEFT      LEFT        RIGHT     RIGHT        CROSS
POST FEET  COMMENT        PROFILE   ALIGNMENT   PROFILE   ALIGNMENT    LEVEL       GAGE

 003-3936  END                                                                     +56. 89
 003-3939  START                                                                   +57. 09
 003-3939  MAXIMUM                                                                 +57. 09
 003-3943  END                                                                     +57. 00
 003-3963  START                                                                   +57. 02
 003-3977  MAXIMUM                                                                 +57. 56
 003-3997  END                                                                     +56. 65
 003-3999  START                                                                   +57. 17
 003-4050  MAXIMUM                                                                 +57. 64
 003-4072  END                                                                     +56. 91
 003-4079  START                                                                   +57. 01
 003-4093  MAXIMUM                                                                 +57. 63
 003-4115  END                                                                     +56. 66
 003-4117  START                                                                   +57. 22
 003-4132  MAXIMUM                                                                 +57. 42
 003-4154  END                                                                     +56. 62
 003-4156  START                                                                   +57. 28
 003-4175  MAXIMUM                                                                 +57. 72
 003-4190  END                                                                     +56. 85
 003-4159  START                                                       - 0. 51
 003-4159  MAXIMUM                                                     - 0. 51
 003-4161  END                                                         - 0. 34
 003-4598  START                                                                   +57. 02
 003-4601  MAXIMUM                                                                 +57. 10
 003-4606  END                                                                     +56. 96
 003-4586  START                                                       - 0. 53
 003-4586  MAXIMUM                                                     - 0. 53
 003-4589  END                                                         - 0. 39
 003-4630  START                                                                   +57. 03
 003-4642  MAXIMUM                                                                 +57. 39
 003-4661  END                                                                     +56. 59
 003-4664  START                                                                   +57. 01
 003-4664  MAXIMUM                                                                 +57. 01
 003-4666  END                                                                     +56. 96
 003-4671  START                                                                   +57. 06
 003-4671  MAXIMUM                                                                 +57. 06
 003-4676  END                                                                     +56. 96
 003-4681  START                                                                   +57. 21
 003-4681  MAXIMUM                                                                 +57. 21
 003-4702  END                                                                     +56. 92
```

Figure 2-13. Typical On-line Exception Listing Report

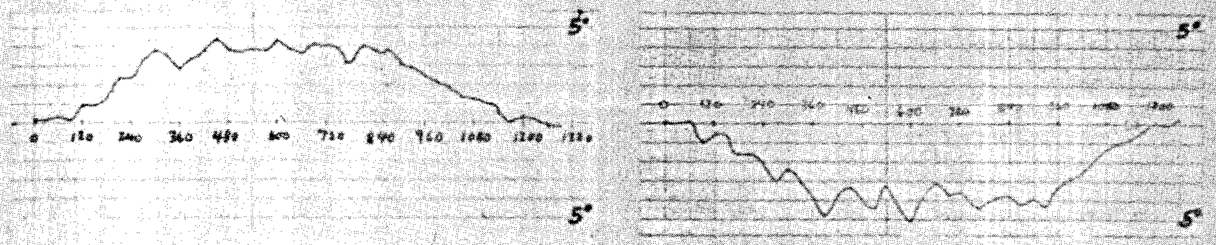
The earliest form of the integrated exception report included profile, gage, crosslevel, and warp data. It was designed as an "ouch" type of report for first-line track supervision. Some of the holdover information from earlier reports can be seen. Not only is the defect magnitude and location printed out, but the beginning and often the end are also located. Such a technique can double or triple the amount of paper without conveying any additional information.

```
   INTEGRATED TRACK GEOMETRY EXCEPTION REPORT        ACQUISITION  31113_1N1   PROCESSED    11/27/73               PAGE  17
   LOC X04
                                                                              FOR XLEVEL AND WARP :  + MEANS NORTH RAIL HIGH
                                                                                                     - MEANS SOUTH RAIL HIGH

   LOCATION : 04     TRACK NUMBER :  1     CLASS  7 TRACK

                              PROFILE ( 14.5 )      ALIGNMENT              GAGE              X LEVEL                   WARP
   THRESHOLDS IN INCHES -->   ( .375)           NOT OPERATIONAL         (57.25)            ( .750)            ( .750)     ( .750)
                           WEST      EAST           WEST        EAST                                              S.WARP      L.WARP
   Mp DIST  MILE  FEET     RAIL      RAIL           RAIL        RAIL   EXC   MAX   DIST   EXC   MAX    DIST      (19.5FT)    (62.0FT)


*   8  2850   2   2633     -.394                                                                                           -.76 E
*   8  2850   2   2637                                                                                         -.77 S
*   8  2900   2   2640                                                                                         -.86 M
*   8  2900   2   2642                                                                                         -.77 E
*   8  2900   2   2659               -.438
*   8  2900   2   2686               -.459
*   8  3150   2   2925               -.491
*   8  4350   2   4097     -.547
*   8  4350   2   4099     -.627
*   8  5100   2   4873                                                                                                     -.83 S
*   8  5100   2   4875                                                                                                     -.94 M
*   8  5100   2   4878                                                                                                     -.86 E
*   8  5100   2   4882      .382
*   8  5150   2   4931                                                 57.30         GP
*   8  5150   2   4938                                                                                          .78
*   8  5200   2   4940                                                 57.28 57.65   12                         .81
*   8  5250   2   5008     -.398
*   9   950   3    671                                                                                                     -.84 S
*   9   950   3    673                                                                                                    -1.11 M
*   9   950   3    685                                                                                                     -.94 E
*   9   950   3    712                                                                                         -.89 S
*   9   950   3    714                                                                                        -1.06 M
*   9  1000   3    724                                                                                         -.78 E
*   9  1000   3    731               -.376                                                                                  .82 S
*   9  1000   3    733               -.587                                                 .98         GP        .82 SM     1.03 M
*   9  1000   3    736               -.466
*   9  1000   3    741                                                                     .80   .98    7       .79 E
*   9  1000   3    743                                                                                                      .85 E
*   9  1900   3   1632     -.462
*   9  1900   3   1635     -.515
*   9  1900   3   1642                .382
*   9  2150   3   1886               -.382
*   9  2200   3   1942     -.395
*   9  2200   3   1944     -.426     -.459
*   9  2200   3   1947               -.395
*   9  2200   3   1956                .452
*   9  2450   3   2217               -.556
*   9  2500   3   2220               -.481
*   9  2850   3   2606     -.377
```

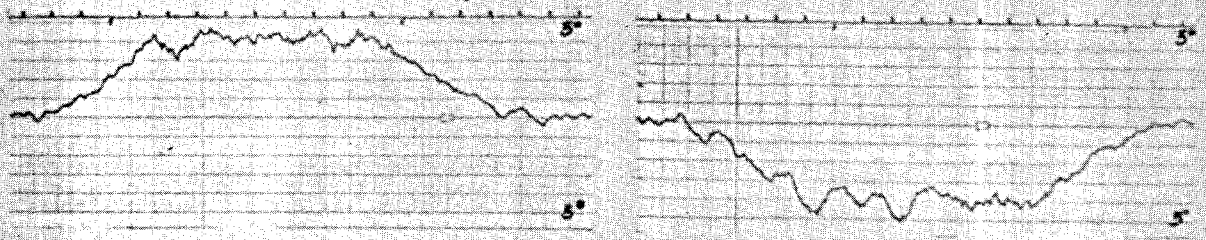
Figure 2-14. Original Integrated Exception Report

The development of a curvature measurement system led to the generation of a curvature defect report. As with crosslevel, there is no way to tell that a single, isolated curvature reading constitutes a defect. Therefore, the data sample averaging technique that was developed for crosslevel was adapted for curvature defects. If the absolute value of the curvature data sample varies more than a predetermined amount from the average, it constitutes a defect. This technique can be used equally well in tangent, curve, or spiral track.

Field testing of the curvature system has shown it to be accurate. Figure 2-15 shows the string line measurements for two curves plotted to the same scale as the strip chart traces. For practical purposes, the string line measurements and chart traces are identical.



STRINGLINE CURVES- 62 foot chord, 10.3 foot stations



CURVATURE SUB-SYSTEM CURVES

Figure 2-15. Comparison of Curvature Data from String Line and Curvature Subsystem Measurements

The same curve was measured by the curvature system at varying train speeds (Figure 2-16). In this figure the speed was varied from 20 mph to 50 mph in 10-mph increments. The resulting strip chart traces are identical.

By combining the inputs of the curvature and crosslevel systems into one program, the curvature analysis report shown in Figure 2-17 was developed. This is not strictly a defect type report. The left third of the figure locates and describes the curve without regard for defects. Neither does this portion of the report specifically attempt to rate the curve. It locates the event, identifies the point of tangent to spiral, the length of the receiving spiral, the point of spiral to curve, the length of curve, the average degree of curve, the average superelevation in the

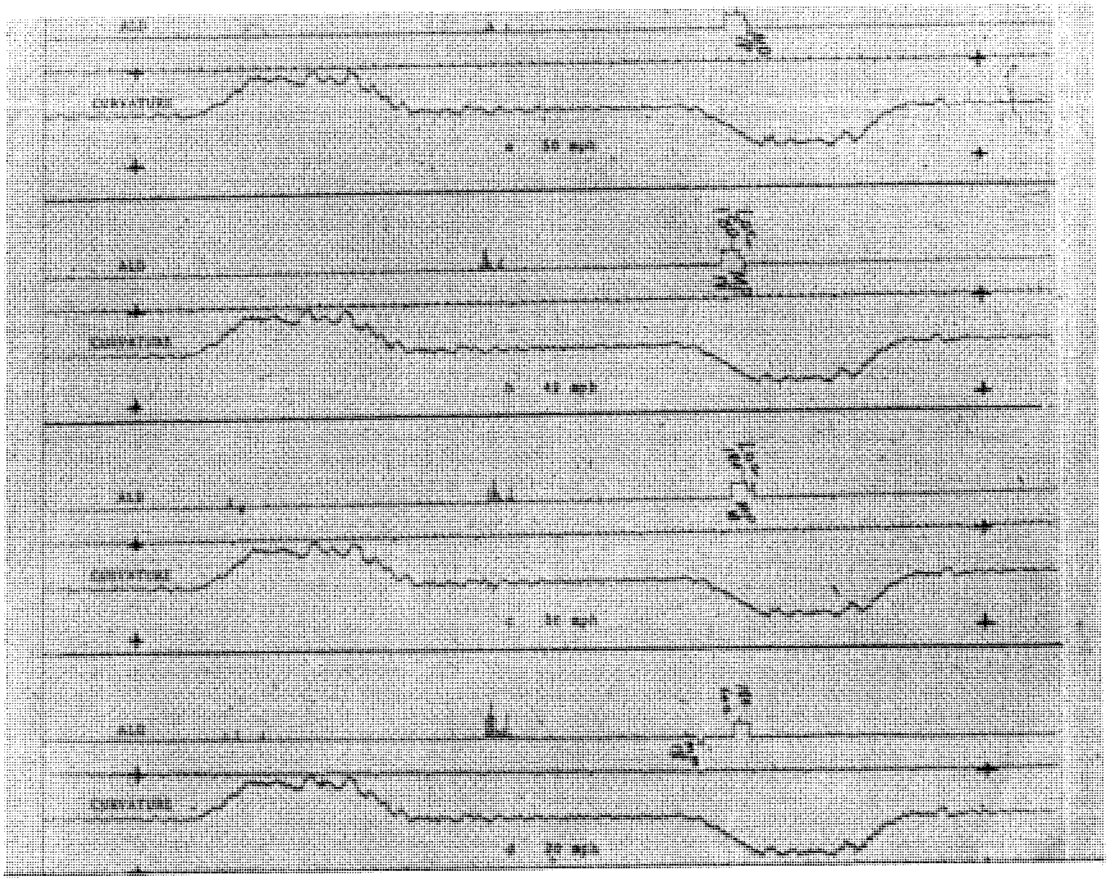
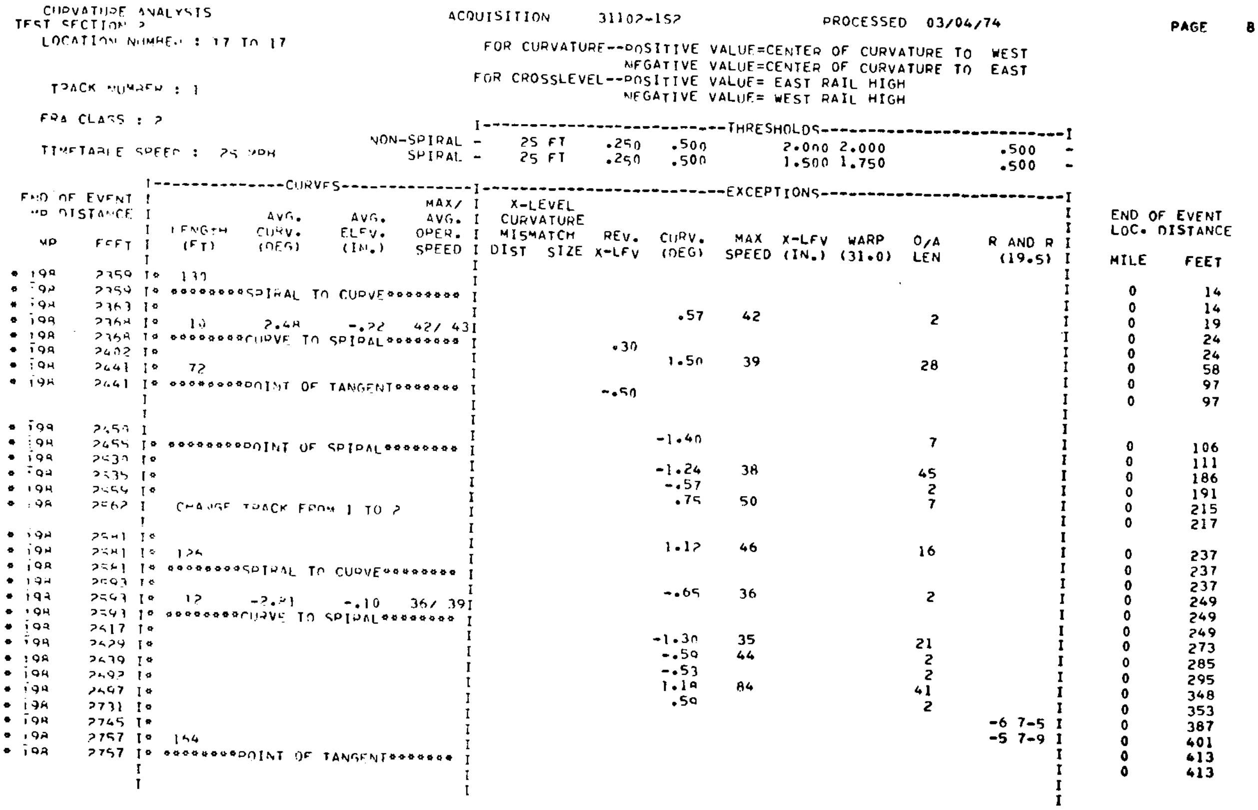


Figure 2-16. Comparison of Curvature Subsystem Data Collected at Various Speeds



```
     CURVATURE ANALYSIS                      ACQUISITION      31102-152             PROCESSED  03/04/74                    PAGE    8
TEST SECTION 2
   LOCATION NUMBER : 17 TO 17                  FOR CURVATURE--POSITIVE VALUE=CENTER OF CURVATURE TO  WEST
                                                              NEGATIVE VALUE=CENTER OF CURVATURE TO  EAST
    TRACK NUMBER : 1                         FOR CROSSLEVEL--POSITIVE VALUE= EAST RAIL HIGH
                                                              NEGATIVE VALUE= WEST RAIL HIGH
   FRA CLASS : 2
                                              I-------------------------THRESHOLDS--------------------------I
   TIMETABLE SPEED :  25 MPH      NON-SPIRAL -    25 FT    .250   .500          2.000 2.000                   .500   -
                                      SPIRAL -    25 FT    .250   .500          1.500 1.750                   .500   -

               I---------------CURVES---------------I---------------------------EXCEPTIONS---------------------------I
 END OF EVENT  I                               MAX/ I  X-LEVEL                                                         I    END OF EVENT
 MP DISTANCE   I              AVG.     AVG.    AVG. I  CURVATURE                                                       I    LOC. DISTANCE
               I  LENGTH     CURV.    ELEV.   OPER. I  MISMATCH    REV.   CURV.    MAX   X-LEV  WARP    O/A       R AND R I
   MP     FEET I   (FT)      (DEG)    (IN.)   SPEED I DIST  SIZE X-LEV   (DEG)   SPEED (IN.)  (31.0)  LEN        (19.5) I    MILE     FEET
               I                                    I                                                                  I
 * 198    2359 I*  137                              I                                                                  I     0        14
 * 198    2359 I* ********SPIRAL TO CURVE********   I                                                                  I     0        14
 * 198    2363 I*                                   I                                                                  I     0        19
                                                    I                         .57    42                   2             I
 * 198    2368 I*   10       2.48     -.22   42/ 43I                                                                  I     0        24
 * 198    2368 I* ********CURVE TO SPIRAL********   I                .30                                               I     0        24
 * 198    2402 I*                                   I                        1.50    39                  28             I     0        58
 * 198    2441 I*   72                              I                                                                  I     0        97
 * 198    2441 I* ********POINT OF TANGENT*******   I               -.50                                               I     0        97
               I                                    I                                                                  I
               I                                    I                                                                  I
 * 199    2450 I                                    I                       -1.40                         7             I
 * 198    2455 I* ********POINT OF SPIRAL********   I                                                                  I     0       106
 * 198    2530 I*                                   I                       -1.24    38                  45             I     0       111
 * 198    2535 I*                                   I                        -.57                         2             I     0       186
 * 198    2559 I*                                   I                         .75    50                   7             I     0       191
 * 198    2562 I   CHANGE TRACK FROM 1 TO 2         I                                                                  I     0       215
               I                                    I                                                                  I     0       217
 * 198    2581 I*                                   I                        1.12    46                  16             I
 * 198    2581 I*  126                              I                                                                  I     0       237
 * 198    2581 I* ********SPIRAL TO CURVE********   I                                                                  I     0       237
 * 198    2593 I*                                   I                        -.65    36                   2             I     0       237
 * 198    2593 I*   12      -2.81     -.10   36/ 39I                                                                  I     0       249
 * 198    2593 I* ********CURVE TO SPIRAL********   I                                                                  I     0       249
 * 198    2617 I*                                   I                       -1.30    35                  21             I     0       249
 * 198    2629 I*                                   I                        -.59    44                   2             I     0       273
 * 198    2639 I*                                   I                        -.53                         2             I     0       285
 * 198    2692 I*                                   I                        1.18    84                  41             I     0       295
 * 198    2697 I*                                   I                         .59                         2             I     0       348
 * 198    2731 I*                                   I                                                                  I     0       353
 * 198    2745 I*                                   I                                                      -6 7-5 I     0       387
 * 198    2757 I*  164                              I                                                      -5 7-9 I     0       401
 * 198    2757 I* ********POINT OF TANGENT*******   I                                                                  I     0       413
               I                                    I                                                                  I     0       413
               I                                    I                                                                  I
                                                                                                                       I
```

Figure 2-17. Curvature Analysis Report

curve, the limiting speed in the curve due to superelevation defects based on FRA track standards, the allowable speed in the curve based on average superelevation as determined from FRA standards, the point of curve to spiral, the length of the leaving spiral, and the point of spiral to tangent. This is a tremendous amount of information. The need for some of it may be questioned, but the data must be developed in order to determine curvature and superelevation defects.

The right-hand two-thirds of Figure 2-17 is strictly a defect report. Errors in matching crosslevel and curvature are noted. These can occur at the tangent end of the receiving or leaving spiral when curvature and superelevation do not begin or end at the same point. This mismatch can also occur at either end of the body of the curve when full curvature and full elevation do not coincide. If a mismatch of more than a preset distance exists, the length of the mismatch is located and printed out as well as the maximum error in crosslevel. In Figure 2-17, the mismatch distance threshold is 50 feet.

Reverse crosslevel can be found in the tangent just ahead of the spiral, when the crosslevel actually goes negative (with respect to the superelevation of the curve). If this condition is sensed above the preset defect threshold, a defect is printed showing its magnitude and location.

A curvature defect is sensed by comparing the actual data point value with the running data sample average. In Figure 2-17, the defect threshold is 1-1/2 degrees greater or less than this average. Again, the magnitude and location of the defect are shown. The maximum allowable speed for the defect is also computed from the formula in the track safety standards and shown next to the curvature defect.

Superelevation defects in curves are shown. These are computed as previously discussed in the determination of crosslevel defects.

Warp can be defined as the rate of change of crosslevel. In Figure 2-17, warp is computed on a 31-foot length, using a 1-1/4 inch defect level for tangents and curves, and 1 inch for spirals. These values can be easily changed in the program to meet the needs of the user.

The periodic irregularities in crosslevel which can produce rock and roll instability can now be computed. In Figure 2-17, it is analyzed over a 19-1/2 foot distance. Given a particular data sample, the program examines the data sample a preset distance away. If the difference in crosslevel between the two samples is above a selectable threshold, the sign of the slope between the two points is saved. Using the preset distance, a new crosslevel difference is examined and compared to the threshold. If it exceeds the threshold, a second slope is calculated; if the sign of the second slope is opposite to that of the first slope, two changes in direction have occurred. If a continuation of this analysis produces a third slope, having a sign opposite to the second slope, a possible rock and roll situation is considered to exist and it is printed out and located. The critical thresholds used for rock and roll in this example are equivalent to three or more successive spots which are 5/8 inch low on alternate rails and 19.5 feet apart. Again, the thresholds can be varied for the user.

In both curvature and crosslevel reporting, a sign convention was developed to identify the direction of curve of the high rail. A positive sign indicates that the curve is to the east, or that the west rail is high. A negative sign indicates that the curve is to the west, or that the east rail is high.

The exception report currently being produced for and used by the railroads to display geometry defects is an improved version of the Integrated Exception Report (Figure 2-18). This is a comprehensive report that displays, by location, profile, curvature, gage, crosslevel (or superelevation), warp, and rock and roll defects on one page. Normally several miles of track geometry defects can be displayed on one sheet. Curvature has replaced the alignment column which was listed and left blank in the original integrated report. To date, it has not been possible to obtain consistent rail alignment data from the 14.5-foot capacitive sensor chord and to interpret it properly. Only one warp is shown, and this is based upon a user-selected warp distance. In Figure 2-18, the selected distance is 31 feet. The second warp value originally displayed in the integrated exception report has been replaced by rock and roll. This, too, is based upon a user-selected frequency distance and is set at 19.5 feet in the example. A fact column has been added to the extreme right of the printout. This informs the user that the defect in question occurs in a tangent or in a curve, in a road crossing, or at a turnout.

```
   INTEGRATED TRACK GEOMETRY EXCEPTION REPORT        ACQUISITION  10/13/74    PROCESSED                          PAGE   8
   LOC X60 MILEPOST 632.0 - 625.2

   LOCATION : 60                                     TRACK NUMBER :  2                            CLASS 2 THRESHOLDS

                         PROFILE ( 14.5 )   CURVATURE         GAGE           X LEVEL      WARP (31.0FT)   R.R (19.5FT)    FACT
THRESHOLDS IN INCHES -->    ( .500)         ( 2.000)         (57.25)         (1.000)        (1.500)         ( .500)
                         NORTH   SOUTH      MAX   O/A      MAX     O/A      MAX   O/A      MAX     O/A
   MP DIST  MILE  FEET    RAIL    RAIL      DEG   DIST     EXC     DIST     EXC   DIST     EXC     DIST      EXCEPTION

* 626 -2528   6   2081    -.52                                                                                            C
* 626 -2666   6   2219                                                                                    -5  6 -6        C
* 626 -2699   6   2252                                    57.36      7                                                    C
* 626 -2740   6   2293                                                                                    -5  7 -7        C
* 626 -2760   6   2313                                                                                   E  6 -7  5       C
* 626 -2803   6   2356    -.55                                                                                            C
* 626 -2895   6   2448                                    57.28     12                                                    C
* 626 -3011   6   2564                                    57.26      5                                                    C
* 626 -3132   6   2685                                    57.38     41                                                    C
* 626 -3137   6   2690                                                                                    -6  7 -6*       C
* 626 -3154   6   2707                                                                                   E  7 -6  8*      C
* 626 -3156   6   2709    -.60                                                                                            C
* 626 -3171   6   2724                                                                                   E -6  8 -6*      C
* 626 -3195   6   2748                                                                                      6 -7  6*      C
* 626 -3275   6   2828    -.50                                                                                            C
* 626 -3311   6   2864    -.69                                                                                            C
* 626 -3371   6   2924                                    57.49     12                                                    C
* 626 -3739   6   3292    -.54                                                                                            C

   TRACK CHANGE :TRACK  2 TO TRACK  1

* 626 -3987   6   3540       ----SENSORS UP----
* 626 -4526   6   4079       ----SENSORS DOWN----

* 625  -123   6   4983                                    57.26      2                                                    C
* 625  -280   6   5140              -.50                                                                                  C
* 625  -324   6   5184                                    57.33      2                                                    C
* 625  -503   7     83                                    57.27      2                                                    C
* 625  -585   7    165                                                                                    -5  6 -7        C
* 625  -604   7    184                                                                                   E  6 -7  6*      C
* 625  -626   7    206                                                                                   E -7  6 -6*      C
* 625  -669   7    249              -.50                                                                                  C
* 625 -1274   7    854    -.50                                                                                            C
* 625 -1609   7   1189                                    57.25      2                                                    C
* 625 -2641   7   2221
                             CHANGE TO CLASS  4 THRESHOLDS

                             PROFILE         CURVATURE           GAGE         X LEVEL          WARP           R.R
                             ( .500)         ( 1.000)         (57.00)         ( .750)         ( .750)        ( .500)
```

Figure 2-18. Current Detailed Integrated Exception Report

One mile summaries have been added to locate track sections by mileposts and to show the number of defects in each parameter within that mile. Two exception levels are available and are user selectable. One might be termed a normal defect level, while the second might be considered a severe defect level. Severe defects shown in the summary listings are identified by stars in the detailed section of the report. An example of this summary portion of the report is shown in Figure 2-19.

Most of the defects displayed in the Integrated Exception Report are not based upon FRA track safety standards. For many parameters they can be if the user so desires. The FRA track safety standards define minimum requirements for safety. The railroad industry should theoretically be able to maintain track at some higher standard. However, it is not practical to set defect levels as deviations from perfect track. While "critical" (within the context used here) defects cannot be ignored and must be identified and corrected for the safety of the trains, the maintenance-of-way officer has a broader responsibility to his company. He must determine that the dollars allocated for maintenance are spent where they are most needed and that the maximum benefit is obtained from the work done. The cost-benefit ratio required to maintain theoretically perfect track would be prohibitive.

In practice, there are probably three general levels of management to which track geometry data reports should be directed. The first level is the track supervisor or roadmaster, who is primarily concerned with defects. Middle management (the division engineer and planning engineer) are not overly concerned with individual defects. Instead, they are more involved in the general quality of the track and the changes taking place in that quality. The geometry rating reports are directed to them. Upper management needs a report that can give a clear and concise picture of the condition of the track and changes in that condition.

ONE MILE SUMMARY EXCEPTION REPORT ACQUISITION 10/13/74 PROCESSED PAGE 1

DATA FROM MP640 TO MP607 TRACK NUMBER : 2

	MILEPOST				PROFILE NORTH RAIL		PROFILE SOUTH RAIL		CURVATURE		GAGE		X LEVEL		WARP (31.0FT)		ROCK + ROLL (19.5FT)	
	START	END	DIST	CLS	EXC	SEV	EXC	SEV	EXC	SEV	EXC	SEV	EXC	SEV	EXC	SEV	EXC	SEV
	640	639	5331	3			1		13		411						2	
•	639	638	5423	2	3		2				121						6	
•	638	637	5077	2	2						281							
•	637	636	5341	2	1		1		1		184							
•	636	635	5350	2							82						1	
•	635	634	5292	2			1				142							
•	634	633	5261	2							245						1	
•	633	632	5314	2	1		1				29						3	
•	632	631	4954	2			2				30						1	
•	631	630	5167	2			1		1									
•	630	629	5160	2	1		1				59						2	1
•	629	628	5599	2	2		1				203						4	
•	628	627	5196	2	1		3				25						2	
•	627	626	5341	2	1		1				13		5				13	2
	TRACK CHANGE :TRACK 2 TO TRACK 1																	
•	626	625	5307	2	10						59						9	5
•	625	624	5290	2	2		2				7						4	2
•	624	623	4770	4							1				8			
•	623	622	5285	4			1		47						5	1	1	1
•	622	621	5309	4			3		36	8	5		1	1	9	5	3	1
•	621	620	5087	4														
•	620	619	5401	3	2													

Figure 2-19. Current One Mile Summary of Integrated Exception Report

GEOPLOT was developed for use by the latter two groups. The example shown here (Figure 2-20) gives a 2-year (or a two successive measurement run) quality rating comparison of gage, profile, crosslevel, and curvature. The ratings are displayed by miles, with approximately 50 miles of track being displayed on one page of computer printout. A maximum of three runs can be presented on this plot.

In order to output such a program, it was necessary to have quality rating values for each of the four parameters. Variance, or standard deviation, was already available as a rating of gage. Track index had been developed as a rating of profile. But no rating systems existed for crosslevel and curvature. These were needed both for GEOPLOT and for investigations of quality changes.

By applying the same general concept that is used to compute the profile index, crosslevel and curvature index values were programmed. In profile index the actual data sample value is compared to theoretically perfect track, and the area under the difference curve is computed. In crosslevel and curvature index, the actual data sample value is compared to an average value. Differences between data sample and averages, when multiplied by the sampling interval and summed over a mile of track, give the index or rating value.

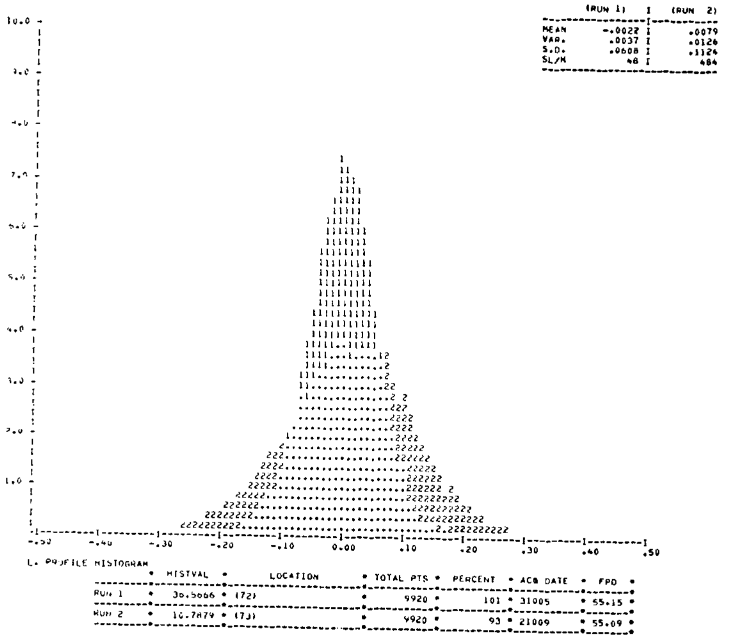
COMPARE is the most recent program to be developed. It is an attempt to give a pictorial record of changes in track through the use of the comparative histogram. In the example (Figure 2-21), one set of data is represented by a "1", while a second set of later data is noted with a "2". Common points are denoted as dots. Track segments of various lengths may be examined, with changes being easily discernible.

2.2 APPLICATIONS

From its inception, the railroads have considered the track geometry study to be a research and development project. Even though the measurement cars had operated on the Northeast Corridor for several years and had been used elsewhere on occasion, they were new to the B&LE and the D&RGW. The results of the first measurement runs over

```
            TRACK PARAMETER QUALITY INDEX CHART          PROCESS DATE  12/19/74                                         PAGE 1
                                                         X=2 OR MORE POINTS THE SAME
            MP603 TO MP741                               N=BAD OR NO DATA
            3 = 1973 DATA
            4 = 1974 DATA

                             GAGE                    PROFILE                  CROSSLEVEL                 CURVATURE
                          STD. DEV.                  INDEX                     INDEX                      INDEX
              INCREMENT =        .02          INCREMENT =     350.00    INCREMENT =     650.00    INCREMENT =     1150.00

(LOC/M.P.) *    .0        .2        .4 1000.0    4500.0    8000.0 2000.0     8500.0   15000.0 2000.0    13500.0  25000.0 * (M.P./LOC)
           *  I.........I.........I      I.........I.........I      I.........I.........I      I.........I.........I     *
     603.0 I  N-------3                  N--------3                 N---------3                N--------3                I603.0
           *  ------X                    ----X                      ---34                      ---3-4                    *
     605.0 I  ----------X                ----34                     -----X                     ------X                   I605.0
           *  ---------X                 -----X                     ----43                     -----34                   *
           *  ------------X              -----34                    -----34                    --------43                *
           *  ---------X                 ------34                   -----X                     ---------X                *
           *  ---------X                 -----34                    ---34                      ------34                  *
     610.0 I  ---------X                 -----34                    ----3-4                    ------34                  I610.0
           *  -----------X               ------34                   ---34                      ----3-4                   *
           *  --------X                  ------X                    ----X                      ----34                    *
           *  ---------X                 --------34                 ----X                      ----34                    *
           *  --------X                  -------X                   ----X                      ----34                    *
     615.0 I  --------X                  -------X                   ---X                       ----3-4                   I615.0
           *  ---------X                 ------34                   ----X                      ------34                  *
           *  --------X                  ------X                    -----X                     ---3-4                    *
           *  -------X                   -----X                     ----X                      ---34                     *
           *  ---------X                 -------X                   -----43                    ----34                    *
     620.0 I  -----X                     ------X                    ---34                      ---34                     I620.0
           *  -----X                     -----X                     -----X                     ----3-4                   *
           *  --------X                  ------X                    ----X                      ----3-4                   *
           *  ---------------X           ------34                   ------34                   ----------34              *
           *  ------------------X        ----------X                ---------X                 ---------X                *
     625.0 I  ---------------X           ------------X              ------------X              -----------4---3          I625.0
           *  ------------------X        -----------34              ----------4--3             -----------4-3            *
           *  -----------4------3        -----4----3                -----4--3                  --------4----3            *
           *  -------4----------3        -----4------3              ------4--3                 ---------4--3             *
           *  ----------X                ----4---3                  -----4-3                   -------------4-----3      *
     630.0 I  ---------4--3              -----4----3                ----4---3                  ---------4---3            I630.0
           *  --------4------3           ----4------3               ----4-----3                --------------4---3       *
           *  --------4----3             ----4---------3            ---4----3                  ----------4---3           *
           *  --------4---3              ---4---------3             ----4-----3                ------------4--3          *
           *  ---------4------3          ----4---3                  ----4----3                 -------------4-----3      *
     635.0 I  ---------4---3             ----4--3                   -----4--3                  -----------4--3           I635.0
           *  --------4---3              ----4--3                   -----4--3                  ----------------4--3      *
           *  ---------4------3          ----4---3                  -----4--3                  -------------4------3     *
           *  ---------4----3            -----4-----3               --------X                  -------------4--3         *
           *  ----------4---3            ------4---3                --------43                 -------------------4-3    *
     640.0 I  ---------X                 -----34                    ------34                   ----------34              I640.0
           *  --------X                  ----34                     ------34                   -----------X              *
           *  -------X                   ----34                     -----X                     ------4-3                 *
           *  -----3--4                  ----34                     ----34                     -------34                 *
           *  -----43                    ---3-4                     ---X                       --4--3                    *
     645.0 I  ----34                     ----X                      --34                       -3--4                     I645.0
           *  ----4-3                    --4---3                    --4-3                      --4--3                    *
           *  ----4-3                    ----4-3                    ---4-3                     ---4-3                    *
           *  ------X                    ---4---3                   --4--3                     --4-3                     *
           *  -----X                     ----43                     ----X                      ---X                      *
     650.0 I  ------34                   -----X                     -----43                    ----X                     I650.0
     651.0 I  ------X                    ------43                   ----4--3                   ---4-------3              I651.0
           *  I.........I.........I      I.........I.........I      I.........I.........I      I.........I.........I     *
```

Figure 2-20. GEOPLOT Report



```
        (RUN 1)    I   (RUN  2)
-------------------I--------------
MEAN        -.0022 I         .0079
VAR.         .0037 I         .0126
S.D.         .0608 I         .1124
SL/M            48 I           484
----------------------------------
```

```
         * HISTVAL   *       LOCATION       * TOTAL PTS * PERCENT * ACQ DATE  *  FPD  *
---------*-----------*----------------------*-----------*---------*-----------*-------*
RUN 1    *  36.5666  * (72)                 *      9920 *     101 * 31005     * 55.15 *
---------*-----------*----------------------*-----------*---------*-----------*-------*
RUN 2    *  16.7879  * (73)                 *      9920 *      93 * 21009     * 55.09 *
---------*-----------*----------------------*-----------*---------*-----------*-------*
```

Figure 2-21. Typical Histogram Comparison Report

tracks of these railroads were presented as strip charts and as profile and gage defect reports. These strip charts were taken into the field, and many of the more severe defects were located and verified before the track maintenance forces were given the data to use in making repairs. As a result, these people have accepted the system and its outputs with few reservations. Today they will ask when the next measurement run is scheduled, or what the last run might have indicated concerning a particular piece of track. They are convinced of the basic validity of the track geometry measurement system, and this proved helpful in developing acceptance of the project.

One of the original requirements of the FRA geometry measurement cars was that they have the ability to test at speeds up to 150 mph. This stipulation necessitated the elimination of the contact sensor for measuring gage. As a result, the capacitive sensor was developed. Although these sensors do not make contact with the rail, their proximity to the rail head makes them susceptible to damage, particularly at road crossings, self-guarded frogs, and raised guard rails. Because they function on an electrical capacitive principle, water on the rail or on the sensor will tend to give faulty readings. The capacitive sensor, then, is definitely a fair weather type of instrument. All-weather sensors are presently under study by the FRA and will be field tested during 1975.

Unfortunately, difficulties with the capacitive gage measurement system have hindered the development of gage rating techniques. At first "mean" gage appeared to be a promising rating value, but after two years of experience, analysis, and field checking it was found that the measurement system could not repeat gage accurately enough from year to year to allow for comparisons.

Calibration errors, lipped or worn rail, and the nonlinearity of the voltage-gap curve in the amplifiers can give a probability of error in gage readings greater than the actual change in gage in the course of the year. This is not to say that the absolute value output for a gage defect is not valid. In reality it is. Experience over the last 3 years has shown that virtually all of the defects reported are real.

For comparative purposes, gage "variance" has proved to be a more meaningful indicator of a general change in gage. Since it is a measure of the variation from average gage, it is not nearly so sensitive to calibration errors. An analysis of repeatability tests made with the measurement cars has shown that a change in the gage "variance" value of 0.0013 can be interpreted as a meaningful change in the gage of that section of track. One consideration in the use of gage "variance" as a rating value is the curve, or section of track, where the gage could conceivable widen uniformly. In such a case the "variance" value might not change because the "mean" and not the scatter of data about the "mean" had changed.

Use of the percentage level rating technique for gage has been hampered by the same instrumentation problems that developed in the attempts to apply "mean" gage for comparative purposes. However, the calibration oriented shifts are somewhat more apparent in the percentage level technique. Continued study of this technique is planned.

Some of these problems will not be solved until the all-weather gage system is installed and field tested. But another change is being considered for the gage reports. At the present time, the reports do not consider tight gage, on the assumption that trains are safely passing over that portion of track and gage does not normally tighten. There appears to be merit in adding a column in the quarter-mile rating summary report to show a 0.5 percent value for gage data similar to the 95, 97, and 99 percent values. This would look at the extreme narrow portion of the distribution curve, and would satisfy safety requirements.

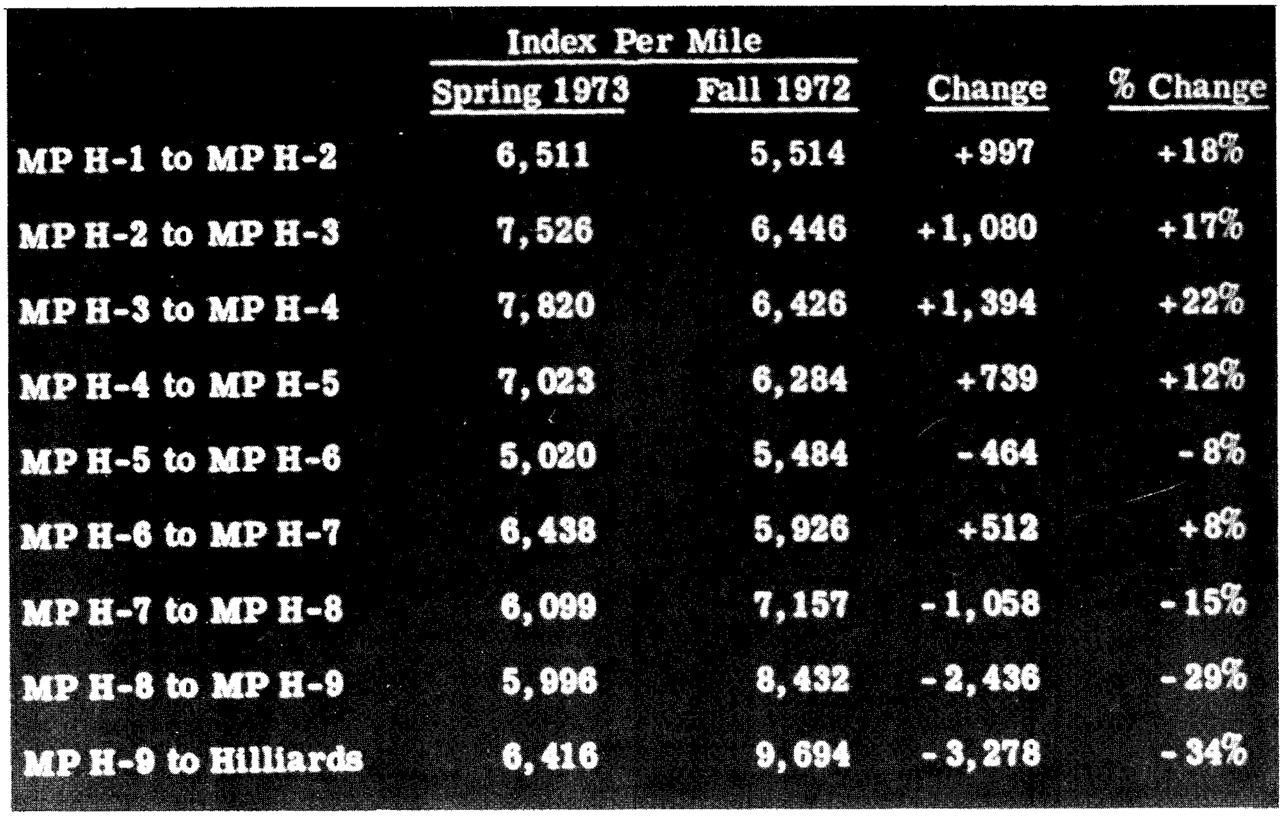
To date, the exception reports have been used to correct gage defects after each measurement run. They have also been used for several years to maintain safe gage on a light traffic branch line even though a tie deterioration problem is developing. Both the defect reports and the gage rating values have been successfully used to assist in the upgrading of another branch line for anticipated heavy tonnage increases.

It has been possible to show progressive gage widening in a few isolated curves by comparing gage rating values over a period of several years. In this process there have developed indications that the mechanized tie gang may, in some cases, actually contribute to long range gage widening. The gage on a curve may slowly widen, either uniformly or in spots, up to 1/4 or 1/2 inch between tie renewal cycles. The tie gang is apt to renew ties without noting a change in gage. If such a set of conditions continues for several cycles, the roadmaster may suddenly discover a curve which has a 1-inch-wide gage although the track is well spiked on generally good ties.

Location and correction of profile defects now require the use of the real-time exception printouts and the Integrated Exception Report. While this may appear to be a duplication of data, each report furnishes somewhat different information. The real-time exception printout indicates "critical" defects that need immediate attention. The Integrated Exception Report lists considerably more defects (many of lesser magnitude) as well as exceptions sorted by severity. A "critical" defect in the context of this paper does not mean an impending derailment, nor does it indicate a violation of the FRA track safety standards. "Critical" defect levels were established by the chief engineer as a statement of minimum acceptable track quality for his staff to follow.

More progress has been made in the rating of track profile than in any other parameter. Some of these rating values are in actual use today. The profile "index" value is one of these. Profile "index" values have been found to range from 600 to 2,000 square inches per quarter mile of continuous welded rail. On bolted rail on branch lines, "index" values can go as high as 3,500 square inches per quarter mile. An analysis of the repeatability tests made with the measurement cars has shown that a change of 125 or more square inches in the "index" from run to run can be interpreted as a meaningful change in profile quality.

The index value has also been found informative. A measurement run was made on the Hilliards Branch track (Figure 2-22) in the fall and repeated the following spring. Between runs the track was raised and lined from Milepost 5 to Hilliards. Changes in the computed index value showed an expected deterioration between Milepost 1 and Milepost 5. From Milepost 5 to Hilliards most of the track showed a definite improvement. However, between Milepost 6 and Milepost 7 the track profile seemed to have become rougher, even though it had been raised.

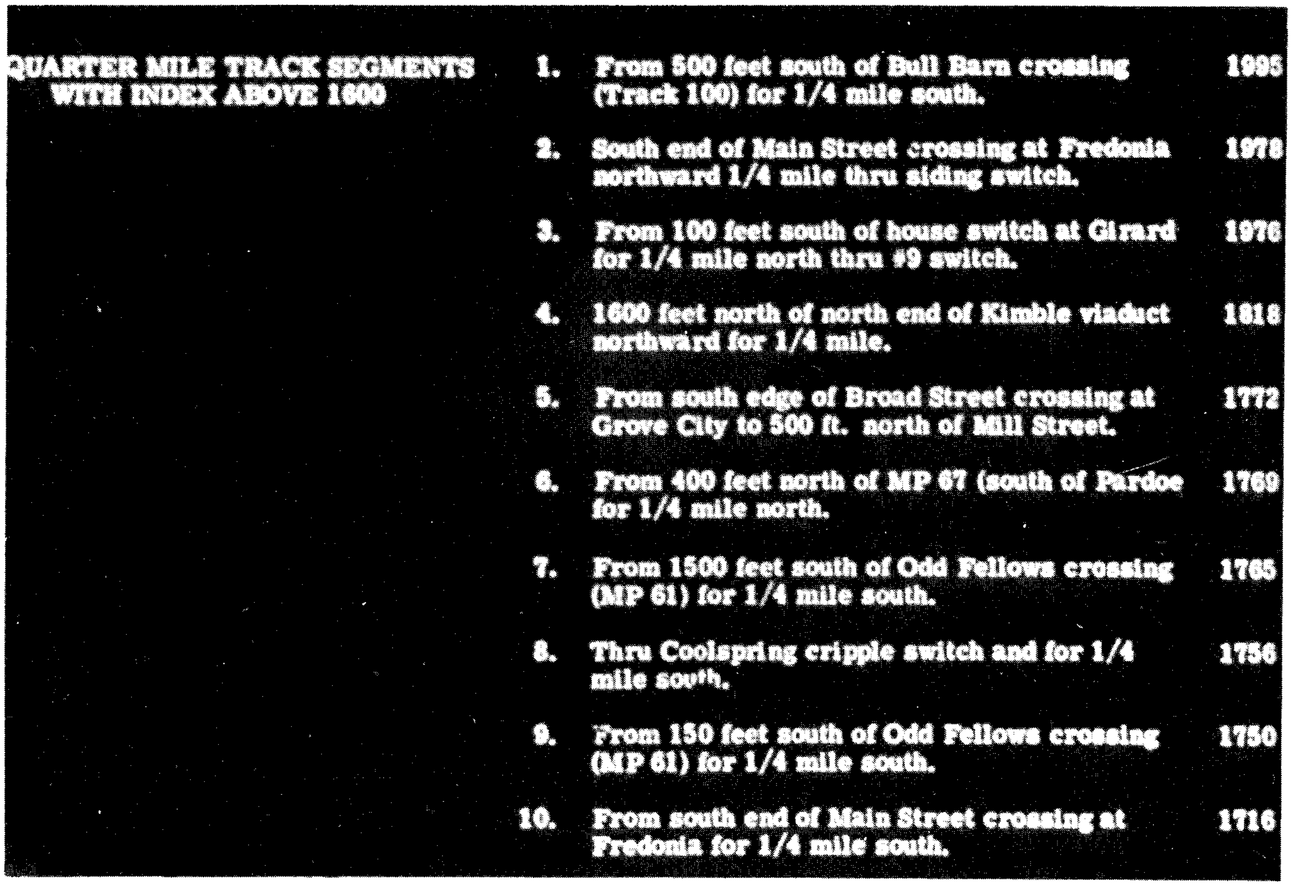


	Index Per Mile			
	Spring 1973	Fall 1972	Change	% Change
MP H-1 to MP H-2	6,511	5,514	+997	+18%
MP H-2 to MP H-3	7,526	6,446	+1,080	+17%
MP H-3 to MP H-4	7,820	6,426	+1,394	+22%
MP H-4 to MP H-5	7,023	6,284	+739	+12%
MP H-5 to MP H-6	5,020	5,484	-464	- 8%
MP H-6 to MP H-7	6,438	5,926	+512	+8%
MP H-7 to MP H-8	6,099	7,157	-1,058	-15%
MP H-8 to MP H-9	5,996	8,432	-2,436	-29%
MP H-9 to Hilliards	6,416	9,694	-3,278	-34%

Figure 2-22. Example of Track Index Value Application (Hilliards Branch)

A discussion with the track supervisor for this territory revealed that surfacing actually began near Milepost 6 with the gang working toward Hilliards. They then returned and raised between Milepost 5 and Milepost 6. This was the first use of the tamper since its winter overhaul, and problems developed in its electrical system. For the first several days of surfacing, production was low and the machine had a tendency to hump, or overraise, the track. The problem was corrected by the time the gang passed Milepost 7.

Each fall the Track Department is given a list of quarter-mile track sections (Figure 2-23) with high index values, so that these sections can be smoothed before the winter freeze sets in. These sections are taken from the track "index" value summary reports which are sorted for severity.



UARTER MILE TRACK SEGMENTS WITH INDEX ABOVE 1600

1.	From 500 feet south of Bull Barn crossing (Track 100) for 1/4 mile south.	1995
2.	South end of Main Street crossing at Fredonia northward 1/4 mile thru siding switch.	1978
3.	From 100 feet south of house switch at Girard for 1/4 mile north thru #9 switch.	1976
4.	1600 feet north of north end of Kimble viaduct northward for 1/4 mile.	1818
5.	From south edge of Broad Street crossing at Grove City to 500 ft. north of Mill Street.	1772
6.	From 400 feet north of MP 67 (south of Pardoe for 1/4 mile north.	1769
7.	From 1500 feet south of Odd Fellows crossing (MP 61) for 1/4 mile south.	1765
8.	Thru Coolspring cripple switch and for 1/4 mile south.	1756
9.	From 150 feet south of Odd Fellows crossing (MP 61) for 1/4 mile south.	1750
10.	From south end of Main Street crossing at Fredonia for 1/4 mile south.	1716

Figure 2-23. Example of Track Segment List Used for Maintenance Planning

The "track index" values and the "cumulative" slope values tell an almost identical story. Quarter-mile values (Figure 2-24) are plotted here for 3-1/2 miles of actual track. Index values are dark, and slope values are light. A correlation analysis of the two values has been made, and the results support the evidence pictured here. A further discussion of this correlation analysis can be found in Chapter 4 of this report.

Presently, these "index" values are also being used by the maintenance-of-way department to locate and verify a significant portion of its annual surfacing program. They are also being used, particularly in the spring, to determine quarter miles of track which need to be improved to the quality of the longer stretches on either side of them.

To date, profile defect and rating data have been developed by the capacitive sensor chord system. Thus it is not compatible with FRA standards. In its present state of development, the profilometer (selected as the replacement instrument for the capacitive profile system) appears to be speed sensitive and has exhibited some wide discrepancies between consecutive runs over the same track at different speeds. However, recent tests indicate an early solution is expected. Once profilometer accuracy has been demonstrated, plans call for developing profile data from this system. However, rating values from the two systems are not entirely compatible, thus both systems will be required for a year or more to insure that comparable data are available over a period of three or four measurement runs. Because the profilometer can output data in terms of the FRA track safety standards, a major effort is being directed toward correcting its problems and verifying its outputs.

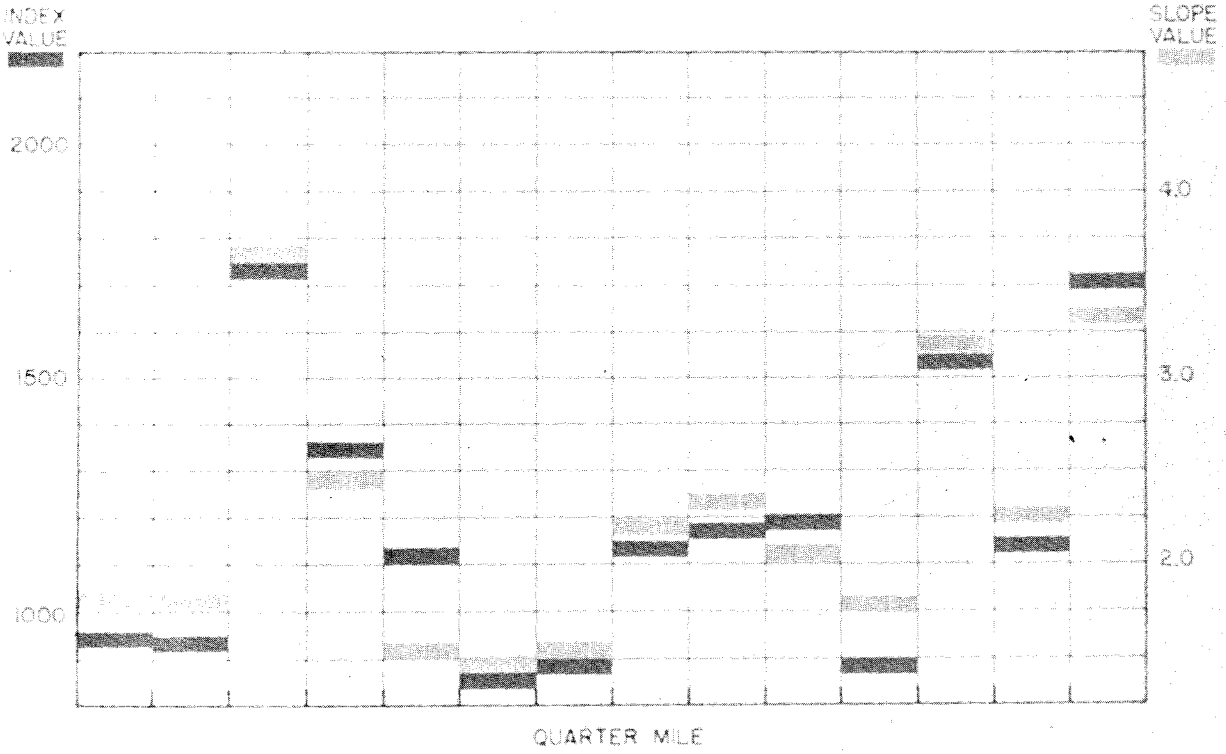


Figure 2-24. Quarter-Mile Rating Value Comparison

Profile "index," slopes, and cumulative slope values are duplicate measures of track quality. At least one of them will probably be discontinued at some time in the future. All rating values are designed to reduce many data samples to one or two numbers. This condensation is mandatory for run-to-run comparisons and for summary reports to higher management. To some extent, this brevity may be paid for by an accompaning loss of some of the information. Each of these three values must be studied in much greater detail to determine which presents the greatest amount of usable data in the most concise form.

At present the severe defects in crosslevel, warp, rock and roll, and curvature are taken from the Integrated Exception Report and checked in the field. Corrections are then made by the track forces. Experience has shown that the reported defects are valid imperfections that need attention. Even though the raw data were taken under load, a large majority of the defects can actually be seen by eye in the field if the investigator knows where to look. However, a track inspector would normally pass over many of the smaller defects without the use of the report.

Aside from the crosslevel and curvature "index" values used to develop GEOPLOT, no rating values for these parameters have yet been devised. Crosslevel and curvature "index" values have yet to be verified and significant values of change determined. There has been no effort to output these values for the quarter-mile track sections for comparative purposes. This effort will be a future project.

The curve definition portion of the curve analysis report is difficult to validate. Not even an experienced surveyor can determine if a curve begins exactly at a given physical point. An ingenious method of validation was recently suggested. Although the length of curve and the degree of curve can be changed, the central angle for that curve does not change as the result of maintenance. It is established by the angle of intersection of the tangent on either end of the curve.

The central angles of all the curves in a rail line are known from the days when the railroad was built or from the data of the most recent line changes. If the central angles for a series of curves are computed from the data in the curvature analysis report, the amount of agreement with the known central angles of these curves is an accurate measure of the correctness of the report. Preliminary work has been started in this area.

But a number of valuable, longer range observations have already been made from curvature and crosslevel data. Instances of crosslevel in tangents, while not of sufficient magnitude to be safety standard violations, indicate that the quality of production tamper raising may not be as good as has been assumed. This may be the result of equipment weakness, human failure, or both. Swings of up to 1-1/2 degrees with a definite periodic frequency have been found in isolated curves. Here the maintenance officers would not believe that they existed until a set of stringline notes proved otherwise. This condition appears to have been the result of curve deterioration resulting from traffic.

A study of the matching of superelevation with curvature, particularly in the spirals, indicates that raising and lining techniques need some improvement. The point of full elevation often does not match the point of full curvature. The beginning point of the spiral does not always match the point of zero crosslevel, yet generally the spiral curve is smooth and the superelevation runout is uniform. It has been suggested that the lining machine, measuring curves ahead of the tamper and then struggling to keep the lining operation close behind the raising gang, cannot show the raising foreman the proper points for starting and ending superelevation. Each foreman must use his best judgment in locating the proper points.

The GEOPLOT program appears to be a very useful summary. The indices are based on statistical values which are relatively insensitive to possible instrument error. Since large-scale maintenance programs are planned for at least one mile of track, any errors in distance measurement would not be great enough to create a serious comparison problem. It gives a snapshot summary of the major parameters to the maintenance planning engineer.

Because the COMPARE program is relatively new, its usage in practical applications has been limited. Its chief benefit appears to lie in its ability to picture track geometry changes in a form that many people can readily understand. In its present form some of the values, particularly gage and profile, are quite sensitive to instrument error. The COMPARE program must lump longer stretches of track together to reduce the required paper to manageable proportions. Even then its output of sheets of paper is many times that of GEOPLOT.

2.3 FUTURE CONSIDERATIONS

It has been claimed that, given the tremendous amount of data developed in one measurement run, reports exceeding the length of the track being measured can be generated. In fact, one of the primary objectives has been to condense and simplify reports. The 1971 gage defect report actually contained almost as many pages as all of the 1974 reports combined. Much has been learned about instrumentation, computer processing, and report generation. Much remains to be learned, but the project is well on its way to developing useful measures of track quality as well as measures of change caused by service and/or maintenance practices and to present this information in a concise manner.

The development of new modified track geometry instrumentation must be continued to permit the final development of effective maintenance-of-way planning techniques. The installation and verification of the all-weather gage system must be done before further progress can be made in the study of gage deterioration. Until the profilometer is modified and its output verified, profile defect data cannot be expressed in terms of the FRA track safety standards. The same situation appears to be true if rail alignment is to be compared to federal standards. An alignometer, which is under development, appears to hold considerable promise in this field. This device would function much like a lateral profilometer. Under study is the possibility that an alignment standard's comparison program can be written for the existing alignment data.

The programs that were discussed earlier are under continuing study and change. In this area the object is to output more usable information, reduce the amount of paper involved, reduce the cost of programming and data processing, explore the possibility of real-time processing of all data, and provide each level of management with the most useful reports.

Particularly in the area of profile, some quality control value is already apparent in the rating summaries. Curvature and crosslevel still require the development of verified rating techniques. Some of these are already developed, but there is much more study needed.

As of this time, no attempt has been made to develop any cost-benefit relation using the track geometry data. This aspect of the study is probably several years in the future.

At present, there are limitations to the use of track geometry data. For example, it can never replace the track man. If track begins to deteriorate, the measurement system can tell where and in what parameters, but not why. A track man must look at that location and use his experience and judgment to determine corrective solutions. Sophisticated systems can only produce valuable information to aid in the decision making process.

Track geometry is not an end in itself. The track structure is merely the stimulus which excites a dynamic response in the railroad car. While some cars can develop undesirable dynamic reactions on poor track at low speeds, other cars can show dangerous excitation on relatively good track at higher speeds. As more is learned about the reactions of car suspensions to the stimulus of track, railroad safety will depend less on "operator judgments" and more on applied technology. The use of automated track measurement systems should then result in safer and more economical railroading.

3.0

MAINTENANCE INFORMATION REPORTS

3.1 INTRODUCTION

Post-run processing of digital track geometry data is performed to provide track maintenance information reports in a format useful to maintenance-of-way personnel. A number of different reports have been developed to evaluate track geometry data. They include:

- Crisis Maintenance Report which highlights exceptions requiring immediate action (includes location and magnitude).
- Detailed Exception Listing which provides detailed information on the magnitude of each exception (gage, profile, crosslevel, curvature, warp, or rock and roll) keyed to geographic location.
- Maintenance Planning Report which presents information on the average quality of track sections in a manner useful for maintenance scheduling and for the evaluation of maintenance performance. This report lists track quality measures and contains summaries that rank sections of track according to quality.
- Data Comparison Report which presents information useful for evaluating the rate of track degradation, the effects of specific types of track maintenance, and the performance of track maintenance equipment by means of (1) histograms for two sets of data which are superimposed to give visual representation of differences in the measured segments of track, and (2) geographic plots where quality measures for selected track geometry parameters are used.

These reports are used to present detailed maintenance information on gage, profile, curvature, integrated exception (a single report summarizing gage, profile, curvature, crosslevel, warp, and rock and roll exceptions), and integrated standards (a report summarizing exceptions to federal track safety standards).

Table 3-1 displays a list of all the reports that are generated for maintenance planning. For each report the table shows which parameters are analyzed and which reports are used by each level of management.

3.2 GAGE REPORTS

The Gage Program produces a multipurpose report which is oriented toward railroad maintenance activities. The report contains data for crisis maintenance, detailed exception analysis, and maintenance planning.

The Gage Critical Threshold List (Figure 3-1) contains a summary of critical gage exceptions found during data acquisition. Critical gage thresholds can be predetermined in order to give the railroad user a list of exceptions which he considers critical. The list is not ordered by severity, but is merely a summary of anomalies encountered. Each entry line includes information which is used to determine the geographic location of the exception (i.e., milepost distance) as well as the distance from the reference location.

The Gage Priority Defect List, also called the Largest Exception List (Figure 3-2), is a one-page summary used for gage crisis maintenance. It lists the one hundred largest gage exceptions in order of decreasing magnitude.

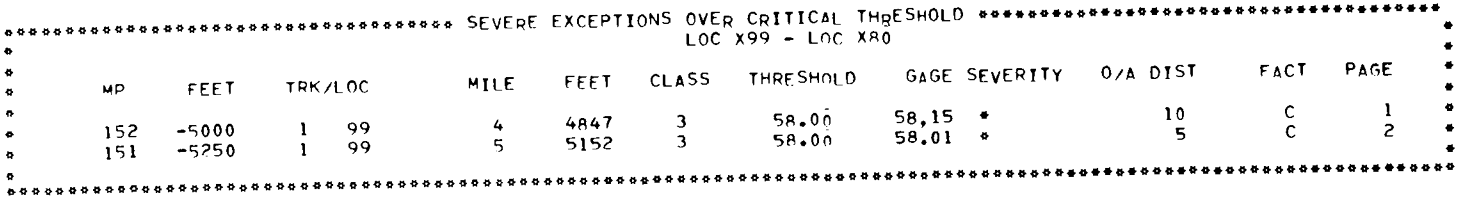
The purpose of these two critical exception reports is to provide the individual railroad user with sufficient information to determine where to concentrate spot maintenance efforts.

Figure 3-3 illustrates the relationship between the strip chart recording of gage and the computer-generated gage exception listing. When a gage value exceeds a selectable low threshold, such as 57.00 inches, a gage exception is indicated. If only a single value within a specified distance is in excess of this threshold, a single line entry will be printed.

TABLE 3-1

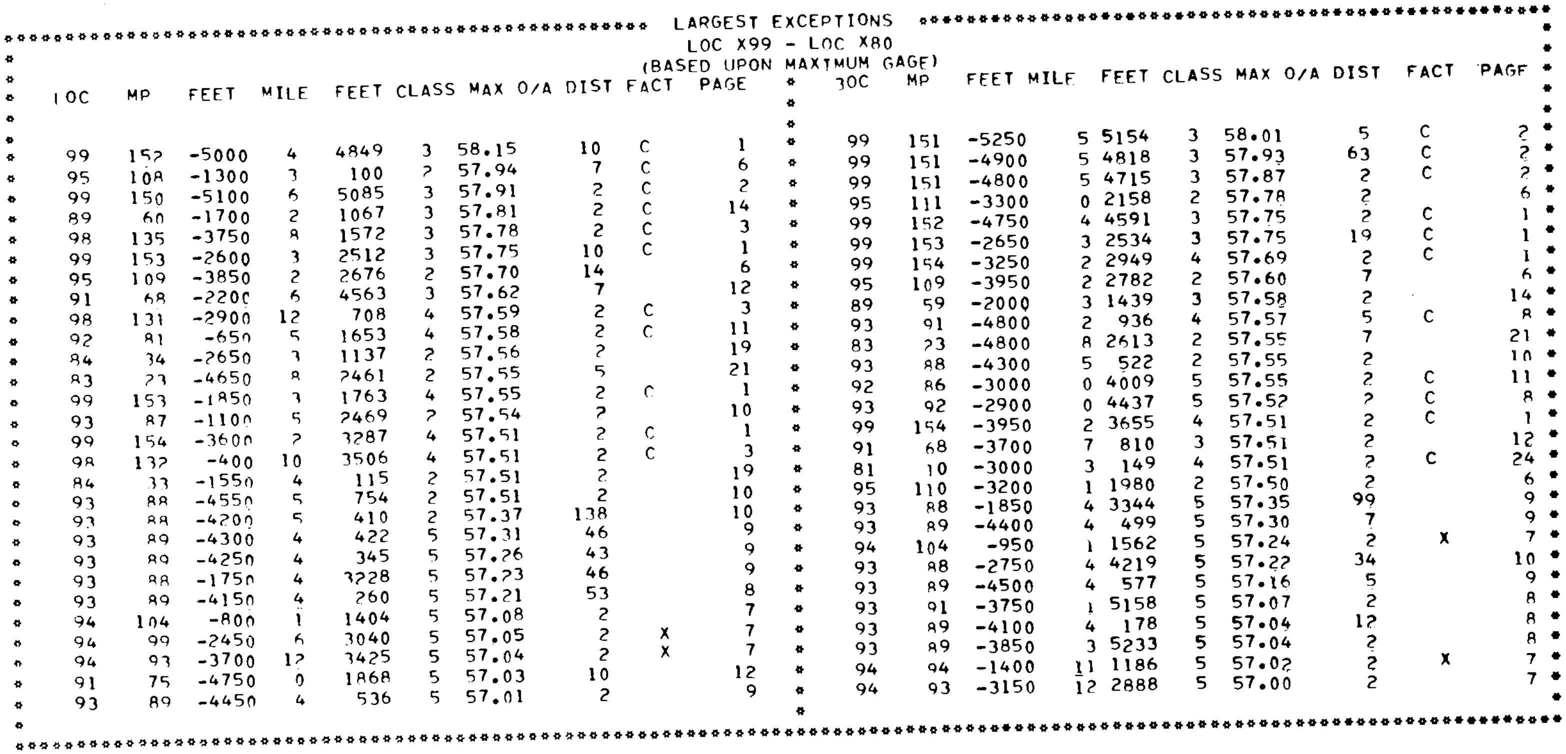
RELATIONSHIP BETWEEN MEASURED PARAMETERS, MAINTENANCE REPORTS, AND MANAGEMENT LEVELS

MAINTENANCE REPORTS	PARAMETERS							MANAGEMENT LEVELS			
	Gage	Profile	Curvature	Alignment	Cross-level	Warp	Rock and Roll	Track Supervisor	Mid Level	Top Level	R&D Engineer
Critical Maintenance											
1. Analog Chart	X	X	X	X	X			X	X		
2. Critical Defect	X	X	X		X	X	X	X	X		
3. Priority Defect	X	X						X	X		
Detailed Exception	X	X	X		X	X	X		X		
Maintenance Planning											
1. One-Mile Exception Sum.	X	X	X		X	X	X		X		
2. One-Mile Class Sum.	X	X			X	X			X	X	
3. Location Sum.		X							X		
4. Track Segment Sum.	X	X							X		
5. Histogram	X	X	X		X				X		
Data Comparison											
1. GEOPLOT	X	X	X		X				X	X	
2. COMPARE	X	X	X		X				X		
3. PSD	X	X	X	X	X						X



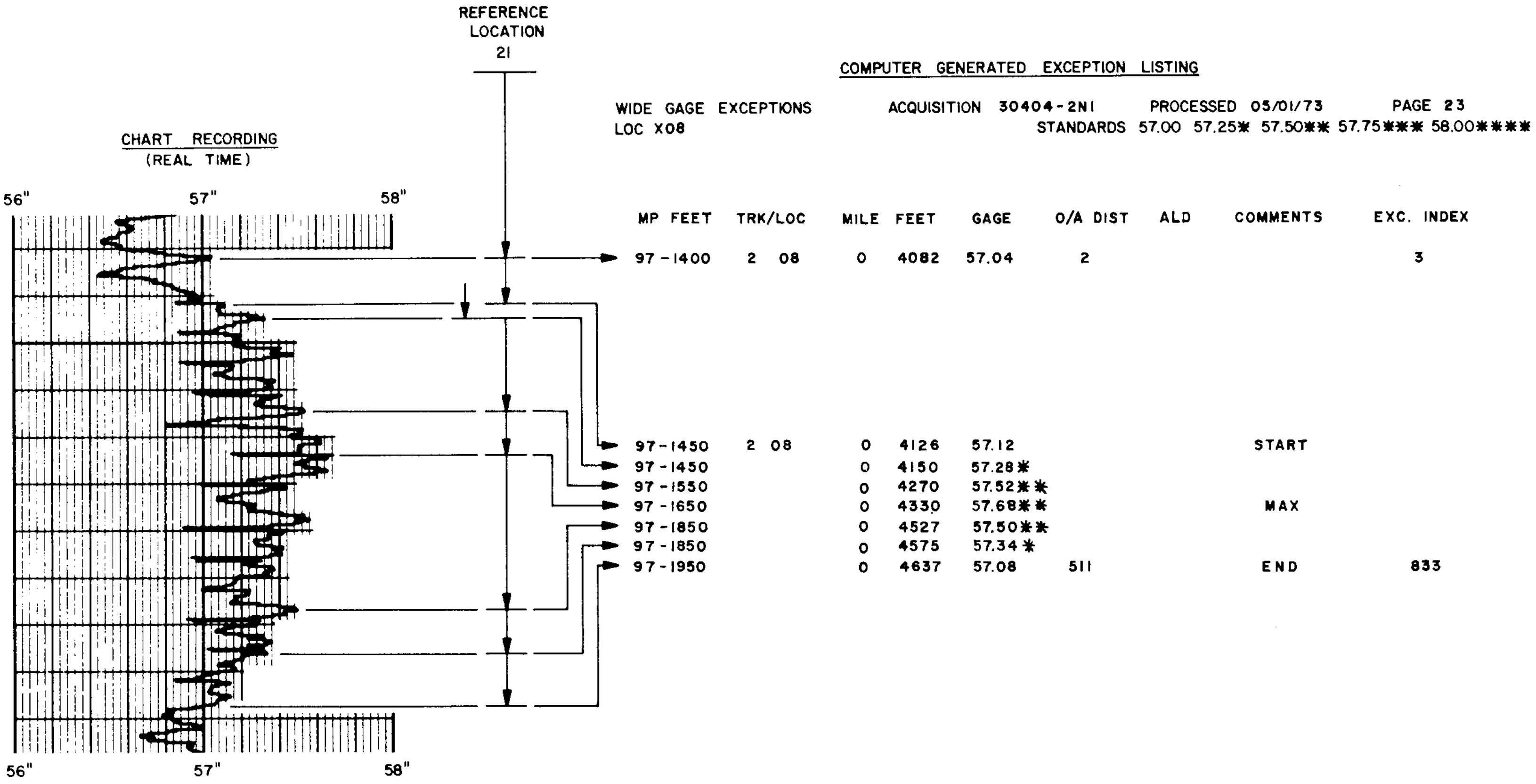
```
************************************ SEVERE EXCEPTIONS OVER CRITICAL THRESHOLD ************************************
                                                 LOC X99 - LOC X80
*
*       MP     FEET     TRK/LOC          MILE    FEET   CLASS   THRESHOLD   GAGE SEVERITY   O/A DIST     FACT   PAGE  *
*
*       152   -5000     1    99            4     4847     3       58.00     58,15  *           10          C      1   *
*       151   -5250     1    99            5     5152     3       58.00     58.01  *            5          C      2   *
*
********************************************************************************************************************
```

Figure 3-1. Gage Critical Threshold List Showing All Defects over a Severe Threshold



```
***************************************************** LARGEST EXCEPTIONS *********************************************************
                                                       LOC X99 - LOC X80
                                                   (BASED UPON MAXIMUM GAGE)
*   LOC   MP   FEET  MILE  FEET CLASS MAX O/A DIST FACT  PAGE  *   LOC   MP   FEET MILE  FEET CLASS MAX O/A DIST  FACT  PAGE  *
*                                                              *
*                                                              *
*    99  152  -5000    4   4849   3  58.15    10    C     1    *    99  151  -5250    5 5154   3  58.01      5    C      2  *
*    95  108  -1300    3    100   2  57.94     7    C     6    *    99  151  -4900    5 4818   3  57.93     63    C      2  *
*    99  150  -5100    6   5085   3  57.91     2    C     2    *    99  151  -4800    5 4715   3  57.87      2    C      2  *
*    89   60  -1700    2   1067   3  57.81     2    C    14    *    95  111  -3300    0 2158   2  57.78      2           6  *
*    98  135  -3750    8   1572   3  57.78     2    C     3    *    99  152  -4750    4 4591   3  57.75      2    C      1  *
*    99  153  -2600    3   2512   3  57.75    10    C     1    *    99  153  -2650    3 2534   3  57.75     19    C      1  *
*    95  109  -3850    2   2676   2  57.70    14          6    *    99  154  -3250    2 2949   4  57.69      2    C      1  *
*    91   68  -2200    6   4563   3  57.62     7         12    *    95  109  -3950    2 2782   2  57.60      7           6  *
*    98  131  -2900   12    708   4  57.59     2    C     3    *    89   59  -2000    3 1439   3  57.58      2          14  *
*    92   81   -650    5   1653   4  57.58     2    C    11    *    93   91  -4800    2  936   4  57.57      5    C      8  *
*    84   34  -2650    3   1137   2  57.56     2         19    *    83   23  -4800    8 2613   2  57.55      7          21  *
*    83   23  -4650    8   2461   2  57.55     5         21    *    93   88  -4300    5  522   2  57.55      2          10  *
*    99  153  -1850    3   1763   4  57.55     2    C     1    *    92   86  -3000    0 4009   5  57.55      2    C     11  *
*    93   87  -1100    5   2469   2  57.54     2         10    *    93   92  -2900    0 4437   5  57.52      2    C      8  *
*    99  154  -3600    2   3287   4  57.51     2    C     1    *    99  154  -3950    2 3655   4  57.51      2    C      1  *
*    98  132   -400   10   3506   4  57.51     2    C     3    *    91   68  -3700    7  810   3  57.51      2          12  *
*    84   33  -1550    4    115   2  57.51     2         19    *    81   10  -3000    3  149   4  57.51      2    C     24  *
*    93   88  -4550    5    754   2  57.51     2         10    *    95  110  -3200    1 1980   2  57.50      2           6  *
*    93   88  -4200    5    410   2  57.37   138         10    *    93   88  -1850    4 3344   5  57.35     99           9  *
*    93   89  -4300    4    422   5  57.31    46          9    *    93   89  -4400    4  499   5  57.30      7           9  *
*    93   89  -4250    4    345   5  57.26    43          9    *    94  104   -950    1 1562   5  57.24      2    X      7  *
*    93   88  -1750    4   3228   5  57.23    46          9    *    93   88  -2750    4 4219   5  57.22     34          10  *
*    93   89  -4150    4    260   5  57.21    53          8    *    93   89  -4500    4  577   5  57.16      5           9  *
*    94  104   -800    1   1404   5  57.08     2          7    *    93   91  -3750    1 5158   5  57.07      2           8  *
*    94   99  -2450    6   3040   5  57.05     2    X     7    *    93   89  -4100    4  178   5  57.04     12           8  *
*    94   93  -3700   12   3425   5  57.04     2    X     7    *    93   89  -3850    3 5233   5  57.04      2           8  *
*    91   75  -4750    0   1868   5  57.03    10         12    *    94   94  -1400   11 1186   5  57.02      2    X      7  *
*    93   89  -4450    4    536   5  57.01     2          9    *    94   93  -3150   12 2888   5  57.00      2           7  *
*                                                              *                                                           *
*********************************************************************************************************************************
```

Figure 3-2. Gage Priority Defect List Showing the 100 Largest Defects Sorted by Decreasing Order of Magnitude



```
                                COMPUTER GENERATED EXCEPTION LISTING

WIDE GAGE EXCEPTIONS      ACQUISITION 30404-2N1     PROCESSED 05/01/73        PAGE 23
LOC X08                             STANDARDS 57.00 57.25* 57.50** 57.75*** 58.00****


 MP FEET   TRK/LOC    MILE  FEET    GAGE     O/A DIST   ALD    COMMENTS     EXC. INDEX

 97-1400   2  08       0    4082   57.04        2                                3



 97-1450   2  08       0    4126   57.12                        START
 97-1450               0    4150   57.28*
 97-1550               0    4270   57.52**
 97-1650               0    4330   57.68**                       MAX
 97-1850               0    4527   57.50**
 97-1850               0    4575   57.34*
 97-1950               0    4637   57.08       511               END            833
```

Figure 3-3. Relationship of Detailed Gage Exception Information and the On-Line Strip Chart Display

If gage values within a specified distance ahead also exceed the low threshold, a group exception will be printed, grouping all exception data ahead until no additional data exceeds the low threshold within the grouping distance. The final group exception entry contains all of the data printed for the single exception mentioned above, plus the word END in the Comments column.

There will always be a START and MAX entry to indicate the beginning and maximum points of an exception group. In addition, there may be entries to indicate the change from one severity level to another.

There is no distinction between wide gage and tight gage exceptions other than in grouping (all wide gage exceptions appear in one report section, tight gage exceptions in another) and in the directionality of surpassing a threshold.

The purpose of the Gage Track Segment Summary (Figure 3-4) is to display an analysis of the quality of the track in terms of the gage parameter. The method of analysis is to calculate various statistical measures for each segment (normally one-quarter mile, unless otherwise specified).

Each entry in the report represents a track segment. The distance information for mileposts and reference locations indicates the point at which the track segment terminates. For each segment, the mean and variance of the gage data are calculated and printed. Included also is a distribution chart for all of the valid data within the segment. The latter is generated by setting six categories for the gage data and determining into which one each measurement falls. When all measurements have been categorized, the number of measurements in each category is presented as a percentage of the total number of measurements made in the segment. Thus each track segment entry in the report shows data percentages for each of the six levels. Three percentage values (95, 97, 99) are extracted from the distribution chart to give an indication of gage width within a given track segment.

```
   TRACK SEGMENT SUMMARIES            ACQUISITION  41014-1E1              PROCESSED  01/13/75                PAGE    1

LOC X99              MP156-MP142.7              PERCENTAGE LEVELS : 1 = BELOW 56.75      2 = 56.75 - 57.00
                                                                    3 = 57.00 - 57.25      4 = 57.25 - 57.50
 TRACK SEGMENT LENGTH =  1320 FEET (   546 SAMPLES)                 5 = 57.50 - 57.75      6 = ABOVE 57.75     TRK CLASS = 4

  MP     FEET          TRK/LOC       MILE       FEET      MEAN     VARIANCE          PERCENTAGE LEVELS          NO.    I    PERCENTAGE VALUES
                                                                              1     2     3     4     5     6 SAMPLES I    95%     97%     99%
                                                                                                                     I
  156   -1600          1   99          0        1319     56.34     .0093    100     0     0     0     0     0    546   I   56.49   56.51   56.56
  156   -2950          1   99          0        2639     56.32     .0098    100     0     0     0     0     0    546   I   56.49   56.50   56.55
  156   -4250          1   99          0        3958     56.34     .0087    100     0     0     0     0     0    546   I   56.54   56.56   56.60
  155    -300          1   99          0        5278     56.37     .0064    100     0     0     0     0     0    546   I   56.50   56.53   56.58
  155   -1600          1   99          1        1317     56.31     .0149    100     0     0     0     0     0    546   I   56.49   56.57   56.65
  155   -2950          1   99          1        2637     56.33     .0094    100     0     0     0     0     0    546   I   56.48   56.51   56.59
  155   -4250          1   99          1        3956     56.37     .0132     99     1     0     0     0     0    546   I   56.53   56.61   56.71
° 154    -300          1   99          1        5276     56.61     .0533     72    24     4     0     0     0    546   I   56.99   57.02   57.10
° 154   -1600          1   99          2        1315     56.44     .0539     88    10     1     0     0     0    546   I   56.86   56.93   57.04
° 154   -2900          1   99          2        2635     56.33     .0240     98     2     0     0     0     0    546   I   56.67   56.72   56.82
° 154   -4250          1   99          2        3954     57.06     .0317      4    32    50    13     1     0    546   I   57.35   57.38   57.47
° 153    -100          1   99          2        5274     56.59     .0541     76    19     5     0     0     0    546   I   57.00   57.11   57.20
° 153   -1400          1   99          3        1313     56.51     .0587     79    19     1     0     0     0    546   I   56.92   56.95   57.06

° 153   -2600 -----  1   99          3        2512                                     CHANGED TO CLASS  3 TRACK

° 153   -2750          1   99          3        2633     56.95     .0761     22    33    36     7     0     3    546   I   57.34   57.45   57.75
° 153   -4050          1   99          3        3952     56.56     .0998     74    13    11     3     0     0    546   I   57.21   57.24   57.31
° 152    -150          1   99          3        5272     56.71     .0579     59    27    13     1     0     0    546   I   57.13   57.18   57.28
° 152   -1450          1   99          4        1311     56.34     .0093    100     0     0     0     0     0    546   I   56.50   56.53   56.57
° 152   -2750          1   99          4        2631     56.72     .0853     55    24    16     4     0     0    546   I   57.24   57.29   57.39
° 152   -4100          1   99          4        3950     56.51     .0750     79    14     7     0     0     0    546   I   57.06   57.11   57.18
° 151    -100          1   99          4        5270     57.03     .0587     12    34    39    12     2     1    546   I   57.45   57.51   57.82
° 151   -1400          1   99          5        1309     56.72     .1164     54    21    19     4     2     0    546   I   57.28   57.42   57.60
° 151   -2700          1   99          5        2629     56.56     .0558     82    13     4     1     0     0    546   I   57.03   57.15   57.29
° 151   -4050          1   99          5        3948     56.62     .0628     68    25     6     1     0     0    546   I   57.05   57.13   57.27
° 150      -0          1   99          5        5268     56.89     .1333     31    38    20     4     1     6    546   I   57.93   57.93   57.93
° 150   -1300          1   99          6        1307     56.47     .0492     87     9     4     1     0     0    546   I   56.99   57.05   57.23
° 150   -2650          1   99          6        2627     56.47     .0354     91     9     0     0     0     0    546   I   56.81   56.84   56.88
° 150   -3950          1   99          6        3946     56.51     .0298     92     8     0     0     0     0    546   I   56.79   56.84   56.93
° 149    -100          1   99          6        5266     56.66     .1331     62    15    17     5     1     0    546   I   57.28   57.36   57.59
° 149   -1450          1   99          7        1305     56.64     .1508     59    16    20     5     0     0    546   I   57.25   57.30   57.37
° 149   -2750          1   99          7        2625     56.48     .0413     90     9     1     0     0     0    546   I   56.86   56.90   57.00
° 149   -4050          1   99          7        3944     56.24     .0113    100     0     0     0     0     0    546   I   56.40   56.43   56.55
° 148    -100          1   99          7        5264     56.59     .1030     62    25    12     1     0     0    546   I   57.09   57.11   57.16
° 148   -1400          1   99          8        1303     56.49     .0660     84    12     4     0     0     0    546   I   56.94   57.06   57.19
° 148   -2750          1   99          8        2623     56.54     .0957     68    25     7     1     0     0    546   I   57.04   57.10   57.24
° 148   -4050          1   99          8        3942     56.71     .0638     56    31    12     1     0     0    546   I   57.12   57.18   57.27
° 147    -100          1   99          8        5262     56.59     .0536     72    25     3     0     0     0    546   I   56.95   57.02   57.14
° 147   -1450          1   99          9        1301     56.47     .0290     92     8     0     0     0     0    546   I   56.80   56.85   56.92
° 147   -2750          1   99          9        2621     56.36     .0083    100     0     0     0     0     0    546   I   56.52   56.54   56.65
° 147   -4100          1   99          9        3940     56.44     .0090    100     0     0     0     0     0    546   I   56.61   56.67   56.73
° 146    -100          1   99          9        5260     56.45     .0221     95     5     0     0     0     0    546   I   56.75   56.83   56.91
° 146   -1450          1   99         10        1299     56.77     .0733     53    20    23     4     0     0    546   I   57.22   57.29   57.42
° 146   -2750          1   99         10        2619     56.71     .0672     60    23    15     1     0     0    546   I   57.18   57.22   57.31
° 146   -4100          1   99         10        3938     56.53     .0496     84    11     4     1     0     0    546   I   57.00   57.10   57.25
```

Figure 3-4. Gage Track Segment Summary Showing an Analysis of Track Quality of Gage by Quarter-mile Segments

The value of this analysis is twofold. First, it is possible to quickly determine the relative quality of one track segment compared to another. As percentages in higher categories increase, the quality of the gage decreases. Second, when analyzing data from one run to another, it is possible to make comparisons of track segments in terms of the respective distributions of their gage measurements. By doing this it is possible to determine whether the gage has widened appreciably in a specific area.

Gage Histograms graphically illustrate the condition of gage by showing the distribution of gage measurements. Gage data histograms are presented with measurement percentages on the ordinate axis and incremental gage values on the abscissa. The sum of the measurement percentages totals 100 percent. Although calculation of the mean gage and other statistics can be performed from the histogram, its primary purpose is to give railroad personnel a graphic comparison of sections of track. As an example, there is little doubt of the relative quality of the track segments represented in Figures 3-5 and 3-6.

The Gage Program provides individual histograms for each reference location (normally about 5 miles of track) and a summary histogram for all of the data analyzed.

3.3 PROFILE REPORTS

The Profile Program produces a multipurpose report which is oriented toward different levels of maintenance activity similar to the Gage Program.

The Profile Critical Threshold List (Figure 3-7) contains a summary of critical profile exceptions found during data acquisition. The thresholds can be predetermined in order to give the individual railroad user a list of profile exceptions which he considers critical. The list is not ordered by severity; rather, it shows each critical anomaly that is encountered.

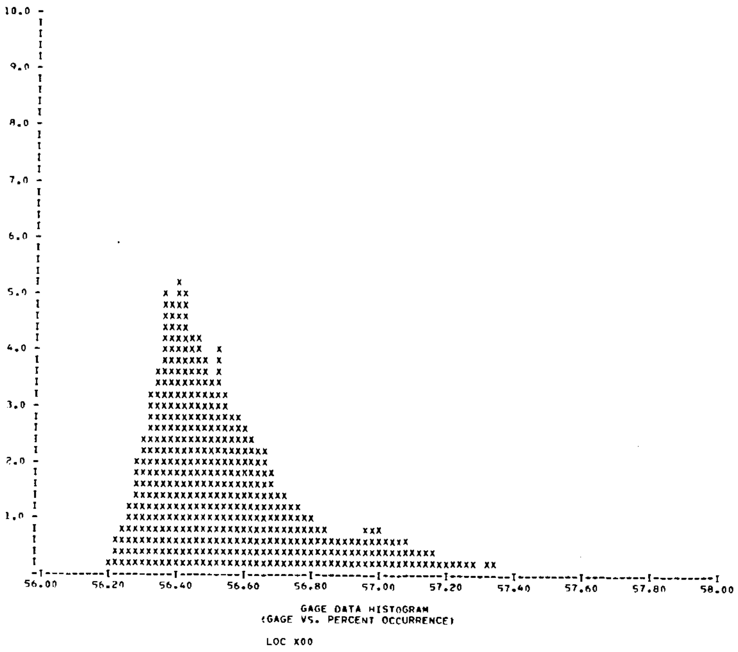


Figure 3-5. Track Gage Data (~~New~~ WORN Rail)

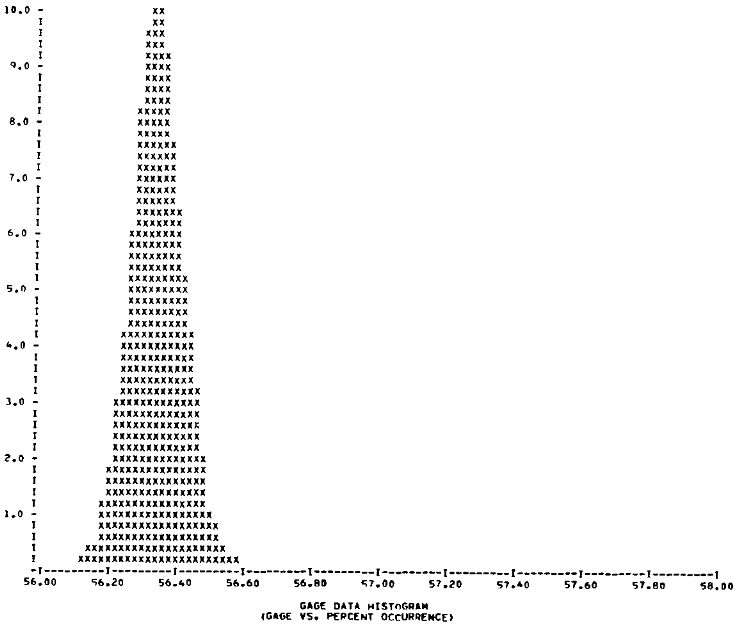


Figure 3-6. Track Gage Data (~~Worn~~ NEW Rail)

```
******************************************** ALL EXCEPTIONS OVER   .750 THRESHOLD *******************************************
*                                                FOR THE LOCATIONS INDICATED                                                *
*                                                                                                                           *
*                     STANDARDS (INCHES)  .375        .500*       .625**     .750***     .875****                           *
*                                                                                                                           *
*                                                   BEGINNING AT LOC X06                                                    *
*                                SOUTH                        *                                NORTH                        *
*    MP  FEET TRK/LOC MILE FEET  PROFILE SEVERITY  FACT  PAGE *    MP  FEFT  TRK/LOCMILE FEET PROFILE SEVERITY FACT  PAGE   *
*                                                             *                                                             *
*                                                             *    191 4000   1  08   1  3845   -.75   ***      GC     14   *
*                                                             *    205 3100   1  09   9    40   -.77   ***      GC     22   *
*    228 2650  1  11    6  831   -.75   ***       G       37 *                                                             *
*                                                             *    229 1900   1  11   7    61   -.75   ***       C     38   *
*    261  300  1  15    7 5010   -.78   ***               59 *                                                             *
*                                                             *    270 5100   1  17   0  1237   -.77   ***       X     65   *
*                                                                                                                           *
*                                                    ENDING WITH LOC X20                                                    *
*                                                                                                                           *
*****************************************************************************************************************************
```

Figure 3-7. Profile Critical Threshold List Showing All Defects Exceeding a Critical (Set by Individual Railroad User) Threshold.

The Profile Priority Defect List (Figures 3-8 and 3-9), also called the Largest Exception List, contains three pages. The first page lists the one hundred largest profile chord offsets for the two rails. Pages two and three list the fifty most severe track segments based on "index" (area under the midchord offset curve) and slope "changes."

The defect detection scheme is the same in the Profile Program as in the Gage Program. When a profile value exceeds a selectable low threshold, such as -0.375 inch, a profile exception is indicated. Because profile anomalies are caused by low joints, and because low-joint information is of short duration, there is no analysis done for grouping exceptions (i.e., all exceptions are point exceptions). Each time an exception is encountered, it is printed out in the appropriate rail column along with additional information about geographic location and severity (Figure 3-10).

Also included on the report page is a line entry for the segment summary whenever the appropriate amount of data has been analyzed. This summary presents data concerning the profile track quality of the segment and includes an analysis of the Index (area under the profile curve), Number of Slope Changes (abrupt change in profile value between adjacent samples), Mean, and Variance. These four quality measures are calculated for each rail.

The Profile Exception Location Summary Report (Figure 3-11) lists all locations sorted according to Index value. The Index value for each rail is summed for all the complete track segments within each location. Once the numbers have been accumulated, the total is divided by the number of track segments to obtain the average Index value per segment. The locations are then sorted by the severity of the average index number.

The purpose of this summary is to give an indication of the quality of track for track segments that average 5 to 10 miles. Planning can be developed for the maintenance of longer sections of track with this type of information.

```
****************************************  MOST SEVERE EXCEPTIONS - CHORD OFFSET  ****************************************
                                                   LOC X06 - LOC X20
*                                                                 *                                                               *
*                                       SOUTH                                                                       NORTH         *
*  MP   FEET  TRK/LOC   MILE  FEET    PROFILE  FACT  PAGE   *  MP   FEET  TRK/LOC   MILE  FEET    PROFILE  FACT  PAGE  *
*                                                           *                                                               *
*                                                           *                                                               *
*  261   300  1  15      7   5010     -.78          59      *  205  3100  1  09      9     40     -.77     GC     22   *
*  228  2650  1  11      6    831     -.75    G     37      *  270  5100  1  17      0   1237     -.77      X     65   *
*  298   950  1  20      1   4527     -.72    G     76      *  191  4000  1  08      1   3845     -.75     GC     14   *
*  259   350  1  15      6    116     -.70          57      *  229  1900  1  11      7     61     -.75      C     38   *
*  178  3600  1  07      7   5240     -.68           8      *  279  4900  1  99      7   3285     -.75     GC     70   *
*  218  4800  1  10      5   3673     -.67     X    32      *  207  1250  1  09     10   3375     -.74      C     23   *
*  229  3850  1  11      7   1989     -.67          38      *  195  1250  1  08      5    993     -.73      C     16   *
*  184   550  1  08      0   1890     -.65     C    10      *  266  2650  1  16      3   3653     -.72            62   *
*  243  2200  1  13      3    320     -.64          47      *  209   500  1  09     12   2591     -.72     GCX    24   *
*  281   400  1  99      8   3991     -.63          70      *  233  3000  1  12      1    991     -.72            42   *
*  298   900  1  20      1   4488     -.63    G     76      *  229   500  1  11      6   3939     -.71            38   *
*  234  4100  1  12      2   2091     -.62          43      *  209   700  1  09     12   2787     -.71     GC     24   *
*  250  2200  1  14      5    959     -.62          52      *  172  4650  1  07      2   1323     -.71             6   *
*  270  2150  1  16      7   3152     -.62          64      *  272  3550  1  99      0   2044     -.70            67   *
*  272  3550  1  99      0   2023     -.61          67      *  211  3650  1  09     15    166     -.70     G      26   *
*  230  1700  1  11      7   5104     -.60          39      *  164  1200  1  06      2   3461     -.69      C      2   *
*  213  5300  1  10      0   4108     -.60          30      *  229  4250  1  11      7   2400     -.69            39   *
*  229  4900  1  11      7   3041     -.60          39      *  279  4700  1  99      7   3089     -.69      C     70   *
*  213   450  1  09     16   2141     -.60          27      *  211  1950  1  09     14   3771     -.68      C     26   *
*  271  3300  1  17      0   4596     -.60          65      *  236  1300  1  12      3   4542     -.67            43   *
*  249  1600  1  14      4    381     -.60          50      *  266  5200  1  16      4    942     -.67            62   *
*  245  2300  1  14      0   1148     -.60          49      *  236  3750  1  12      4   1730     -.66            44   *
*  193  1000  1  08      3    741     -.60          15      *  207  4700  1  09     11   1561     -.66      C     24   *
*  213   850  1  09     16   2532     -.59          28      *  206   850  1  09      9   3080     -.65     G      22   *
*  233  3150  1  12      1   1148     -.59          42      *  205  3200  1  09      9    117     -.65     GC     22   *
*  213   900  1  09     16   2568     -.59          28      *  210  1350  1  09     13   3154     -.65      C     25   *
*  255   650  1  15      2   1009     -.59          55      *  207  1450  1  09     10   3571     -.64      C     23   *
*  213  1150  1  09     16   2858     -.59      X   28      *  224  1900  1  11      2     78     -.64      C     36   *
*  280   650  1  99      7   4331     -.59          70      *  194   400  1  08      4    159     -.64      C     15   *
*  229  4400  1  11      7   2574     -.59          39      *  229  4500  1  11      7   2632     -.64            39   *
*  261  2150  1  15      8   1564     -.58          59      *  184  1000  1  08      0   2349     -.64      C     10   *
*  299  5050  1  20      3   3479     -.58    G     77      *  206  3350  1  09     10    294     -.64     GC     23   *
*  175  5050  1  07      5   1609     -.58           7      *  288  2400  1  19      0   2434     -.63     GC     74   *
*  224  4650  1  11      2   2838     -.58          36      *  253  1600  1  15      0   1692     -.63      C     54   *
*  222  3750  1  11      0   2088     -.58    G     35      *  253  2450  1  15      0   2552     -.63      C     54   *
*  289  1450  1  19      1   1470     -.58    G     74      *  225   850  1  11      2   4399     -.62     GC     36   *
*  230  1100  1  11      7   4481     -.58          39      *  170  1350  1  06      8   3640     -.62             5   *
*  233  1050  1  12      0   4333     -.58          42      *  180  3300  1  07      9   4866     -.62      C      8   *
*  213  2400  1  10      0   1223     -.57          29      *  224  1950  1  11      2    158     -.62      C     36   *
*  250  1850  1  14      5    647     -.57          51      *  229  2250  1  11      7    373     -.62            38   *
*  208  3750  1  09     12    583     -.57      X   24      *  249  1900  1  14      4    673     -.61            51   *
*  259  1900  1  15      6   1672     -.57    GC    58      *  278  3300  1  99      6   1771     -.61      C     69   *
*  289  1300  1  19      1   1351     -.56    G     74      *  237  2750  1  12      5    684     -.61            44   *
*  229  3900  1  11      7   2028     -.56          38      *  229  4000  1  11      7   2127     -.61            38   *
*  172   250  1  07      1   2219     -.56           6      *  248  3000  1  14      3   1802     -.61            50   *
*  242  2550  1  13      2    682     -.56          46      *  163  4300  1  06      2   1253     -.61      C      1   *
*  266  3050  1  16      3   4059     -.56          62      *  215   400  1  10      1   4652     -.61       X    30   *
*  184  3550  1  08      0   4879     -.56          11      *  272  2950  1  99      0   1423     -.61            67   *
*  235  4200  1  12      3   2186     -.56          43      *  229  4500  1  11      7   2671     -.60            39   *
*  183  4850  1  08      0    872     -.56          10      *  188  1600  1  08      4   2413     -.60      C     13   *
*                                                           *                                                               *
********************************************************************************************************************************
```

Figure 3-8. Priority Profile Defect List (Chord Offset) Showing 100 Largest Profile Exceptions in Decreasing Order of Magnitude

```
                    MOST SEVERE EXCEPTIONS - TRACK SEGMENT SUMMARY
                                 LOC X06 - LOC X20

                              BASED ON SEVERITY OF INDEX

  MP      FEET      TRK/LOC      MILE     FEET       INDEX    SLOPE     MEAN       VAR      PAGE

  213     3800      1   10         0      2639       2342      259     -.002     .0330      29
  213     3800      1   10         0      2639       2273      253      .009     .0320      29
  213      900      1   09        16      2607       2273      243     -.003     .0342      28
  164     1700      1   06         2      3954       2232      253     -.054     .0293       2
  213     5150      1   10         0      3958       2203      217      .002     .0297      30
  184     1300      1   08         0      2639       2142      224     -.021     .0295      10
  206     4350      1   09        10      1299       2122      222     -.031     .0279      23
  213     5150      1   10         0      3958       2097      217     -.008     .0264      30
  213      900      1   09        16      2607       2073      228     -.002     .0277      28
  214     1000      1   10         0      5278       2066      226      .001     .0259      30
  207     1800      1   09        10      3938       2060      197     -.032     .0283      23
  229     4450      1   11         7      2625       2034      214     -.010     .0271      39
  250     2500      1   14         5      1309       2018      209     -.006     .0270      52
  280      250      1   99         7      3944       2013      202     -.017     .0276      70
  191     4100      1   08         1      3956       2009      178      .005     .0264      14
  213     2500      1   10         0      1319       1984      216     -.010     .0252      29
  249     3850      1   14         4      2631       1973      195      .013     .0268      51
  255     4900      1   15         2      5274       1954      195     -.025     .0242      55
  195     1600      1   08         5      1309       1946      190      .023     .0235      16
  253     5200      1   15         0      5278       1945      188     -.049     .0229      54
  214     1000      1   10         0      5278       1944      213     -.001     .0244      30
  253     2550      1   15         0      2639       1937      191     -.031     .0252      54
  217     2550      1   10         4      1311       1929      150     -.005     .0256      32
  183     5300      1   08         0      1319       1925      184     -.004     .0244      10
  229     4450      1   11         7      2625       1924      188     -.016     .0275      39
  206     1700      1   09         9      3940       1916      186     -.010     .0246      22
  212     3450      1   09        15      5248       1915      212     -.002     .0232      27
  212     2150      1   09        15      3928       1909      183      .001     .0233      27
  184     3950      1   08         0      5278       1901      168     -.011     .0245      11
  216     3750      1   10         3      2633       1900      188     -.004     .0231      31
  212     2150      1   09        15      3928       1878      175     -.007     .0234      27
  250     2500      1   14         5      1309       1876      158      .033     .0211      52
  230     1850      1   11         7      5264       1872      180     -.009     .0236      39
  195     2900      1   08         5      2629       1867      168      .020     .0219      16
  255     4900      1   15         2      5274       1862      181     -.012     .0227      55
  230      550      1   11         7      3944       1842      160     -.007     .0231      39
  245     2450      1   14         0      1319       1841      149      .001     .0211      49
  229     1850      1   11         6      5266       1841      178     -.019     .0223      38
  230      550      1   11         7      3944       1840      193     -.011     .0226      39
  259     2850      1   15         6      2627       1838      171     -.031     .0212      58
  272     1200      1   17         1      2637       1830      202     -.001     .0221      66
  249     5150      1   14         4      3950       1818      171     -.002     .0215      51
  192      250      1   08         1      5276       1818      142      .019     .0210      14
  206     1700      1   09         9      3940       1816      170     -.004     .0214      22
  164      400      1   06         2      2635       1810      178     -.047     .0181       1
  209     1800      1   09        12      3934       1809      158     -.015     .0217      25
  229      500      1   11         6      3946       1793      177      .000     .0211      38
  200     4250      1   09         4      1311       1792      181      .005     .0203      20
  249     5150      1   14         4      3950       1791      142      .044     .0176      51
  207      500      1   09        10      2619       1791      184     -.019     .0204      23
```

Figure 3-9. Priority Profile Defect List (Track Segment Summary - Index). A Similar List Can Be Prepared for Decreasing Values of the "Slope" Index Number.

```
   PROFILE FVALUATION                    ACQUISITION  41009-1W1              PROCESSED  12/20/74                       PAGE   2
LOC X06                      MP161.8-MP170.5       STANDARDS (INCHES)  -.375         -.500*        -.625**       -.750***      -.875****

   TRACK NUMRER : 1    LOCATION NUMRER : 06

                                           - - EXCEPTIONS - -                   SOUTH   - - SEGMENT SUMMARY ( 1320 FEET)    -  NORTH
        MP   FEFT   MILE FEET    SOUTH         NORTH      DIST FACT        INDEX  SLOPES  MEAN     VAR          INDFX  SLOPES  MEAN      VAR

    *   164   800    2  3036                  -.52*      77    C
    *   164   850    2  3094                  -.38       58    C
    *   164   900    2  3133                  -.58*      39   GC
    *   164  1050    2  3304                  -.41             C
    *   164  1100    2  3345                  -.39       41    C
    *   164  1150    2  3370                  -.42       24    C
    *   164  1150    2  3387                  -.46       17    C
    *   164  1200    2  3461                  -.69**     75    C
    *   164  1300    2  3558                  -.40       97    C
    *   164  1350    2  3599     -.42                    41    C
    *   164  1600    2  3855                  -.50            G
    *   164  1700    2  3954                                              1614    147   -.034   .0152        2233    253   -.054   .0293

    *   164  3000    2  5259                  -.43             C
    *   164  3050    2  5274                                              1218     80   -.019   .0097        1428    107   -.024   .0127

    *   164  3700    3   644                  -.49
    *   164  4000    3   951                  -.38
    *   164  4050    3  1031                  -.42       80
    *   164  4100    3  1055     -.39                    24
    *   164  4350    3  1313                                              1397    107   -.016   .0121        1468    120   -.025   .0142

    *   164  4400    3  1357                  -.38
    *   164  4550    3  1500                  -.47
    *   164  4600    3  1565                  -.41       65
    *   164  4900    3  1877                  -.41
    *   165   400    3  2633                                              1410    107   -.026   .0120        1538    116   -.051   .0135

    *   165   750    3  2988     -.54*                        G
    *   165   900    3  3162     -.45
    *   165  1150    3  3397                  -.59*            C
    *   165  1700    3  3952                                              1422    127   -.023   .0137        1469    128   -.030   .0132

    *   165  2000    3  4259                  -.39
    *   165  2050    3  4296                  -.43       36
    *   165  2450    3  4682                  -.38             C
    *   165  2850    3  5096     -.55*                        G
    *   165  2900    3  5173     -.38                    77
    *   165  3000    3  5272                                              1554    122   -.029   .0146        1672    134   -.033   .0168

    *   165  3050    4    48     -.47
    *   165  4100    4  1063     -.38
```

Figure 3-10. Detailed Profile Exception Report

```
*****************************************  LOCATION SUMMARY :  LOC X06 - LOC X20  ****************************************
*                                                         I                                                                *
*                                                         I                                                                *
*                                                         I   AVG       AVG          TOTAL NUMBER OF EXCEPTIONS             *
*                      LOCATION NAME                      I  INDEX     SLOPES            ABOVE THRESHOLDS :  *               *
*                                                         I PER SEG   PER SEG      1        2        3        4        5    *
*                                                         I                                                                *
*    LOC X17                                              I   3047      271        41        6        0        1        0    *
*    LOC X09                                              I   2989      264         4        0        0        0        0    *
*    LOC X08                                              I   2960      216        51       12        2        1        0    *
*    LOC X15                                              I   2950      240       151       27        3        1        0    *
*    LOC X14                                              I   2921      224        93       15        0        0        0    *
*    LOC X10                                              I   2915      232       130       20        1        0        0    *
*    LOC X08                                              I   2821      219        92       14        2        0        0    *
*    LOC X09                                              I   2810      218       207       40       11        1        0    *
*    LOC X06                                              I   2795      211       112       10        1        0        0    *
*    LOC X13                                              I   2728      205        42        5        1        0        0    *
*    LOC X11                                              I   2628      198       135       40        5        2        0    *
*    LOC X18                                              I   2626      176        59        7        0        0        0    *
*    LOC X99                                              I   2502      179        74       15        4        0        0    *
*    LOC X12                                              I   2472      168        66       16        3        0        0    *
*    LOC X07                                              I   2382      136        42        8        2        0        0    *
*    LOC X16                                              I   2370      150        59       11        2        0        0    *
*    LOC X20                                              I   2275      138        58       10        2        0        0    *
*    LOC X19                                              I   2014       75        10        3        1        0        0    *
*                                                         I      0        0         0        0        0        0        0    *
*                                                         I                                                                *
****************************************************************************************************************************

  *  -  EXCEPTION THRESHOLDS MAY VARY FROM LOCATION TO LOCATION
```

Figure 3-11. Profile Exception Location Summary Report Ranking Locations by Magnitude of the Profile Index Value

The Profile Track Segment Summary Report (Figure 3-12) provides a more detailed Profile Exception Track Segment Summary. Track segments within each location are analyzed for severity of the index value. As with the Location Summary, the purpose of this section is to provide useful information for maintenance planning of larger sections of track.

Like the Gage Report, the Profile Report also displays relative track quality by means of data histograms. These graphical displays indicate quality by illustrating the distribution of profile measurements. The report provides one chord offset data histogram for each reference location derived from data combined from the two rails.

3.4 CURVATURE REPORT

The Curve Evaluation Program produces a report based on curve definition and FRA track safety requirements. It contains data similar to gage and profile reports for crisis maintenance, detailed exception analysis, and maintenance planning.

The Curve Evaluation Program generates four exception lists, with each one ordering the one hundred largest measurement exceptions in decreasing order of magnitude. The four measurements used are curvature, crosslevel, warp, and rock and roll (Figure 3-13).

The main curvature exception report gives a geographically ordered accounting of curves and exceptions as they are encountered during data collection. Curves are broken down into spirals and bodies (constant curvature). Exceptions are noted for crosslevel curvature mismatch, reverse crosslevel, curvature, crosslevel, warp, and rock and roll (Figure 3-14).

The detailed curvature exception list is divided into two sections: curve description and exception analysis (Figure 3-15). The detailed curve description completely defines each curve by location and magnitude, and gives point of spiral, spiral to curve, curve to spiral, and point of tangent, together with geographic location and overall length information. Also incorporated into the curve

```
******************** TRACK SEGMENT SUMMARY FOR LOCATION : LOC X06                     MP161.8-MP170.5        ********************
*                                       I                                                                                      *
*     TRACK SEGMENT =  1320 FEET        I EXCEPTION THRESHOLD LEVELS : 1 =  .375,  2 =  .500,  3 =  .625,  4 =  .750,  5 =  .875 *
*                                       I                                                                                      *
*                                       I                 NUMBER OF EXCEPTIONS    I                  NUMBER OF EXCEPTIONS      *
*           SEGMENT LOCATION      DATA  I   SOUTH    SOUTH  ABOVE THRESHOLDS :    I    NORTH    NORTH  ABOVE THRESHOLDS :      *
*       MP    FEET MILE   FEET  IN SEG  I   INDEX   SLOPES   1   2   3   4   5    I    INDEX   SLOPES   1   2   3   4   5      *
*                                       I                                         I                                            *
*      164    1700    2   3954     100  I    1614      147   2                    I     2233      253  11   2   1             *
*      164     400    2   2635     100  I    1529      130   2                    I     1811      178   3                     *
*      169    1700    7   3944     100  I    1447      107   4                    I     1733      173   2                     *
*      166     400    4   2631     100  I    1463      129                        I     1732      163   8                     *
*      166    4350    5   1309     100  I    1724      175   5   1                I     1584      141   2                     *
*      166    1750    4   3950     100  I    1312       98   1                    I     1718      161   6                     *
*      168    1300    6   3946     100  I    1563      135                        I     1702      161   2                     *
*      165    3000    3   5272     100  I    1554      122   1   1                I     1672      134   3                     *
*      169    4300    8   1303     100  I    1577      120   2                    I     1649      123   3                     *
*      169     350    7   2625     100  I    1452      110   4                    I     1635      142   3                     *
*      167    5650    6   2627     100  I    1226       94                        I     1606      145   4                     *
*      165     400    3   2633     100  I    1410      107                        I     1538      116   4                     *
*      169    3000    7   5264     100  I    1532      124   2                    I     1471      103   4                     *
*      166    3050    4   5270     100  I    1421      115   1                    I     1511      130                         *
*      162    4250    1   1317     100  I    1121       67                        I     1506      123   2                     *
*      167     400    5   2629     100  I    1452       96   2                    I     1499      109   3                     *
*      165    4350    4   1311     100  I    1491      126   4                    I     1211       81                         *
*      165    1700    3   3952     100  I    1422      127   1   1                I     1469      128       1                 *
*      164    4350    3   1313     100  I    1397      107   1                    I     1468      120   3                     *
*      167    1700    5   3948     100  I    1328       89   1                    I     1467      100   3                     *
*      161    4350    0   1319      96  I    1431      121   3                    I     1216       81                         *
*      164    3050    2   5274     100  I    1218       80                        I     1428      107   1                     *
*      168    3950    7   1305     100  I    1278       79       1                I     1428      106   1                     *
*      162    1600    0   3958     100  I    1427       84   1                    I     1409       92                         *
*      163    3000    1   5276     100  I    1338      109   2                    I     1360      104   1                     *
*      167    4350    6   1307     100  I    1347      105                        I     1203       81                         *
*      163    1700    1   3956     100  I    1056       41                        I     1342       62                         *
*      168    2600    6   5266     100  I    1162       78                        I     1315       77                         *
*      162    2950    0   5278     100  I    1117       58                        I     1314       89                         *
*      163     400    1   2637     100  I    1273       71                        I     1304       76                         *
*      167    3000    5   5268     100  I    1067       65                        I     1303       90   1                     *
*      170     350    8   2623     100  I    1194       83                        I     1260       80                         *
*      170    1650    8   3942     100  I    1111       59   1   1                I     1191       82       1                 *
*      163    4350    2   1315     100  I    1076       68                        I     1160       73       1                 *
*      170    3000    8   5262     100  I    1019       48   1                    I     1144       61                         *
*      162     300    0   2639      90  I     825       31                        I     1068       52   1                     *
* *    170    3300    9    272     100  I     235        6                        I      283       15                         *
*                                       I                                         I                                            *
********************************************************************************************************************************

      *  =  SEGMENT IS LESS THAN FULL TRACK SEGMENT
```

Figure 3-12. Profile Exception Track Segment Summary Report. This Report Ranks Quarter-Mile Segments Within a Location by Magnitude of the Profile Index Value

```
******************************************** LARGEST  CURVATURE EXCEPTIONS ************************************************
*                                                 LOC X    - LOC X                                                         *
*                                              (BASED UPON MAXIMUM VALUE)                                                  *
*   LOC    MP  FEET   MILE  FEET  CLASS   MAX   O/A LEN   PAGE   *   LOC    MP  FEET   MILE  FEET  CLASS    MAX   O/A LEN   PAGE  *
*                                                                *                                                         *
*                                                                *                                                         *
*    28   361 -4152      8  2608    5    -1.25     19       7    *    28   361 -4949      8  3406    5    -1.25      2        8   *
*    28   361 -4935      8  3391    5    -1.23      4       7    *    28   361 -4915      8  3372    5    -1.04      2        7   *
*    28   361 -4802      8  3259    5     1.03      2       7    *    28   360  -911      8  4653    5    -1.02      2        8   *
*    28   361 -3678      8  2135    5    -1.01      9       7    *    28   361 -4125      8  2582    5    -1.01      2        7   *
*    28   360  -191      8  3933    5     -.98      2       8    *    28   360  -435      8  4177    5     -.94      2        8   *
*    28   368 -4009      1  2966    5     -.92      4       2    *    28   361 -4210      8  2666    5      .88      7        7   *
*    28   361 -4649      8  3097    5     -.88      2       7    *    28   361 -4118      8  2575    5     -.87      7        7   *
*    28   361 -4193      8  2650    5      .86      2       7    *    28   361 -4942      8  3399    5     -.84      2        7   *
*    28   361 -3688      8  2144    5     -.84      2       7    *    28   364 -2506      5  1000    5     -.80      4        5   *
*    28   360  -251      8  3993    5      .80      2       8    *    28   364 -2511      5  1005    5     -.78      2        5   *
*    28   361 -4966      8  3423    5     -.78      2       8    *    28   368 -3995      1  2951    5     -.78      2        2   *
*    28   361 -3664      8  2120    5     -.78      2       7    *    28   361 -5123      8  3580    5     -.78      2        8   *
*    28   360  -319      8  4061    5     -.77      2       8    *    28   361 -4959      8  3416    5     -.76      2        8   *
*    28   364 -2492      5   986    5     -.76      2       5    *     0     0     0      0     0    0     0.00      0        0   *
***************************************************************************************************************************
```

Figure 3-13. Curvature Priority Defect List. The Same Type of List is Generated for Crosslevel, Warp, and Rock and Roll Exceptions

```
   CURVATURE ANALYSIS                                  ACQUISITION     31102-1S2            PROCESSED  03/04/74                PAGE    8
TEST SECTION 2
   LOCATION NUMBER : 17 TO 17                            FOR CURVATURE--POSITIVE VALUE=CENTER OF CURVATURE TO  WEST
                                                                        NEGATIVE VALUE=CENTER OF CURVATURE TO  EAST
                                                        FOR CROSSLEVEL--POSITIVE VALUE= EAST RAIL HIGH
    TRACK NUMBER : 1                                                    NEGATIVE VALUE= WEST RAIL HIGH

   FRA CLASS : 2                                           I-------------------------THRESHOLDS-------------------------I
                                              NON-SPIRAL -     25 FT    .250   .500          2.000 2.000             .500    -
   TIMETABLE SPEED :  25 MPH                      SPIRAL -     25 FT    .250   .500          1.500 1.750             .500    -

                 I-------------CURVES----------------------I-----------------------EXCEPTIONS-----------------------------I
END OF EVENT     I                                    MAX/ I   X-LEVEL
 MP DISTANCE     I              AVG.       AVG.       AVG. I  CURVATURE                                                   I   END OF EVENT
                 I  LENGTH     CURV.      ELEV.      OPER. I  MISMATCH  REV.  CURV.    MAX  X-LEV  WARP     O/A    R AND R I   LOC. DISTANCE
  MP       FEET  I   (FT)      (DEG)      (IN.)      SPEED I DIST  SIZE X-LEV  (DEG)  SPEED  (IN.) (31.0)    LEN     (19.5) I
                 I                                         I                                                              I   MILE      FEET
* 198      2359 I*  139                                    I                                                              I    0       14
* 198      2359 I* ********SPIRAL TO CURVE********         I                                                              I    0       14
* 198      2363 I*                                         I                    .57     42                    2           I    0       19
* 198      2368 I*    10       2.48       -.22      42/ 43I                                                              I    0       24
* 198      2368 I* ********CURVE TO SPIRAL********         I            .30                                                I    0       24
* 198      2402 I*                                         I                   1.50     39                   28           I    0       58
* 198      2441 I*   72                                    I                                                              I    0       97
* 198      2441 I* ********POINT OF TANGENT*******         I           -.50                                                I    0       97
                I                                          I                                                              I
                I                                          I                                                              I
* 198      2450 I                                          I                  -1.40                            7           I    0      106
* 198      2455 I* ********POINT OF SPIRAL********         I                                                              I    0      111
* 198      2530 I*                                         I                  -1.24     38                   45           I    0      186
* 198      2535 I*                                         I                   -.57                           2           I    0      191
* 198      2559 I*                                         I                    .75     50                    7           I    0      215
* 198      2562 I   CHANGE TRACK FROM 1 TO 2               I                                                              I    0      217
                I                                          I                                                              I
* 198      2581 I*                                         I                   1.12     46                   16           I    0      237
* 198      2581 I*  124                                    I                                                              I    0      237
* 198      2581 I* ********SPIRAL TO CURVE********         I                                                              I    0      237
* 198      2593 I*                                         I                   -.65     36                    2           I    0      249
* 198      2593 I*    12      -2.81       -.10      36/ 39I                                                              I    0      249
* 198      2593 I* ********CURVE TO SPIRAL********         I                                                              I    0      249
* 198      2617 I*                                         I                  -1.30     35                   21           I    0      273
* 198      2629 I*                                         I                   -.59     44                    2           I    0      285
* 198      2639 I*                                         I                   -.53                           2           I    0      295
* 198      2692 I*                                         I                   1.18     84                   41           I    0      348
* 198      2697 I*                                         I                    .59                           2           I    0      353
* 198      2731 I*                                         I                                                    -6  7-5   I    0      387
* 198      2745 I*                                         I                                                    -5  7-9   I    0      401
* 198      2757 I*  144                                    I                                                              I    0      413
* 198      2757 I* ********POINT OF TANGENT*******         I                                                              I    0      413
                I                                          I                                                              I
                I                                          I                                                              I
```

Figure 3-14. Detailed Curve Evaluation Report

```
CURVATURE ANALYSIS                    ACQUISITION     31102-152           PROCESSED   11/20/73                  PAGE    3

LOCATION NUMBER : 16 TO 17                 FOR CURVATURE--POSITIVE VALUE=CENTER OF CURVATURE TO  WEST
                                                          NEGATIVE VALUE=CENTER OF CURVATURE TO  EAST
                                          FOR CROSSLEVEL--POSITIVE VALUE= EAST RAIL HIGH
 TRACK NUMBER : 1                                         NEGATIVE VALUE= WEST RAIL HIGH

FRA CLASS : 2                             I------------------------THRESHOLDS------------------------I
                                NON-SPIRAL -    25 FT     .250   .500       2.000 2.000           .500   -
TIMETABLE SPEED :  25 MPH          SPIRAL -    25 FT     .250   .500       1.500 1.750           .500   -

                   I--------------CURVES--------------I------------------------EXCEPTIONS------------------------I
 END OF EVENT      I                          LIM./I  X-LEVEL                                                    I   END OF EVENT
 MP DISTANCE       I           AVG.     AVG.   AVG. I  CURVATURE         CURV.                                   I   LOC. DISTANCE
                   I  LENGTH   CURV.    ELEV.  OPER.I  MISMATCH   REV.   (DEG-    MAX   X-LEV  WARP    O/A   R AND R I
   MP      FEET    I   (FT)  (DEG-MIN)  (IN.)  SPEED I DIST  SIZE X-LEV  MIN)   SPEED (IN.) (31.0)  LEN   (19.5) I   MILE     FEET
                   I                                 I                                                           I
*  184      677 I* ********POINT OF SPIRAL******** I                                                           I     0      3884
*  184     1075 I*   398                              I                                                           I     0      4282
*  184     1075 I* ********SPIRAL TO CURVE******** I                                                           I     0      4282
*  184     1535 I*   459        2.83      4.59   58/ 61I                                                           I     0      4741
*  184     1535 I* ********CURVE TO SPIRAL******** I                                                           I     0      4741
*  184     1909 I*   375                              I                                                           I     0      5116
*  184     1909 I* ********COMPOUND CURVE******** I                                                           I     0      5116
*  184     1909 I* ********SPIRAL TO CURVE******** I  126   1.84                                                I     0      5116
*  184     2499 I*   590         .73      1.70   81/ 97I                                                           I     1       426
*  184     2499 I* ********COMPOUND CURVE******** I                                                           I     1       426
*  184     2499 I* ********CURVE TO SPIRAL******** I                                                           I     1       426
*  184     2663 I*   164                              I                                                           I     1       590
*  184     2663 I* ********SPIRAL TO CURVE******** I                                                           I     1       590
*  184     2922 I*   259        1.59      3.29   68/ 74I                                                           I     1       849
*  184     2922 I* ********CURVE TO SPIRAL******** I                                                           I     1       849
*  184     3166 I*   244                              I                                                           I     1      1093
*  184     3166 I* ********POINT OF TANGENT******** I                                                           I     1      1093
```

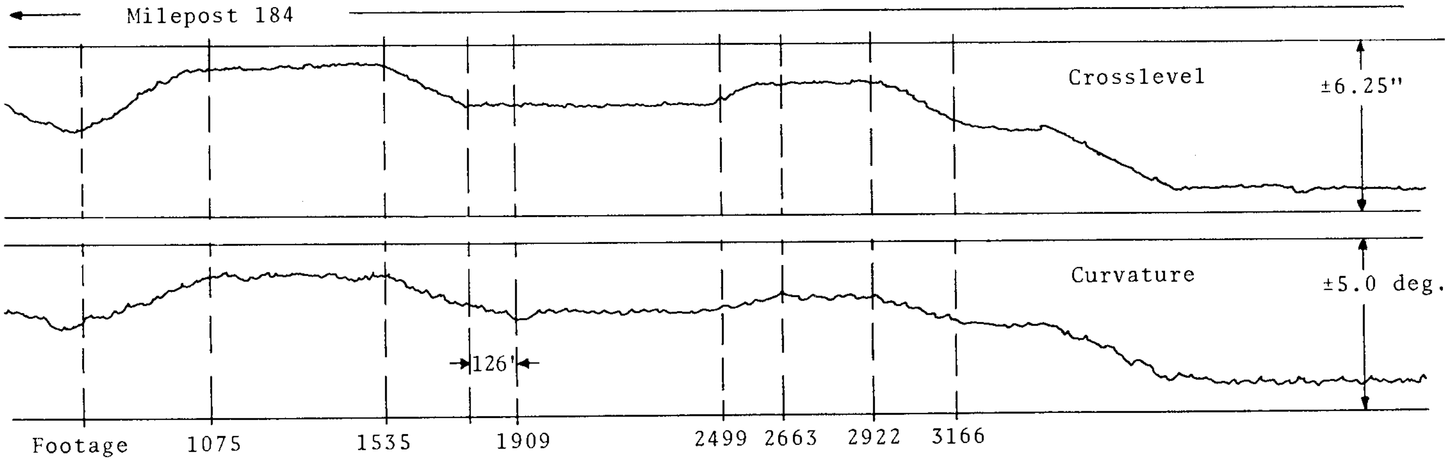


Figure 3-15. Relationship of Detailed Curve Information and the On-Line Strip Chart Display

display are statistics showing average superelevation, average curvature, and corresponding limiting and average speed information as defined by the following FRA Track Safety Standards equation which correlates curvature, elevation, and speed.

$$V_{max} = \sqrt{\frac{E + 3}{0.0007d}}$$

where E = elevation

d = degree of curvature

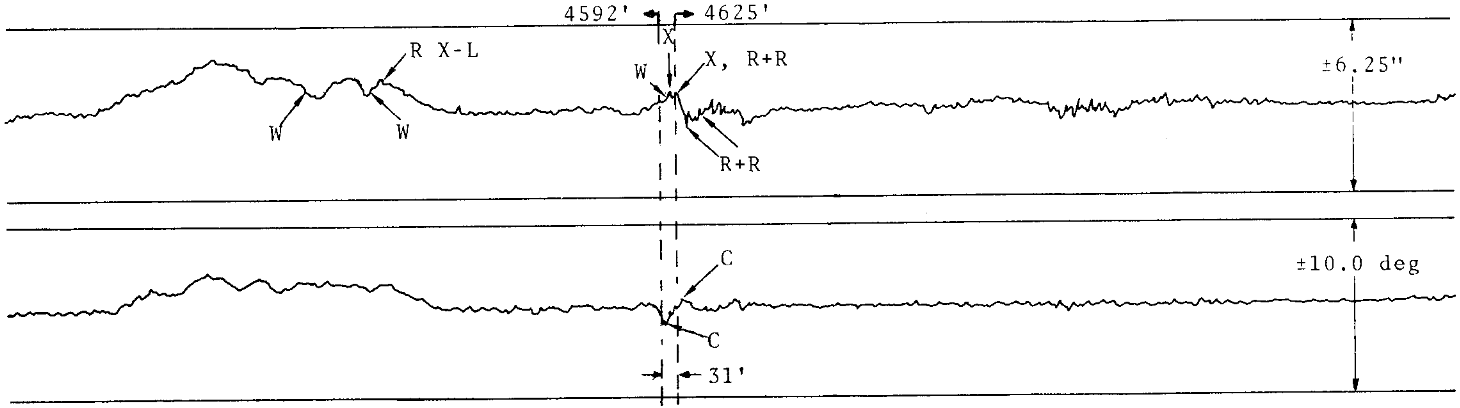
V_{max} = maximum allowable speed

The detailed curvature exception list defines six types of exceptions in terms of location, magnitude, and overall length (Figure 3-16). Crosslevel data are analyzed for possible crosslevel exceptions in tangent, spiral, or curve body areas. Warp is defined as the difference in measured crosslevel over a specified "warp" distance. Each warp condition is checked for a possible exception. Also defined is a reverse crosslevel exception condition (known as "undershoot" or "overshoot" at the start or end of a spiral). Another type of exception which is defined is rock and roll. This condition is determined by a difference in measured crosslevel over a specified distance and by a change in slope from one difference to the next.

Curvature exceptions are defined as those areas where curvature deviates from the average by more than a given threshold. The exceptions are described in terms of magnitude and overall length.

The last type of exception compares crosslevel and curvature data to define potentially dangerous areas of superelevation-curvature mismatch. This anomaly, in which curvature occurs before superelevation, is defined by length-distance between the start of curvature and the start of superelevation, as well as by magnitude-superelevation required for the measured amount of curvature.

```
CURVATURE ANALYSIS              ACQUISITION      40510-1N1              PROCESSED   05/25/74                PAGE    2

LOCATION NUMBER :   3 TO   3          FOR CURVATURE--POSITIVE VALUE=CENTER OF CURVATURE TO  EAST
                                                     NEGATIVE VALUE=CENTER OF CURVATURE TO  WEST
                                     FOR CROSSLEVEL--POSITIVE VALUE= EAST RAIL HIGH
 TRACK NUMBER : 2                                    NEGATIVE VALUE= WEST RAIL HIGH

FRA CLASSES NOT USED                 I--------------------------THRESHOLDS--------------------------I
                        NON-SPIRAL -      50 FT    .250    .750          .750  .750            .500   -
                            SPIRAL -      50 FT    .250    .750          .750  .750            .500   -

                 I---------------CURVES---------------I--------------------------EXCEPTIONS--------------------------I
END OF EVENT I                                  LIM./I   X-LEVEL                                                      I    END OF EVENT
MP DISTANCE I               AVG.      AVG.      AVG. I  CURVATURE            CURV.                                    I    LOC. DISTANCE
            I     LENGTH    CURV.     ELEV.     OPER.I  MISMATCH     REV.   (DEG-    MAX   X-LEV  WARP    O/A    R AND P I
 MP    FEET I      (FT)   (DEG-MIN)   (IN.)    SPEED I DIST  SIZE  X-LEV     MIN)  SPEED  (IN.) (19.5)  LEN     (39.0) I    MILE     FEET
            I                                        I                                                                I
  9    3586 I*                                       I                                         .77    2               I     3       3351
  9    3772 I*                                       I                                        -.82    7               I     3       3537
  9    3794 I*   512      3.25       2.44    42/ 43I                                                               I     3       3559
  9    3794 I* ********CURVE TO SPIRAL********       I             -.39                                               I     3       3559
  9    4048 I*   254                                 I                                                                I     3       3812
  9    4048 I* *********POINT OF TANGENT*********    I                                                                I     3       3812
            I                                        I                                                                I
            I                                        I                                                                I
  9    4594 I                                        I                                                       5-0-5    I     3       4358
  9    4596 I                                        I                                        -.75    2               I     3       4371
  9    4603 I                                        I                    -1.25                      16               I     3       4373
  9    4625 I                                        I                                   .80           2               I     3       4390
  9    4647 I                                        I                                  1.25          12               I     3       4412
  9    4652 I                                        I                      .92                        4               I     3       4416
```



R X-L = Reverse Crosslevel; W = Warp; X = Crosslevel; C = Curvature; R+R = Rock and Roll

Figure 3-16. Relationship of Detailed Exception Information and the On-Line Strip Chart Display

Summary information for curves is used in determining track quality and conditions of curves. Each entry into the Curvature Summary Report (Figure 3-17) represents each curve as defined in the detailed report. For each curve, all of the curve quantifying information is transferred from the detailed report along with information about the central angle traversed through the curve. An exception tally for each type of exception is also displayed for each curve.

3.5 INTEGRATED EXCEPTION REPORT

The Integrated Exception Program (INGRATE) incorporates data from different track geometry parameters into a single data reduction exception report. Whereas the three previously mentioned programs analyze individual parameters, INGRATE analyzes multiple track geometry parameters simultaneously and generates a multipurpose report. It contains data for detailed exception analysis and maintenance planning.

The INGRATE program uses the same analytic techniques for exception detection as are used in the Gage, Profile, and Curvature Programs. The parameters analyzed for anomalies are gage, profile, curvature, crosslevel, warp, and rock and roll. The Detailed Integrated Track Geometry Exception Report (Figure 3-18) displays exceptions for each parameter, with the capability of displaying one or more exceptions simultaneously if they occur at the same location on the track. Each exception is defined in terms of geographic location, magnitude, and overall length. The primary importance of this report is that the detailed information contained in the three preceding reports are combined to allow the user to simultaneously observe anomalies for multiple track geometry parameters.

The One-Mile Exception Summary Report displays the number of exception samples for each parameter processed. Two columns are provided for each parameter. The first contains the number of exception samples per mile and the second presents the count of exception samples using a different exception threshold. Thus, in the summary

```
                                                        CURVE SUMMARY
   TRACK NUMBER : 1                                     LOCATION : 16                                   FRA TRACK  CLASS : 2

                                 FOR CURVATURE--POSITIVE VALUE=CENTER OF CURVATURE TO WEST
                                                NEGATIVE VALUE=CENTER OF CURVATURE TO EAST
                                FOR CROSSLEVEL--POSITIVE VALUE= EAST RAIL HIGH
                                                NEGATIVE VALUE= WEST RAIL HIGH

------GEOGRAPHY-----   ---------------------SUMMARY---------------------   ---------------EXECEPTION TALLY-------------
                     I CURVE  OVER    AVG.    AVG.   AVG.  LIMITING  CENT.  I  CURV.  XLEV.  WRAP   PNR     MIS-  REVERSE  I  PAGE
 START       END     I BODY   ALL     CURV.   ELEV   SPEED  SPEED    ANGLE  I                (19.5) (39.0)  MATCH  XLEVEL   I
(MP) (FT)  (MP) (FT) I (FT)   (FT)    (DEG)   (IN)   (MPH)  (MPH)  (DEG-MIN)I                                               I
                     I                                                      I                                               I
                     I                                                      I                                               I
-83  5029  184  590  I   51    872    3.16    5.21    60      58    16    0 I   0      0      0      0      0      0       I    1
                     I                                                      I                                               I
                     I                                                      I                                               I
-84   677            I  459           2.83    4.59    61      58            I                                               I
 COMPOUND            I  590            .73    1.70    97      81            I                                               I
 COMPOUND  184  3166 I  253   2490    1.59    3.29    74      68    37   50 I   0      0      0      0      1      0       I    1
                     I                                                      I                                               I
                     I                                                      I                                               I
-84  3441  184  5160 I  853   1718   -3.42   -4.65    56      53    46   10 I   0      0      0      0      0      1       I    2
                     I                                                      I                                               I
                     I                                                      I                                               I
-85  1670  185  2864 I  288   1194   -3.69   -4.65    53      50    29   50 I   0      0      0      0      2      0       I    2
                     I                                                      I                                               I
                     I                                                      I                                               I
-86  1513  186  2615 I  254   1102    3.13    5.01    60      56    22   40 I   1      0      0      0      0      1       I    2
                     I                                                      I                                               I
                     I                                                      I                                               I
-86  4555  187  1274 I 1380   1776   -1.16   -1.79    76      63    19    0 I   1      0      0      0      2      0       I    3
                     I                                                      I                                               I
                     I                                                      I                                               I
-87  1460  187  2284 I  329    824    1.63    3.88    77      73    10   25 I   0      0      0      0      1      0       I    3
                     I                                                      I                                               I
                     I                                                      I                                               I
-87  4705  188   843 I  930   1575   -2.26   -3.36    62      59    29   45 I   0      0      0      0      1      0       I    3
                     I                                                      I                                               I
                     I                                                      I                                               I
-88  4611  189    83 I  184    802   -2.34   -3.30    61      58    13   20 I   0      0      0      0      1      0       I    3
                     I                                                      I                                               I
                     I                                                      I                                               I
-89  3504  189  4676 I  639   1173    1.41    3.79    82      73    13   55 I   0      0      0      0      1      0       I    4
                     I                                                      I                                               I
                     I                                                      I                                               I
-90  1692  190  2484 I  556    793     .71    2.02    99      84     5   15 I   0      0      0      0      1      0       I    4
                     I                                                      I                                               I
                     I                                                      I                                               I
-90  2953  190  3545 I   97    592   -1.60   -2.40    69      65     6   30 I   0      0      0      0      2      0       I    4
                     I                                                      I                                               I
                     I                                                      I                                               I
-90  4787  191   413 I  536    893   -1.17   -1.84    76      64     9    5 I   0      0      0      0      2      0       I    5
                     I                                                      I                                               I
                     I                                                      I                                               I
```

Figure 3-17. Curve Summary Report. Report Displays a Summary of Every Curve Encountered During a Test Run

```
 INTEGRATED TRACK GEOMETRY EXCEPTION REPORT        ACQUISITION  10/13/74    PROCESSED                             PAGE   8
 LOC X60 MILEPOST 632.0 - 625.2

 LOCATION : 60                                     TRACK NUMBER :  2                                  CLASS 2 THRESHOLDS

THRESHOLDS IN INCHES -->  PROFILE ( 14.5 )   CURVATURE      GAGE           X LEVEL      WARP (31.0FT)   R+R (19.5FT)     FACT
                          ( .500)            ( 2.000)      (57.25)        (1.000)        (1.500)        ( .500)
                          NORTH    SOUTH     MAX   O/A     MAX     O/A    MAX   O/A     MAX      O/A
   MP DIST   MILE  FEET   RAIL     RAIL      DEG   DIST    EXC     DIST   EXC   DIST    EXC      DIST    EXCEPTION

* 626 -2528   6    2081   -.52                                                                                            C
* 626 -2666   6    2219                                                                                    -5  6 -6       C
* 626 -2699   6    2252                                    57.36     7                                                    C
* 626 -2740   6    2293                                                                                    -5  7 -7       C
* 626 -2760   6    2313                                                                                  E  6 -7  5       C
* 626 -2803   6    2356   -.55                                                                                            C
* 626 -2895   6    2448                                    57.28    12                                                    C
* 626 -3011   6    2564                                    57.26     5                                                    C
* 626 -3132   6    2685                                    57.38    41                                                    C
* 626 -3137   6    2690                                                                                    -6  7 -6*      C
* 626 -3154   6    2707                                                                                  E  7 -6  8*      C
* 626 -3156   6    2709   -.60                                                                                            C
* 626 -3171   6    2724                                                                                  E -6  8 -6*      C
* 626 -3195   6    2748                                                                                     6 -7  6*      C
* 626 -3275   6    2828   -.50                                                                                            C
* 626 -3311   6    2864   -.69                                                                                            C
* 626 -3371   6    2924                                    57.49    12                                                    C
* 626 -3739   6    3292   -.54                                                                                            C
   TRACK CHANGE :TRACK  2 TO TRACK  1

* 626 -3987   6    3540     ----SENSORS UP----
* 626 -4526   6    4079     ----SENSORS DOWN----


* 625  -123   6    4983                                    57.26     2                                                    C
* 625  -280   6    5140            -.50                                                                                   C
* 625  -324   6    5184                                    57.33     2                                                    C
* 625  -503   7      83                                    57.27     2                                                    C
* 625  -585   7     165                                                                                    -5  6 -7       C
* 625  -604   7     184                                                                                  E  6 -7  6*      C
* 625  -626   7     206                                                                                  E -7  6 -6*      C
* 625  -669   7     249            -.50                                                                                   C
* 625 -1274   7     854   -.50                                                                                            C
* 625 -1609   7    1189                                    57.25     2                                                    C
* 625 -2641   7    2221
                            CHANGE TO CLASS  4 THRESHOLDS

                            PROFILE        CURVATURE       GAGE           X LEVEL        WARP          R+R
                            ( .500)        ( 1.000)       (57.00)         ( .750)       ( .750)       ( .500)
```

Figure 3-18. Detailed Integrated Track Geometry Exception Report. This Report Displays Exceptions for Each of Six Different Measurement Parameters.

displayed in Figure 3-19, the first column under Gage shows the number of samples which exceed a 57.00-inch threshold, while the second column shows the number of samples that exceed a less stringent threshold. This allows two different analyses of the same section of track.

3.6 INTEGRATED STANDARDS REPORT

The Integrated Standards Program was developed to analyze track geometry data for exceptions to the track safety standards as defined by the FRA Office of Safety. Parameters are evaluated according to track safety standards in a detailed exception analysis and maintenance planning format. Besides the computer output, the program generates a file of information which can be subsequently used for a graphic display of the data.

This program uses the same set of parameters as the Integrated Exception Program. However, curvature and rock and roll are not analyzed for exceptions (Figure 3-20). Curvature data are used for determining geographic location of track curves. Once the track type (tangent, spiral, curve) has been established, this information is used to determine which set of thresholds is required for the analysis of the data. Profile data are taken from the signal of the inertial profilometer and converted to 62-foot chord information. Warp is evaluated for anomalies for distances between 2-1/2 feet (single sample length) and 62 feet.

As with the other reports, each parameter exception is defined by geographic location, magnitude, and in most cases overall length. The length displayed for a warp exception represents the distance which has produced the maximum anomaly found in a 62-foot window area.

As with the Integrated Exception Program, the Integrated Standards Program generates a one-mile exception summary which displays the number of exception samples for each parameter processed (Figure 3-21). For each parameter, two columns provide the capability to

```
ONE MILE SUMMARY EXCEPTION REPORT                ACQUISITION  10/13/74    PROCESSED                  PAGE   1
DATA FROM MP640 TO MP607                                                                     TRACK NUMBER : 2

                             PROFILE          CURVATURE     GAGE       X LEVEL     WARP       ROCK + ROLL
                       NORTH ' SOUTH
  MILEPOST              RAIL      RAIL                                           (31.0FT)     (19.5FT)
  START END  DIST  CLS EXC  SEV  EXC  SEV     EXC    SEV    EXC  SEV   EXC  SEV   EXC    SEV   EXC    SEV

  640   639  5331   3             1           13            411                                 2
• 639   638  5423   2   3         2                         121                                 6
• 638   637  5077   2   2                                   281
• 637   636  5341   2   1         1            1            184
• 636   635  5350   2                                        82                                 1
• 635   634  5292   2             1                         142
• 634   633  5261   2                                       245                                 1
• 633   632  5314   2   1         1                          29                                 3
• 632   631  4954   2             2                          30                                 1
• 631   630  5167   2             1            1
• 630   629  5160   2   1         1                          59                                 2      1
• 629   628  5599   2   2         1                         203                                 4
• 628   627  5196   2   1         3                          25                                 2
• 627   626  5341   2   1         1                          13         5                      13      2
 TRACK CHANGE :TRACK  2 TO TRACK  1

• 626   625  5307   2  10                                    59                                 9      5
• 625   624  5290   2   2         2                           7                                 4      2
• 624   623  4770   4                                         1                    8
• 623   622  5285   4             1           47                                   5      1     1      1
• 622   621  5309   4             3           36      8       5         1    1     9      5     3      1
• 621   620  5087   4
• 620   619  5401   3   2
```

Figure 3-19. One-Mile Exception Summary Report. Report Displays Per Mile the Number of Exceptions/Severe Exceptions Found for Six Measured Parameters

```
INTEGRATED TRACK GEOMETRY SAFETY STANDARD REPORT     ACQUISITION  41013-1E1   PROCESSED  2/7/75                   PAGE   2
   LOC X60 MILEPOST 632.0 - 625.2

   LOCATION : 60      TRACK NUMBER :  1      CLASS  4 TRACK
                              PROFILE                   ALIGNMENT                GAGE        X LEVEL         WARP          SPEED(MPH) FACT
   THRESHOLDS IN INCHES -->      (2.000)              NOT OPERATIONAL            (57.25)     (1.250)         (1.250)
                          NORTH RAIL    SOUTH RAIL                            MAX     O/A    MAX     O/A    MAX
   MP DIST   MILE   FEET    MAX  O/A      MAX  O/A                            EXC    DIST    EXC    DIST    EXC    LENGTH


* 622 -1300  10     379                                                                    -1,93      2    -2.12  31.4          0       S 0
* 622 -1500  10     596     ----SENSORS DOWN----
* 622 -3000  10    2085                                                    57.44      2                                        18       T
* 622 -5150  10    4224                                                                                -1.36  60.4            39       T
* 622 -5150  10    4257                                                                  1.36      5                           41       T
* 622 -5200  10    4284                                                                  1.98     22                           41       T
* 620  -550  11    4746     CHANGE TO CLASS  3 TRACK

   THRESHOLDS IN INCHES -->         PROFILE                                   GAGE       X-LEVEL         WARP
                                    (2.250)                                  (57.50)     (1.750)         (1.750)

* 619 -3150  13    2212     CHANGE TO CLASS  5 TRACK
                                    PROFILE                                   GAGE       X-LEVEL         WARP
   THRESHOLDS IN INCHES -->         (1.250)                                  (57.00)     (1.000)         (1.000)


* 619 -4200  13    3234                                                                  1,13      2                           57       T
* 619 -4200  13    3246                                                                  1,14      7                           57       T
* 619 -4200  13    3261                                                                  1,25     10                           58       T
   LOCATION CHANGE: LOC X59 MILEPOST  625.2 - 617.4

* 618 -4700   0    1750                                                                                  1.10  60.4            43       T
* 618 -4950   0    1999                                                                 -2,36    191                           41       T 1


* 617 -4750   1    1762                                                    57.14      2                                        18       T


* 616 -3100   2     139                                                    57.26     17                                        43       T
```

Figure 3-20. Integrated Track Geometry Safety Standards Report. Report Displays all Exceptions to FRA Track Safety Standards for Five Measured Parameters

```
ONE MILE SUMMARY EXCEPTION REPORT              ACQUISITION  41013-1E1   PROCESSED  2/7/75                 PAGE   2

DATA FROM MP640 TO MP607
TRACK NUMBER :  1

                                       PROFILE                   ALIGNMENT
                                 NORTH        SOUTH          NOT OPERATIONAL           GAGE        X LEVEL         WARP
    MILEPOST                      RAIL         RAIL          RAIL          RAIL
  START    END    DIST     OPCL   CL1   OPCL   CL1     OPCL   CL1    OPCL   CL1     OPCL   CL1   OPCL   CL1    OPCL    CL1


*  622     621    5309                                                                1           12      1      2       1
*  621     620    5087
*  620     619    5401
*  619     618    5329                                                                             8
*  618     617    5249                                                                            79             1
*  617     616    5280                                                                1
*  616     615    5249                                                                5
*  615     614    4906
*  614     613    5341                                                                                           2
*  613     612    5341                                                                                           1
*  612     611    5191                                                                                           2
*  611     610    5263                                                                             2             2
*  610     609    5092                                                                             6             1
*  609     608    5285                                                                            19             1
*  608     607    5263                                                               15           43             1
*  607     606    5309                                                                                           2
*  606     605    5244
*  605     604    5007
*  604     604    1075
 TOTAL EXCEPTIONS          0      0      0      0                                   22     0     172     1      20       1
```

Figure 3-21. One-Mile Exception Summary Report. Report Lists Per Mile the Number of Operating Class and Class 1 Exceptions for Each of Five Measured Parameters.

look at the number of exception samples per mile for two different sets of thresholds. As an example, it is possible to observe the number of defects according to appropriate track class while at the same time determining how many miles of track need immediate maintenance because of the presence of exceptions exceeding Class 1 standards.

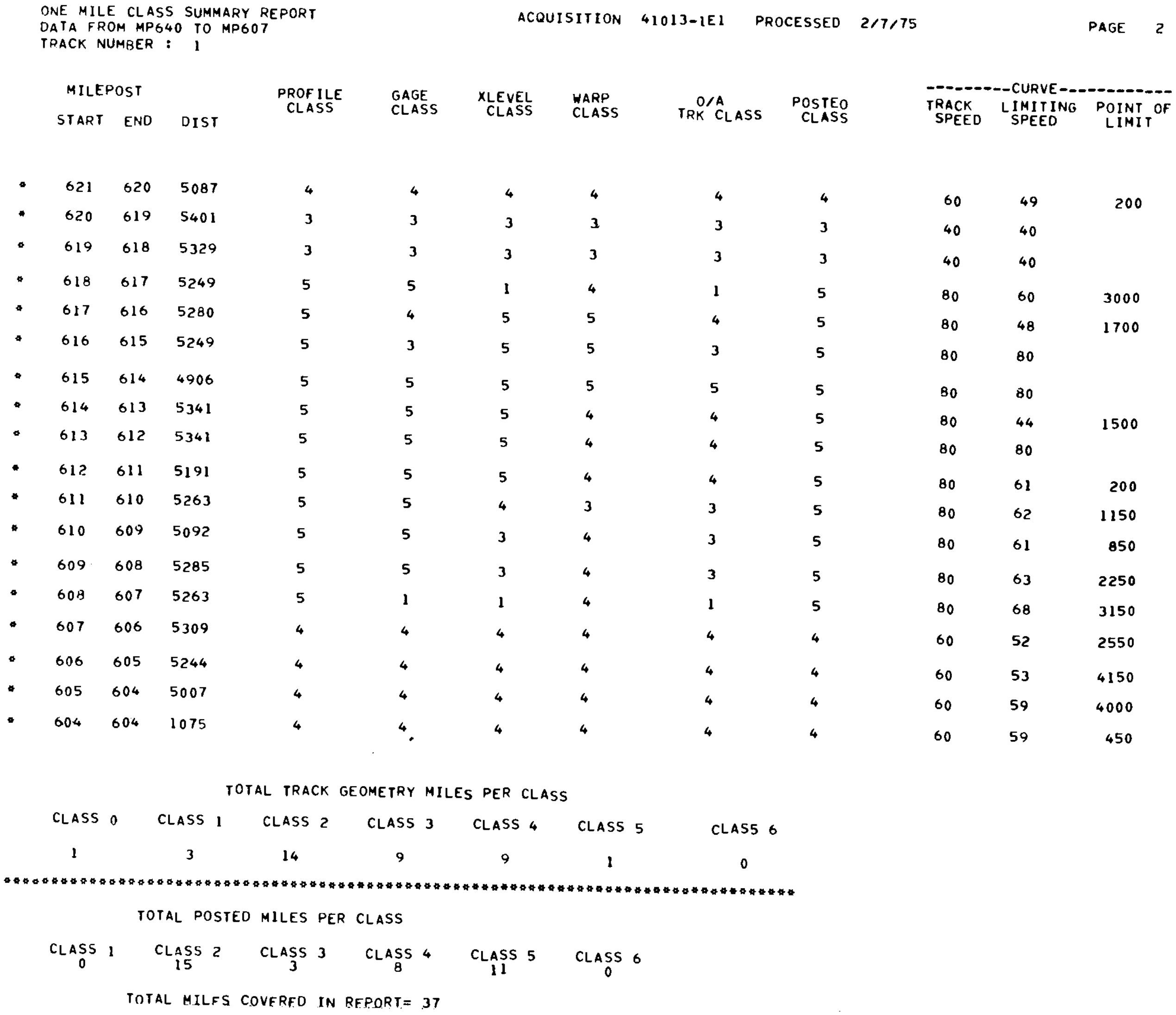
The One-Mile Class Summary gives information on compliance with safety standards once deviations have been located. The highest allowable operating class is displayed per mile for each parameter processed. Also printed for each mile is the operating class as set by the railroad and the overall limiting class as determined by parameter comparison with safety standards. Other speed information displays any restrictions found from the comparison of elevation and curvature on every curve within each mile. Figure 3-22 gives an example.

The Curve Summary (Figure 3-23), which shows the points of change from tangent to spiral and spiral to curve for each mile, is included as an aid in determining where curves have been located for changes in class standards.

As mentioned above, one added feature of this program is that it has the capability for generating a graphic display of all information provided in the summaries. In Figure 3-24, the top four plots show the number of posted class and Class 1 exceptions for each of four parameters for each mile tested. The fifth plot displays the railroad operating speed along with any limiting curve speeds as defined by the FRA Track Safety Standards. The last plot presents the operating class and the highest allowable class as determined by the severity of deviations for the parameters analyzed.

3.7 DATA COMPARISON REPORTS

Data comparison reports are used to provide relative comparisons between different sets of track geometry data for higher level maintenance planning. Two programs (COMPARE and GEOPLOT) have been developed for this purpose.



```
ONE MILE CLASS SUMMARY REPORT                    ACQUISITION  41013-1E1   PROCESSED  2/7/75              PAGE   2
DATA FROM MP640 TO MP607
TRACK NUMBER :  1

   MILEPOST            PROFILE    GAGE    XLEVEL   WARP       O/A      POSTED       ---------CURVE------------
                        CLASS     CLASS    CLASS   CLASS   TRK CLASS   CLASS       TRACK  LIMITING  POINT OF
 START  END   DIST                                                                 SPEED   SPEED     LIMIT

*  621  620   5087       4         4        4       4          4         4           60      49        200
*  620  619   5401       3         3        3       3          3         3           40      40
*  619  618   5329       3         3        3       3          3         3           40      40
*  618  617   5249       5         5        1       4          1         5           80      60       3000
*  617  616   5280       5         4        5       5          4         5           80      48       1700
*  616  615   5249       5         3        5       5          3         5           80      80
*  615  614   4906       5         5        5       5          5         5           80      80
*  614  613   5341       5         5        5       4          4         5           80      44       1500
*  613  612   5341       5         5        5       4          4         5           80      80
*  612  611   5191       5         5        5       4          4         5           80      61        200
*  611  610   5263       5         5        4       3          3         5           80      62       1150
*  610  609   5092       5         5        3       4          3         5           80      61        850
*  609  608   5285       5         5        3       4          3         5           80      63       2250
*  608  607   5263       5         1        1       4          1         5           80      68       3150
*  607  606   5309       4         4        4       4          4         4           60      52       2550
*  606  605   5244       4         4        4       4          4         4           60      53       4150
*  605  604   5007       4         4        4       4          4         4           60      59       4000
*  604  604   1075       4         4        4       4          4         4           60      59        450

                 TOTAL TRACK GEOMETRY MILES PER CLASS

  CLASS 0    CLASS 1    CLASS 2    CLASS 3    CLASS 4    CLASS 5    CLASS 6

     1          3          14          9          9          1          0
*****************************************************************************
             TOTAL POSTED MILES PER CLASS

  CLASS 1    CLASS 2    CLASS 3    CLASS 4    CLASS 5    CLASS 6
     0         15          3          8         11          0

            TOTAL MILES COVERED IN REPORT= 37
```

Figure 3-22. One-Mile Class Summary Report. Report Displays Per Mile the Maximum Allowable Class for Four Parameters Plus the Overall Allowable Class

```
                    CURVE SUMMARY                        PAGE  11

    DATA FROM MP640 TO MP607

 MP DISTANCE    LOC  DISTANCE
 -----------    ------------
  MP    FT      MILES   FT                    EVENT
 ---  -----     -----  ----    ------------------------------



 623  -1750       9     825    START SPIRAL UP
 623  -1850       9     912    START SUPERELEVATED SECTION
 623  -2050       9    1108    END SUPERELEVATED SECTION
 623  -2050       9    1108    START SPIRAL DOWN--NO COMPOUND
 623  -2150       9    1219    END SPIRAL DOWN--START TANGENT

 622  -1100      10     176    START SPIRAL UP
 622  -1200      10     270    START SUPERELEVATED SECTION
 622  -1300      10     362    END SUPERELEVATED SECTION
 622  -1300      10     362    START SPIRAL DOWN--NO COMPOUND
 622  -1450      10     545    END SPIRAL DOWN--START TANGENT

 622  -2700      10    1773    START SPIRAL UP
 622  -2800      10    1904    START SUPERELEVATED SECTION
 622  -2900      10    1964    END SUPERELEVATED SECTION
 622  -2900      10    1964    START SPIRAL DOWN--NO COMPOUND
 622  -2950      10    2049    END SPIRAL DOWN--START TANGENT

 622  -5200      10    4284    START SPIRAL UP
 621   -150      10    4557    START SUPERELEVATED SECTION
 621   -200      10    4618    END SUPERELEVATED SECTION
 621   -200      10    4618    START SPIRAL DOWN--NO COMPOUND
 621   -450      10    4850    END SPIRAL DOWN--START TANGENT

 621  -4400      11    3528    START SPIRAL UP
 621  -4650      11    3748    START SUPERELEVATED SECTION
 621  -4750      11    3888    END SUPERELEVATED SECTION
 621  -4750      11    3888    START SPIRAL DOWN--NO COMPOUND
 621  -5050      11    4168    END SPIRAL DOWN--START TANGENT

 620  -1250      12     191    START SPIRAL UP
 620  -1500      12     430    START SUPERELEVATED SECTION
 620  -1900      12     819    END SUPERELEVATED SECTION
 620  -1900      12     819    START SPIRAL DOWN--NO COMPOUND
 620  -2150      12    1049    END SPIRAL DOWN--START TANGENT

 619  -4200      13    3261    START SPIRAL UP
 619  -4350      13    3379    START SUPERELEVATED SECTION
 618  -3000       0      39    END SUPERELEVATED SECTION
 618  -3000       0      39    START SPIRAL DOWN--NO COMPOUND
 618  -3100       0     169    END SPIRAL DOWN--START TANGENT
```

Figure 3-23. Curve Summary Report. Report Gives Summarized Curve Information for Each Curve Encountered

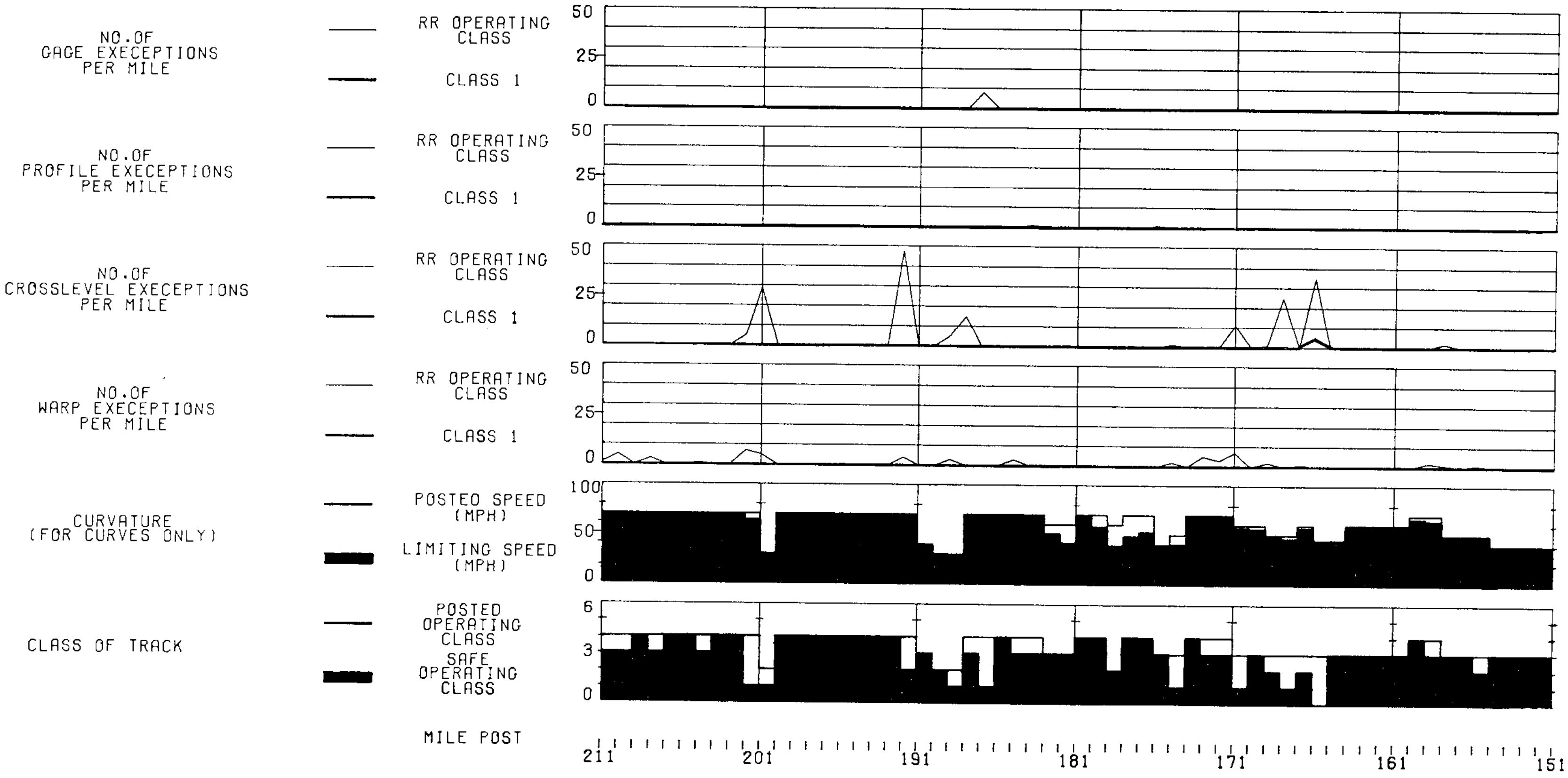


Figure 3-24. Integrated Standards Graphic Display. Display Shows Operating Class and Class 1 Exceptions for Four Parameters. These are Combined to Show Posted and Safe Operating Class for Each Mile of Tested Track.

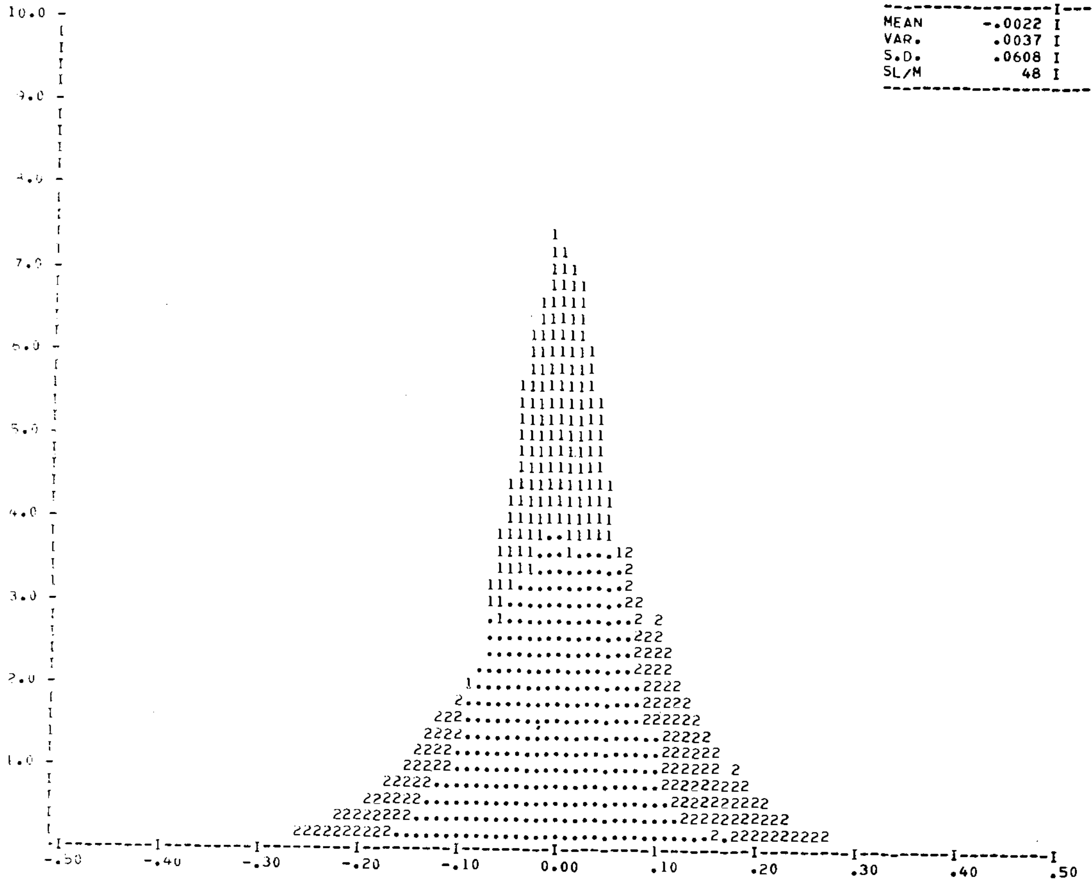
The COMPARE Report provides a statistical comparison between two sets of track geometry data. Various statistical measures of each data set are included in addition to a histogram overlay plot and a Power Spectral Density plot of each data set. This data processing program was developed to compare track geometry statistics and present conclusions in both graphical and tabular format. This analysis can be made with either one or two sets of data. Two sets of data are used to display a historical trend in the condition of the track (Figure 3-25).

The histogram shows not only the percentage of measurements which have exceeded the exception thresholds, but also the percentage of measurements which are on the verge of becoming exceptions. It also shows how closely the measurements are clustered about the design value.

Power Spectral Density (PSD) plots (Figure 3-26) are commonly used in the characterization of electrical signals varying randomly with time, as the area contained under the PSD curve between any two frequencies can be related to the total electrical power delivered by the random signal within that bandwidth. Similarly, the area between any two frequencies under the track geometry PSD curve is related to the dynamic energy delivered to a traveling vehicle by the track. Track geometry PSD's are useful both as track quality indicators and as inputs to dynamic models for vehicle response analysis because of the amplitude versus wavelength information content.

Single data set histograms and PSD's can also be used to provide a graphical comparison of different types of track. The gage histograms and profile PSD's shown in Figure 3-27 are examples of the type of information that can be presented.

```
         (RUN 1)    I    (RUN  2)
--------------------I-------------
MEAN       -.0022   I      .0079
VAR.        .0037   I      .0126
S.D.        .0608   I      .1124
SL/M           48   I        484
----------------------------------
```



```
L. PROFILE HISTOGRAM
                * HISTVAL   *         LOCATION         * TOTAL PTS *  PERCENT  * ACQ DATE   *  FPD  *
      ----------*-----------*--------------------------*-----------*-----------*------------*-------*
      RUN 1     *  36.5666  * (72)                     *      9920 *       101 * 31005      * 55.15 *
      ----------*-----------*--------------------------*-----------*-----------*------------*-------*
      RUN 2     *  10.7879  * (73)                     *      9920 *        93 * 21009      * 55.09 *
      ----------*-----------*--------------------------*-----------*-----------*------------*-------*
```

Figure 3-25. Comparison Report - Profile Histogram Example

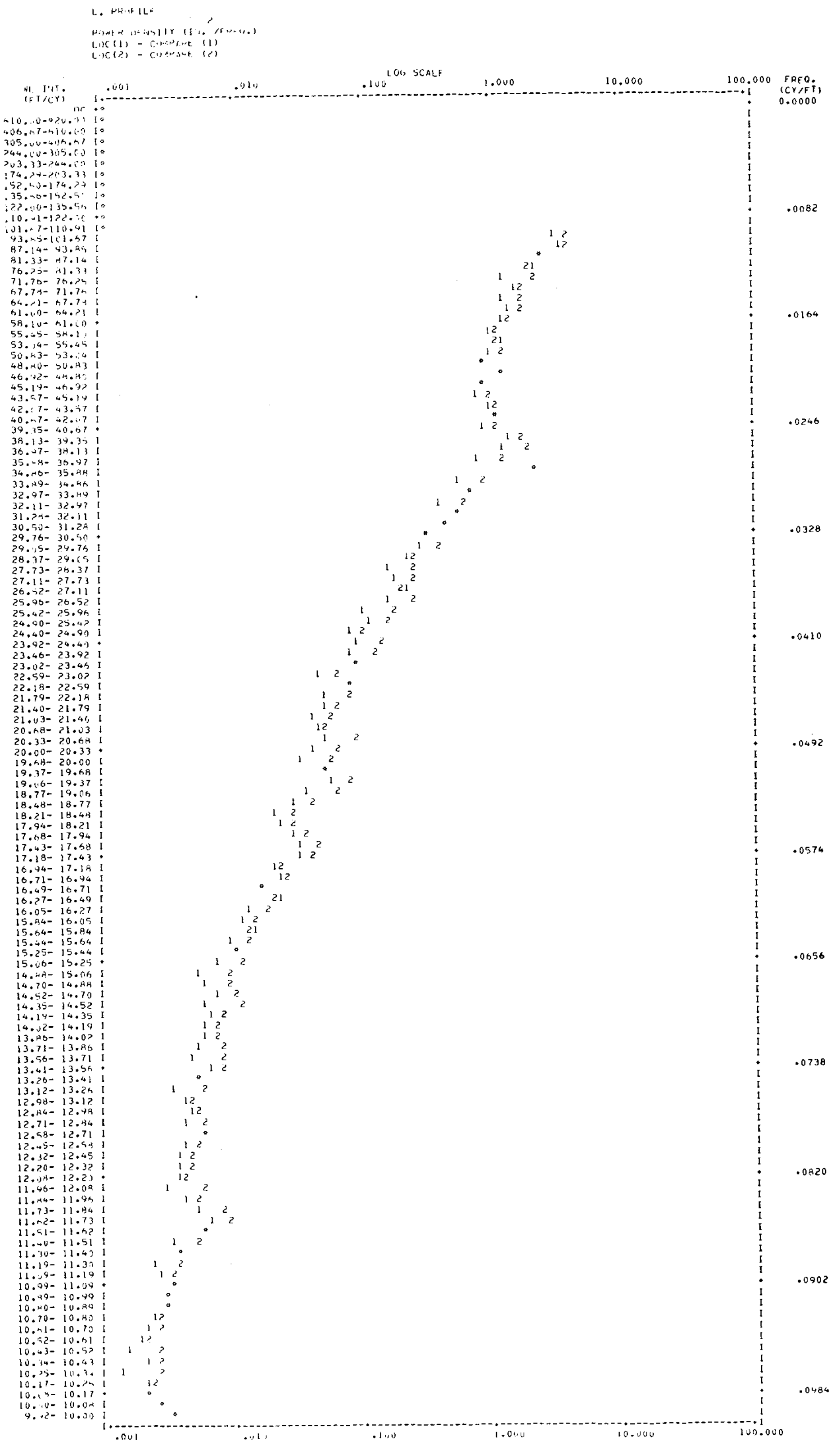


Figure 3-36. Comparison Report - Profile PSD Example

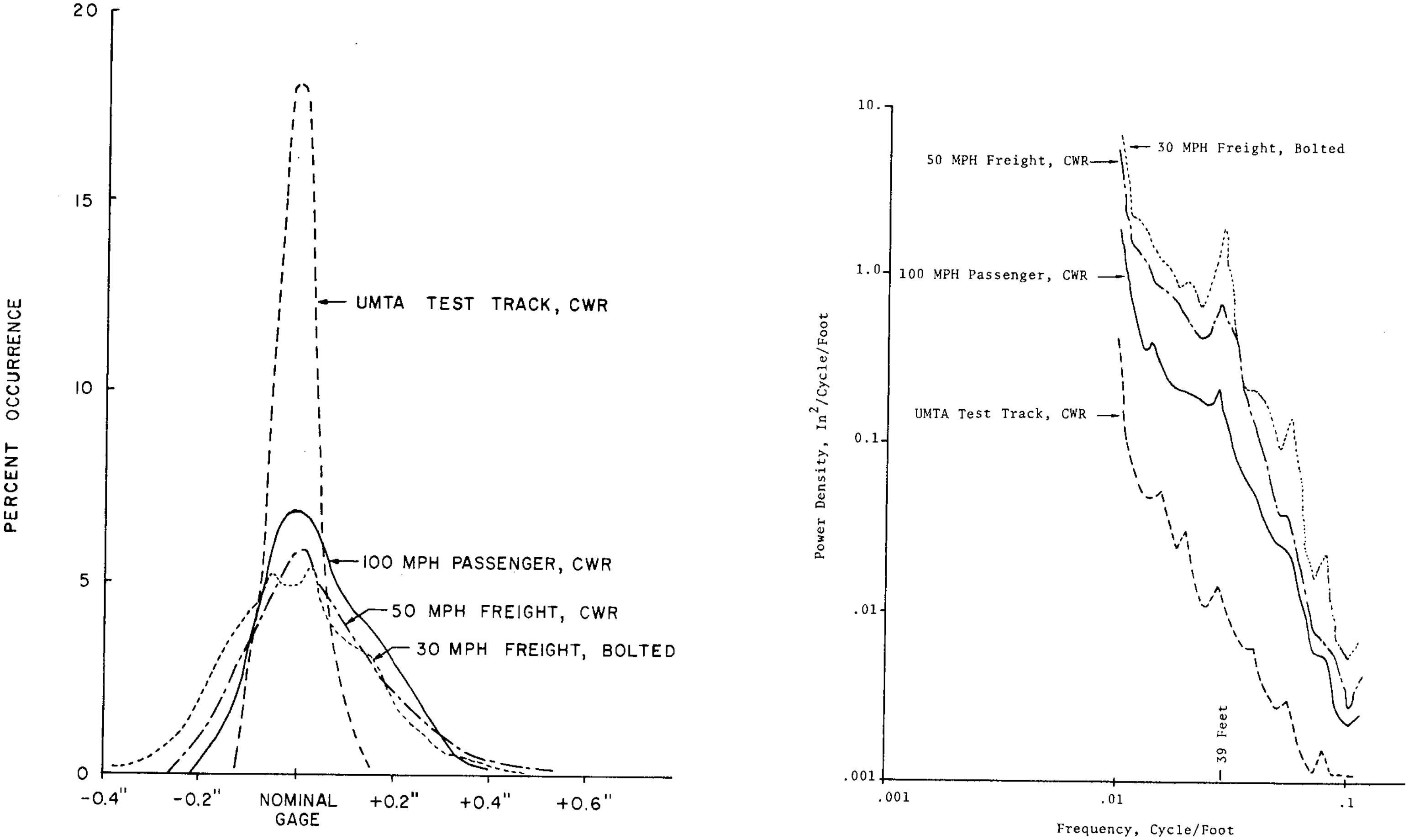


Figure 3-27. Examples of Single Data Set Histogram and PSD Comparisons

GEOPLOT is a data processing program used to compare data from historical test runs. The object of the report is to provide a visual display that will assist maintenance-of-way personnel in determining whether a specific section of track has degraded as a result of little or no maintenance or has improved as the result of maintenance actions taken between runs. Some railroads are using this report as a tool for evaluating the status of track maintenance and the effectiveness of maintenance equipment, and for determining the extent of track degradation. Visual identification of changes in the condition of track over several years is a valuable feature of the report.

The GEOPLOT Report produces a plot which displays up to four computed track quality measures from up to three separate test runs over the same trackage. The program overlays the data from the multiple surveys and displays the computer measurement on a mile-by-mile basis (Figure 3-28).

```
                 TRACK PARAMETER QUALITY INDEX CHART          PROCESS DATE  12/19/74                                  PAGE 1
                                                              X=2 OR MORE POINTS THE SAME
                 MP603 TO MP741                               N=BAD OR NO DATA
                 3 = 1973 DATA
                 4 = 1974 DATA

                                GAGE                    PROFILE                   CROSSLEVEL                 CURVATURE
                             STD. DEV.                  INDEX                       INDEX                    INDEX
                 INCREMENT =          .02    INCREMENT =     350.00    INCREMENT =     650.00    INCREMENT =     1150.00

  (LOC/H.P.) *     .0         .2         .4 1000.0     4500.0     8000.0 2000.0     8500.0     15000.0 2000.0     13500.0    25000.0 * (H.P./LOC)
             *   I.........I.........I   I.........I.........I   I.........I.........I   I.........I.........I     *
       603.0 I   N-------3               N---------3             N---------3             N--------3                I603.0
             *   ------X                 ----X                   ---34                   ---3-4                    *
       605.0 I   -----------X            ----34                  -----X                  ------X                   I605.0
             *   ---------X              -----X                  ----43                  -----34                   *
             *   -------------X          -----34                 -----34                 ---------43               *
             *   ---------X              ------34                -----X                  ---------X                *
             *   ---------X              -----34                 ---34                   -------34                 *
       610.0 I   ----------X             -----34                 ----3-4                 -------34                 I610.0
             *   ------------X           ------34                ---34                   ----3-4                   *
             *   -------X                ------X                 ----X                   ----34                    *
             *   ---------X              --------34              ----X                   ----34                    *
             *   --------X               -------X                ----X                   ----34                    *
       615.0 I   --------X               -------X                ---X                    ----3-4                   I615.0
             *   ---------X              ------34                ----X                   -------34                 *
             *   --------X               ------X                 -----X                  ---3-4                    *
             *   ------X                 -----X                  ----X                   ---34                     *
             *   ---------X              -------X                -----43                 ----34                    *
       620.0 I   -----X                  ------X                 ---34                   ---34                     I620.0
             *   -----X                  -----X                  -----X                  ----3-4                   *
             *   --------X               ------X                 ----X                   ----3-4                   *
             *   ---------------X        ------34                ------34                ---------34               *
             *   ------------------X     -----------X            ----------X             ---------X                *
       625.0 I   ----------------X       ------------X           ------------X           ------------4---3         I625.0
             *   ------------------X     ------------34          -----------4--3         ------------4-3           *
             *   ------------4------3    -----4----3             -----4--3               ---------4----3           *
             *   -------4----------3     -----4------3           ------4--3              ---------4--3             *
             *   ----------X             ----4---3               -----4-3                --------------4-----3     *
       630.0 I   ---------4--3           -----4----3             ----4---3               ---------4---3            I630.0
             *   -------4------3         ----4-------3           ----4-----3             ---------------4---3      *
             *   -------4----3           ----4---------3         ---4----3               ---------4---3            *
             *   --------4---3           ---4---------3          ----4-----3             ------------4--3          *
             *   ---------4-----3        ----4---3               ----4----3              ---------------4-----3    *
       635.0 I   ---------4---3          ----4--3                -----4--3               -----------4--3           I635.0
             *   --------4---3           ----4--3                -----4--3               -----------------4--3     *
             *   ----------4-----3       ----4---3               -----4--3               ---------------4------3   *
             *   ---------4----3         -----4-----3            --------X               ------------4--3          *
             *   ----------4---3         ------4---3             --------43              -------------------4-3    *
       640.0 I   ---------X              -----34                 ------34                ----------34              I640.0
             *   --------X               ----34                  ------34                -----------X              *
             *   ------X                 ----34                  -----X                  -------4-3                *
             *   -----3--4               ----34                  ----34                  --------34                *
             *   -----43                 ---3-4                  ---X                    --4--3                    *
       645.0 I   ----34                  ----X                   --34                    -3--4                     I645.0
             *   ----4-3                 --4---3                 --4-3                   --4--3                    *
             *   ----4-3                 ----4-3                 ---4-3                  ---4-3                    *
             *   ------X                 ---4---3                --4--3                  --4-3                     *
             *   -----X                  ----43                  ----X                   ---X                      *
       650.0 I   ------34                -----X                  -----43                 ----X                     I650.0
       651.0 I   ------X                 ------43                ----4--3                ---4-------3              I651.0
             *   I.........I.........I   I.........I.........I   I.........I.........I   I.........I.........I     *
```

Figure 3-28. GEOPLOT Report. This Report Shows Quality Index Comparisons of 50 Miles of Data for Two Different Years

4.0

SYSTEM VALIDATION AND QUALITY INDEX DEVELOPMENT

4.1 INTRODUCTION

Studies were performed under the Rail Research Program to promote better utilization of the data gathered by the FRA measurement cars and to investigate new methods and techniques for solving rail research problems. One of the most significant studies was an extensive track geometry system validation effort which verified the accuracy of track geometry measurements. Other studies included efforts to examine the relationship of track geometry to ride quality; generate ride quality indices from track geometry data; and to study the repeatability of index generation.

4.2 FRA TRACK GEOMETRY MEASUREMENT SYSTEM VALIDATION

An extensive testing program was conducted to validate the track geometry measurement system installed on the FRA measurement cars to establish the accuracy and repeatability of measurements. Comparisons were made between manual and high-speed electronic measurements of rail gage, crosslevel, profile, and alignment.

The lack of a set of absolute reference standards made it necessary to include not only field tests of the systems, but also controlled laboratory tests of various components. The field tests permitted comparison of system measurements with manual measurements, as well as the evaluation of system repeatability under various operating speeds, car directions, and types of track.

Analysis of field test results provided information on system performance, while the laboratory tests were designed to evaluate the operational characteristics of various components in an absolute sense.

System repeatability studies and comparisons with manual measurements were made by calculating point-to-point measurement differences and performing statistical analysis on the set of differences. A summary of the validation results is presented in Table 4-1.

It should be noted that if the variances of the manual measurement and the electronic repeatability are combined, they nearly equal the variance associated with manual versus electronic measurement differences. This agreement supports the conclusion that system measurement is generally more accurate than manual measurement.

The results provide estimates on the average performance of the measurement subsystems over a long section of track. Special local conditions may cause increased errors in the measurements at isolated points or segments of track. The effect of such conditions, including worn rails, joint bars, etc., is discussed in detail in the report entitled "Track Geometry System Validation Report," DOT-FR-73-08.

4.3 RELATIONSHIP OF TRACK GEOMETRY AND TRACK QUALITY

Track quality measures show the measurement of track degradation and the determination of maintenance needs. A number of measures were developed and investigated for reliability, repeatability, and significance, and the Bessemer and Lake Erie (B&LE) and the Denver and Rio Grande Western (D&RGW) railroads have studied several measures for use in maintenance planning. These track quality measures are derived from gage, profile, crosslevel, and curvature parameter measurements.

A list of measurements and definitions is included in Appendix A. Those currently under investigation are: Standard Deviation, Slopes, and Index. Standard Deviation is calculated as the square root of the statistical variance, Slopes as the number of significant changes between two adjacent data samples, and Index as the area under the data curve.

TABLE 4-1a
SUMMARY OF SYSTEM PERFORMANCE DATA

		STANDARD DEVIATIONS							
		Gage		Profile		Alignment		Crosslevel	
		Mainline	Yard	Mainline	Yard	Mainline	Yard	Mainline	Yard
Loaded Manual Versus Electronic	High	0.055"	0.130"	0.060"	0.275"	0.065"	0.255"	0.100"	0.190"
	Avg.	0.045"	0.100"	0.035"	0.250"	0.050	0.245"	0.075"	0.140"
	Low	0.035"	0.070"	0.025"	0.225"	0.055"	0.220"	0.040"	0.080"
Electronic System Repeatability	High	0.035"		0.045"		0.065"		0.045"	
	Avg.	0.025"		0.025"		0.030"		0.030"	
	Low	0.010"		0.005"		0.015"		0.015"	
Unloaded Manual Repeatability	High	0.045"		0.030"		0.035"		0.080"	
	Avg.	0.040"		0.020"		0.030"		0.035"	
	Low	0.010"		0.010"		0.015"		0.015"	

TABLE 4-1b
SUMMARY OF VALIDATION RESULTS

	Maximum Range of Measurement	Accuracy	
		Electronic System Repeatability	Variations from Manual Measurements
GAGE	55.5"-61.5"	±0.025"	±0.05"
PROFILE*	±2"	±0.025"	±0.04"
ALIGNMENT*	±2"	±0.030"	±0.05"
CROSSLEVEL	±6.5"	±0.030"	±0.08"

*Mid-chord offset using a 14.5-foot chord.

A number of experiments have been performed to investigate track quality measures. One of the investigations involved a test run on the B&LE Railroad to relate track quality indices to track ride quality as rated by two experienced railroad supervisors.

The supervisors were asked to rate the quality of ride of each section of track measured, although neither the rating scale nor the exact meaning of "ride quality" was explicitly defined. Each section was rated by the supervisors as they rode the track geometry car over different sections of track during three days of testing, by using a scale of 1 (for excellent ride quality) to 10 (for poor ride quality). Since railroad reported the numerical average of the pair of ratings for each section, no analysis was made on the degree to which the railroad supervisors agreed on their ratings. All of the track was continuously welded rail maintained for 45-mph freight operation.

A computer was used after the test run to calculate a number of different track quality measures for each section of track based on recorded profile and gage measurements. These measures were then compared with the ride quality ratings made by the supervisors during the test run.

Each of the measures calculated from profile measurements ranked the track in approximately the same order as that selected by the supervisors. The track geometry measure that best correlated with ride quality rankings was calculated by counting abrupt profile changes (changes greater than 0.1 inch between adjacent data samples). This measure, "Slopes Per Mile," exhibited an absolute average error of less than 10 percent and a maximum single error of less than 20 percent of the ride quality ratings assigned by the railroad supervisors. (See Table 4-2.)

None of the measures calculated from gage measurements correlated well with the ride quality ratings. Gage apparently had little effect on ride quality, at least within the range of gage conditions found on the B&LE main line.

TABLE 4-2

DISTRIBUTION OF ABSOLUTE ERROR TERMS USING THE SIMPLIFIED SLOPES PER MILE RELATIONSHIP

SECTION NUMBER	REPORTED RIDE QUALITY RATING	ESTIMATED RIDE QUALITY RATING	ABSOLUTE DIFFERENCE
1	2.5	2.0	0.5
2	4.0	5.3	1.3
3	6.0	5.3	0.7
4	2.0	3.3	1.3
5	3.0	1.9	1.1
6	7.5	5.5	2.0
7	7.0	5.6	1.4
8	5.5	3.6	1.9
9	2.0	3.2	1.2
10	2.5	1.7	0.8
11	4.5	4.6	0.1
12	4.0	3.9	0.1
13	4.0	3.0	1.0
14	4.0	6.0	2.0
15	5.0	6.5	1.5
16	4.0	3.9	0.1
17	6.0	5.9	0.1
18	5.5	4.6	0.9
19	2.5	2.8	0.3
20	3.0	3.4	0.4
21	5.5	6.8	1.3
22	1.0	1.4	0.4
23	2.0	2.8	0.8
24	1.5	2.9	1.4
		Average Difference	0.94

Further information can be found in the report titled "Correlation Between Track Geometry Indices and Perceived Ride Quality," Report No. DOT-FR-73-15.

A second experiment was conducted on the D&RGW railroad. Track geometry data were processed for many sections of trackage where known maintenance had been performed between successive track geometry surveys. Selected track geometry measures were then calculated for each mile of track in these maintenance control zones. Graphic presentations of the measures were used to enable the qualitative comparisons of the consistency and responsiveness of the measures to several maintenance levels. Figure 4-1 displays an example of the graphic presentation. In the figure six sections of track show the responsiveness of the Profile Slopes measure to the maintenance action of laying new rail. Various gage and profile measures were tested using three types of maintenance: new rail, spot raise, and skin lift. The results showed that Standard Deviation, Slope, and Index were the measures which were most consistent and responsive to different types of maintenance.

The study of the correlation of track geometry indices to human judgment and known track maintenance improvements has shown that stable correlations do exist. Additional investigations will provide the basis for the evaluation of the usefulness of track geometry indices for track maintenance planning. Although it is not suggested that track geometry measurement cars replace the judgment of experienced supervisors, it does appear that such cars can be used as a tool by these supervisors to provide reliable and accurate measures of ride quality useful in the process of allocating major track maintenance.

4.4 TRACK GEOMETRY MEASUREMENT AND MEASURES REPEATABILITY

There are four major causes for differences in the track geometry measurements at any point along the track at two different times.

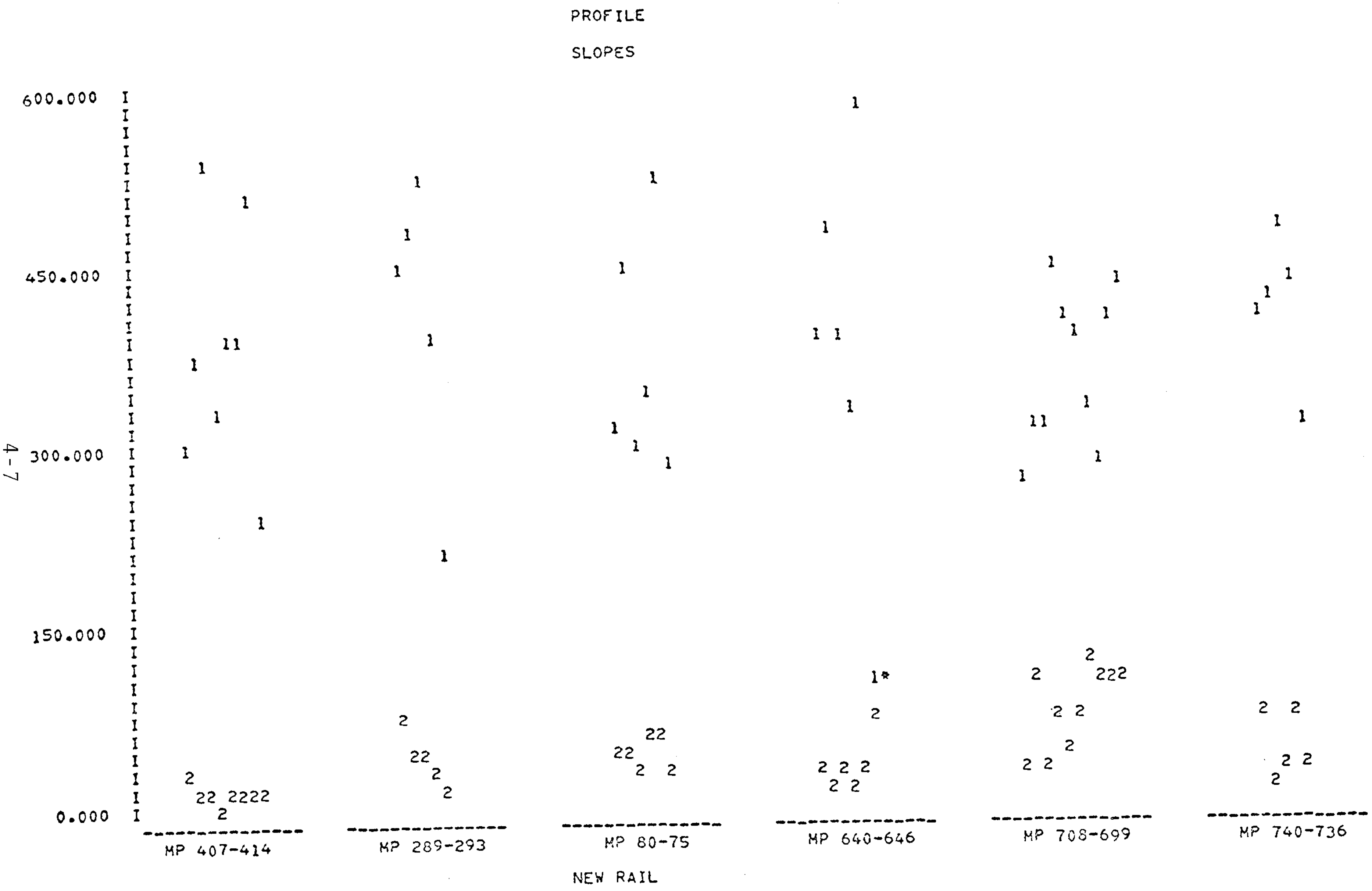


Figure 4-1. Graphic Display of Quality Measure Difference for Certain Types of Maintenance

- Sample error--the track geometry is sampled at increments of 2.41 feet during each test, so two measurements assumed to be made at the same point may actually be made at points up to 1.205 feet apart.
- System noise--including random vibration of the sensors, round-off errors in digitizing, system noise and nonlinearity, etc.
- Calibration errors.
- Changes in the track geometry.

The ability of the track geometry system to measure track degradation or change depends on the repeatability of the measurements and the indices calculated from the measurements. To check the repeatability of the system, four test runs were made over a 6-1/2 mile section of B&LE mainline over a period of approximately 1-1/2 hours. Since it can be assumed that the track geometry did not change during this test, the differences from one run to the next are an indication of the degree of repeatability of the measuring system. This test essentially eliminated the influences of calibration errors and changes in track geometry upon measurement repeatability.

A preliminary analysis has resulted in an estimate of the magnitude of the other sources of error. These imply a confidence interval for individual point measurements which is as follows:

TRACK GEOMETRY PARAMETER	NORMAL RANGE	95% CONFIDENCE LIMITS OF INDIVIDUAL MEASUREMENTS
Gage	56" to 57.5"	±0.07"
Profile (beam system)	-3/4" to +3/4"	at 0" ±0.03" at ±3/8", ±0.07"
Crosslevel	±5"	±0.17"
Curvature	±6°	±0.3°

A similar repeatability analysis will be performed for the profilometer. This will allow comparison of the profilometer to the beam profile system, and will allow evaluation of the effects of different chord lengths used to calculate mid-chord offset.

5.0

SYSTEM DESCRIPTION

5.1 INTRODUCTION

This chapter provides a nontechnical description of the track geometry measurement system installed onboard the FRA measurement cars. Data processing provides real-time computation and reporting of track geometry characteristics, and digital recording of both raw and computed data.

5.2 BASIC SYSTEM CONCEPT

The major subsystems and signal flow of the FRA Track Geometry Measurement System are shown in Figure 5-1. As shown, each subsystem is configured to measure, record, and display a particular parameter of track geometry. The parameters include:

- Profile
- Alignment
- Gage
- Crosslevel
- Curvature
- Location

Each subsystem utilizes one or more sensors, signal processors, a digital computer, recording equipment for digital magnetic tape, and display equipment which provide on-line printout and analog reports. The components associated with each subsystem are discussed in the following paragraphs.

5.3 PROFILE AND ALIGNMENT MEASUREMENT SUBSYSTEM (Figure 5-2)

Mid-Chord Offset (MCO) profile and alignment sensors are located in pairs at six locations on the two 14.5-foot truck-mounted beams. The sensors are arranged in pairs, and are located at the ends and center of each beam. The beams are situated so that the sensors are in proximity to the top of each rail. Each sensor is connected in a capacitive feedback loop to an instrumentation amplifier inside the car. Each sensor amplifier produces an output signal that is proportional to the distance between the rail and sensors, which is dependent upon:

- Vertical distance from the sensor to the rail
- Lateral displacement of the sensor with respect to the rail

MCO profile computations are based on the vertical distance from a pair of sensors (i.e., LOR, LIR) to the surface of the rail, while alignment computations are based on differences in lateral displacement of the two sensors which constitute a pair.

A typical sensor pair is shown in Figure 5-3. The arrangement of sensor pairs on the two beams is shown in Figure 5-4.

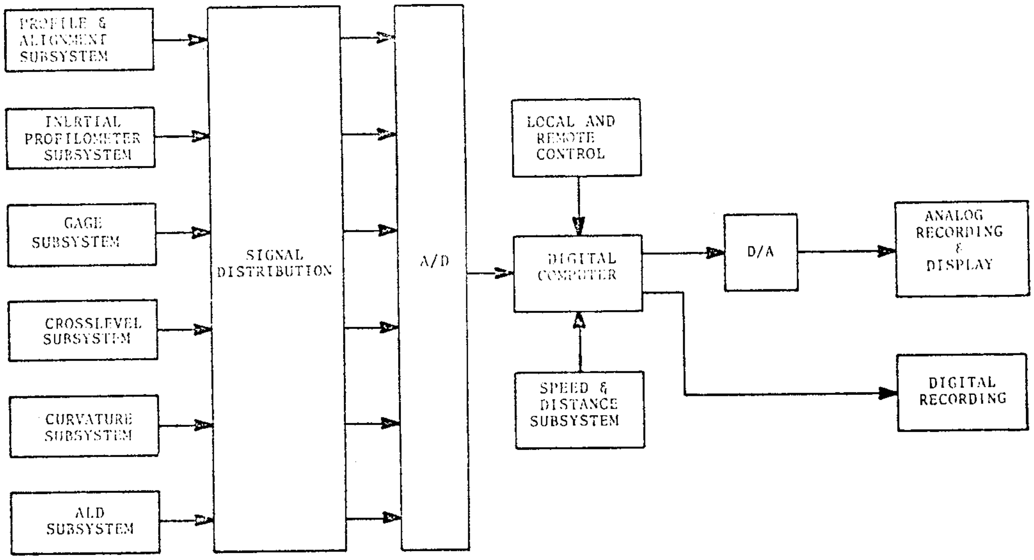


Figure 5-1. Track Geometry Measurement System Block Diagram

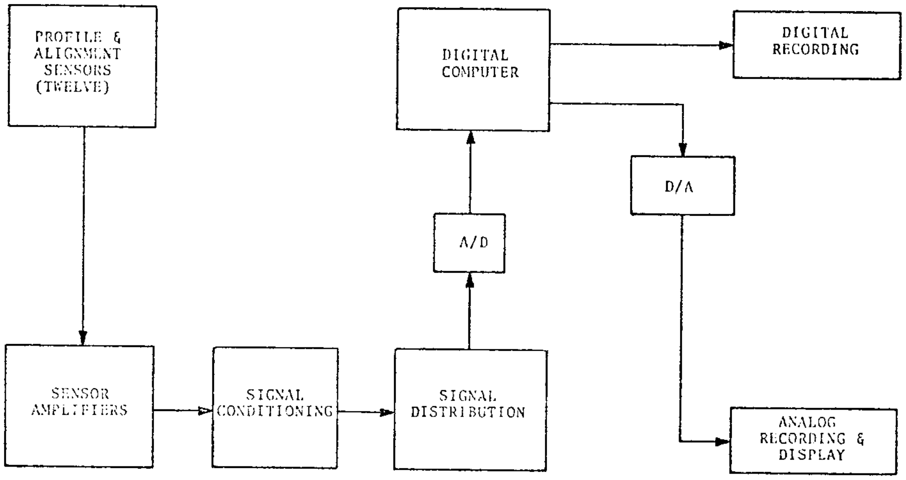


Figure 5-2. Profile and Alignment Subsystem Block Diagram

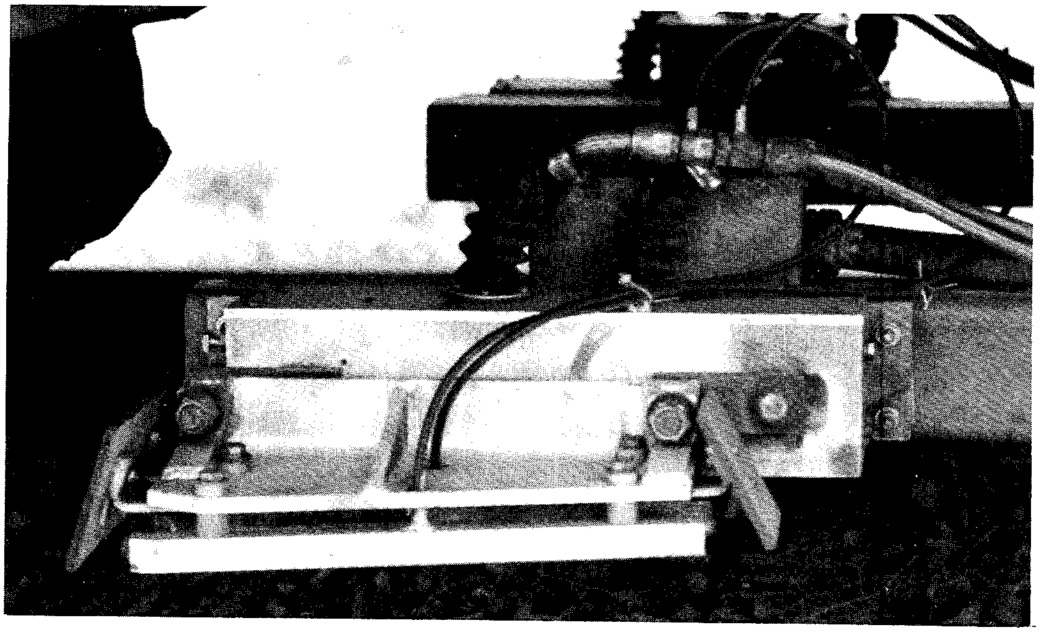


Figure 5-3. Typical Capacitive Sensor Pair

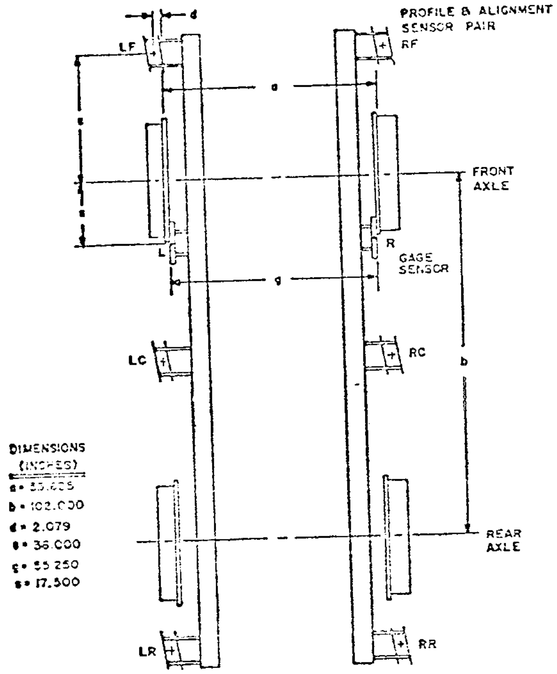


Figure 5-4. Location of Capacitive Sensors on Truck-Mounted Beam

Rail curvature in the horizontal and vertical planes can be determined using a mid-ordinate to chord measurement technique. This technique utilizes the displacement of the mid-point of an arc from the mid-point of the chord drawn between the end points of the arc as a measure of the curvature. As shown in Figure 5-5, if P_1 and P_3 are the end points of a chord and lie on the arc, then D is the displacement of the mid-point of the arc from the (P_2) of a chord, or D is the mid-ordinate to chord measure of the curvature of the arc. If P_1 and P_2 do not lie on the arc, then the mid-ordinate to chord measure (D) becomes:

$$D = \frac{(a-b) + (c-b)}{2}$$

$$= \frac{a-2b+c}{2}$$

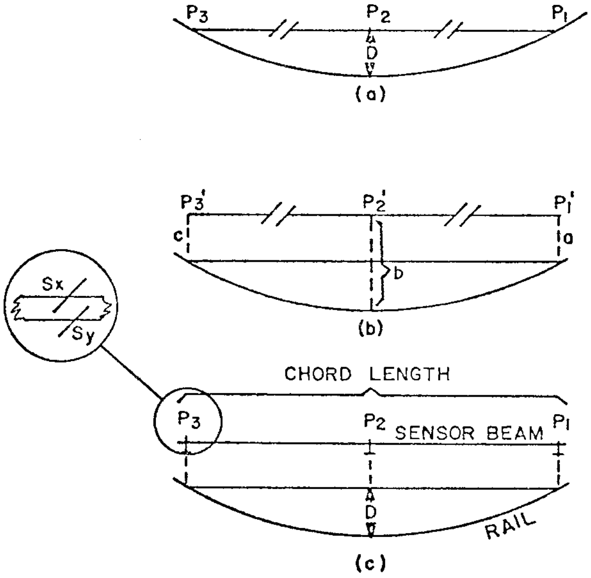


Figure 5-5. Mid-Ordinate To Chord Measurements

Since the capacitive sensors on the FRA measurement car are non-contacting, this equation is used to compute the mid-ordinate to chord measure of the vertical (profile) and lateral (alignment) rail curvature.

The signals developed by a pair of sensors are then combined to form one signal for front, rear, and mid-chord points. The vertical distance from the rail top to each capacitive sensor pair is a nonlinear function of the sensor output voltages. A bilinear function is used to closely approximate the calibration curves determined in laboratory tests.

The three vertical distances measured by the three sensor pairs on each beam are then used to compute the mid-chord offset (MCO) for profile. Details of profile data processing are covered in "Profile Program Manual," DOT-FR-73-05.

While the MCO measurement technique is an effective method of measuring rail profile, certain restrictions are imposed due to the characteristic frequency response of the system. The frequency response of the FRA MCO system is shown in Figure 5-6. It can be seen that the response is null at wavelengths of 1/2, 1/4, 1/6, 1/8 ... of the chord length, and double at wavelengths of 1/3, 1/5, 1/7, 1/9 ... of the chord length. However, the profilometer exhibits a flat frequency response throughout the wavelength range of interest. For that reason, an inertial profilometer has recently been added to increase the FRA Test Car profile measurement capability. The inertial profile sensors (profilometers) are mounted on the car truck on each side of the car. The profilometers establish an inertial reference and develop signals which are proportional to deviations from that reference.

The profilometer is basically composed of a mass which is attached to a wheel of the test car through a spring and damper assembly (Figure 5-7). The mass motion is restricted to the vertical direction by low-friction guides. An accelerometer is attached to the mass, and a displacement transducer is connected between the mass and vehicle wheel (axle).

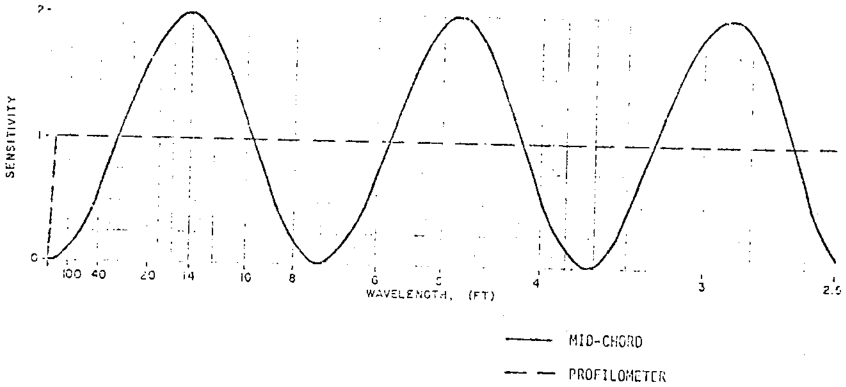


Figure 5-6. Frequency Responses of MCO and Profilometer Systems

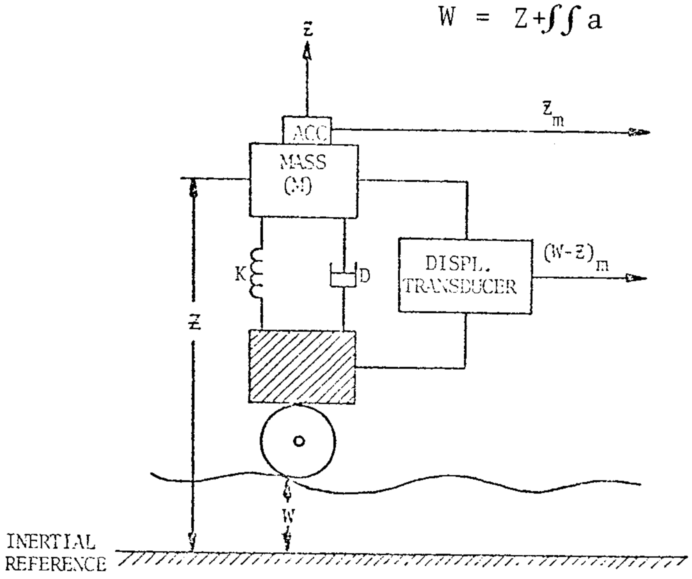


Figure 5-7. Principles of Profilometer Operation

As the vehicle moves along a track, the mass acts as an inertial reference in the vertical plane. Vertical displacements of the rail act as inputs to the profilometer, and are measured directly by the displacement transducer. Low-frequency inputs, which fall below the natural frequency of the profilometer mechanism, are measured by double-integration of the output of the accelerometer, and then adding the integrated signal to that developed by the displacement transducer.

Due to mounting space limitations on the FRA measurement cars, the profilometer transducers are not mounted directly over the rails. Thus, the point of measurement (rail center) extends beyond the actual location of the profilometer transducer, as shown in Figure 5-8. This condition is termed "overhang," and is represented by distances B and C in the illustration. The signal produced by each transducer does not represent the true profile of the rail but, rather, is a scaled linear combination of profile of both rails. As shown in Figure 5-9, actual profile (Z_R and Z_L) is always greater than the measured signals (Z_{RT} and Z_{LT}). This condition is corrected by compensation circuits consisting of operational amplifiers with gain characteristics set to provide the required output. A block diagram of the profilometer instrumentation is shown in Figure 5-10.

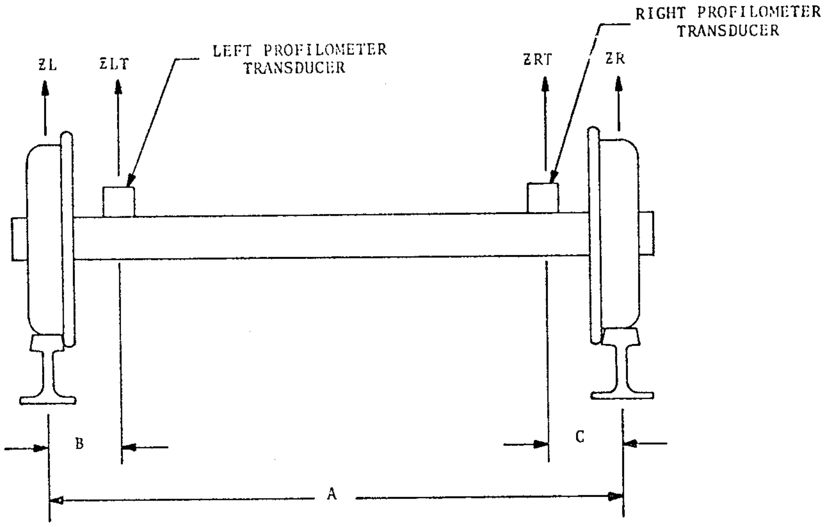


Figure 5-8. Location of Profilometer Sensors Relative to Rail Center

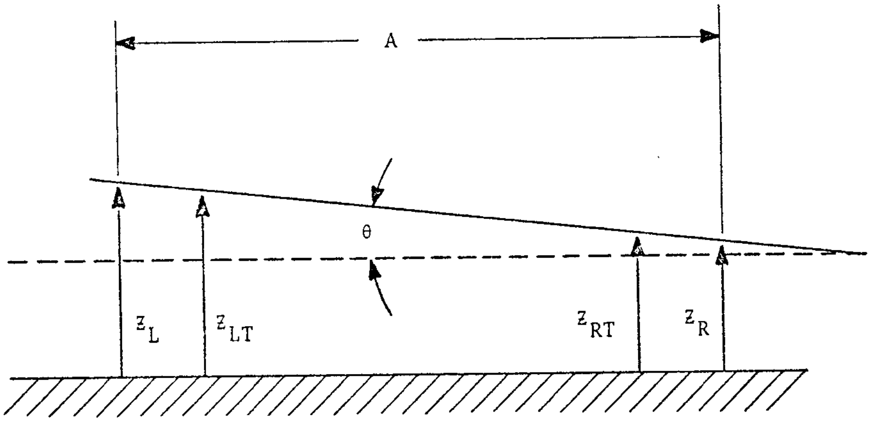


Figure 5-9. Graphical Representation of Overhang Showing Left Rail High

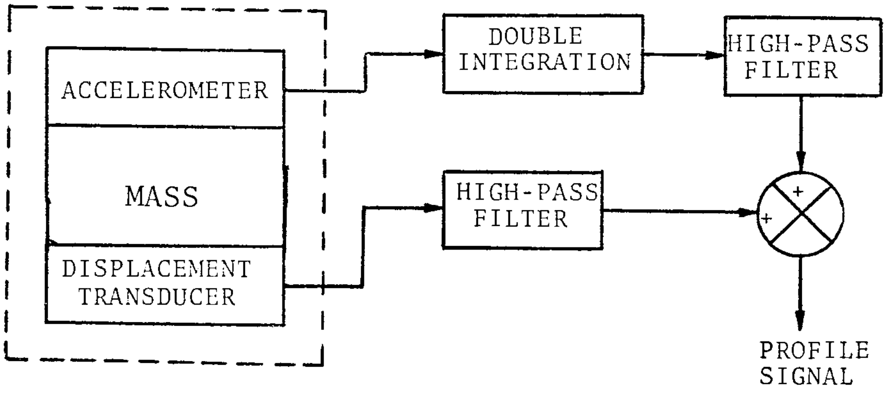


Figure 5-10. Profilometer System Block Diagram

5.4 GAGE MEASUREMENT SUBSYSTEM (Figure 5-11)

The gage sensors, which are also capacitive proximity devices, are mounted in the shadow of the wheel flanges on the 14.5-foot truck-mounted beams. The sensors face the inside of the rails and measure at a point approximately 5/8 inch below the top of the rail. The signals produced are proportional to the distance between the face of the sensors and the inside of the railhead. The signals are then processed by signal conditioning amplifiers, and are routed through the analog terminal unit to the analog multiplexer of the digital computer. The data are sampled and stored in the same manner as the profile and alignment MCO signals previously discussed.

The distance between the faces of the left and right gage sensors is referred to as faceplate distance (Figure 5-12). Therefore, addition of the implied distance from the right sensor to the right rail (RG), the implied distance from the left sensor to the left rail (LG), and the faceplate distance (FPD) provides the measurement of gage.

The two gage gaps are combined with the faceplate distance using the following equation:

$$\text{Gage} = LG + RG + FPD$$

The capacitance between the rail and the sensor is a nonlinear function of the distance between them. Therefore, a linearization process consisting of a five-degree power series is used to represent the nonlinear relationship between the output voltage of each sensor and the distance (gap) between the sensor and rail. Details of gage processing are covered in "Gage Program Manual," DOT-FR-72-03.

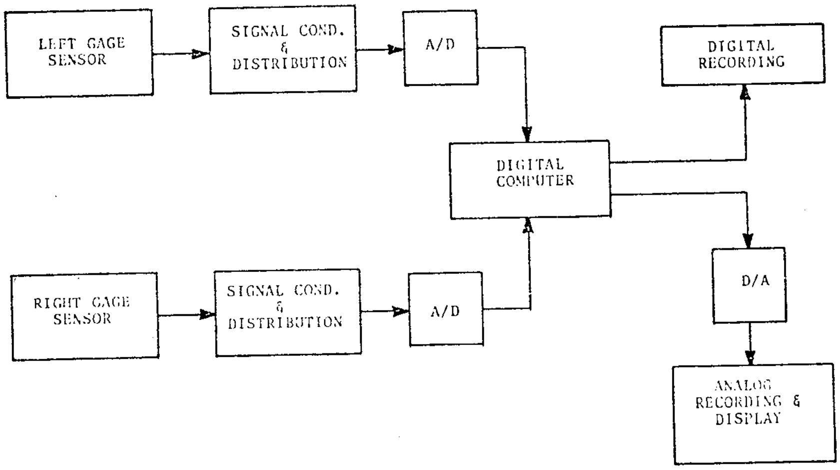


Figure 5-11. Gage Measurement Subsystem Block Diagram

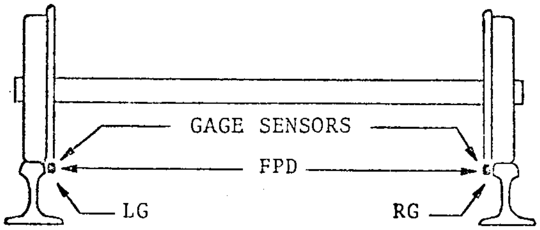


Figure 5-12. Measurements Used in Gage Computation

5.5 CROSSLEVEL MEASUREMENT SUBSYSTEM (Figure 5-13)

The Crosslevel Measurement Subsystem measures the difference in elevation in inches, between the right and left rails. The subsystem consists of a self-erecting gyroscope, two displacement transducers (linear potentiometers--one mounted on each side of the car), and analog circuitry to process the signals.

The vertical gyroscope is the principal reference for the Crosslevel Measurement Subsystem. It is floor-mounted in Car T-3, above the "A" truck, and provides an output voltage which is proportional to the roll angle of the car body from absolute vertical. Since there is a fixed relationship between degree of inclination and crosslevel, only simple conversion and correction are required to obtain crosslevel measurement directly.

Since the body of the car is free to roll through bolster action with respect to the truck, an angular correction is required to determine the roll angle of the truck. The two displacement transducers are used for this correction, and are positioned to measure the difference in height between each side of the car body and the truck. Figure 5-14 shows the relationship of the gyro and transducer locations.

The crosslevel computer is an analog circuit which generates an output signal proportional to crosslevel. A positive output voltage denotes left rail high; a negative voltage denotes right rail high. The output of the crosslevel computer is input to the analog multiplexer of the digital computer. Digitized crosslevel data are stored for recording on magnetic tape and are directly displayed on a strip chart recorder. Figure 5-15 displays the crosslevel computer technique.

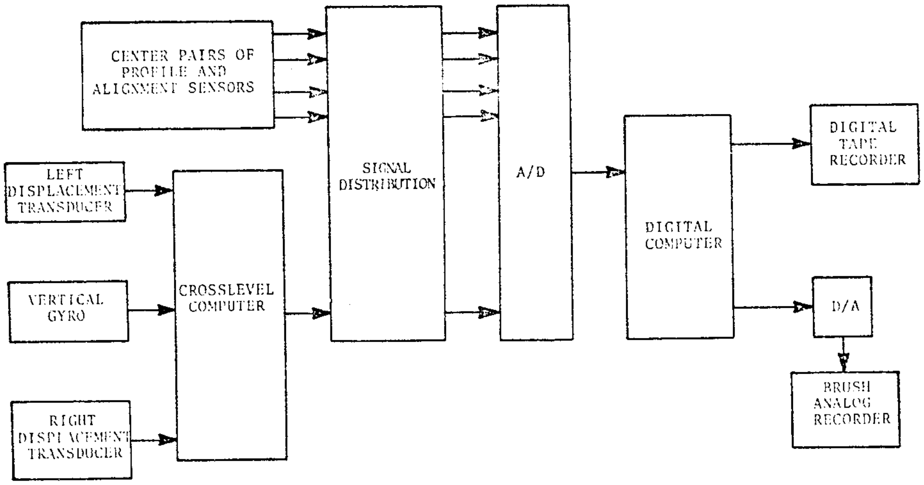


Figure 5-13. Crosslevel Measurement Subsystem Block Diagram

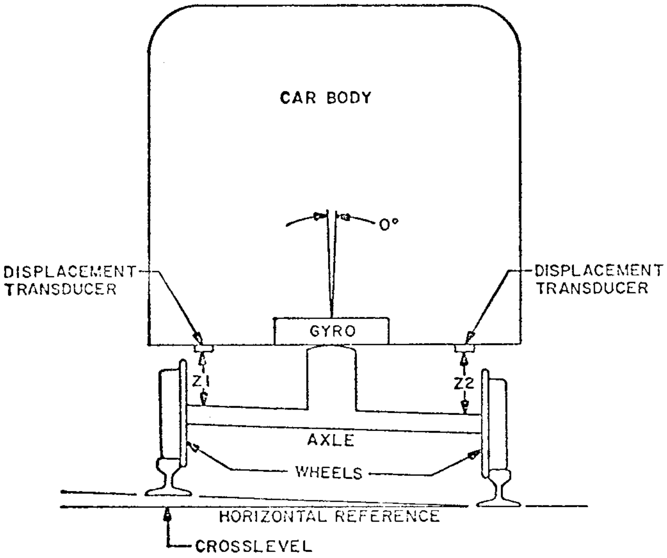
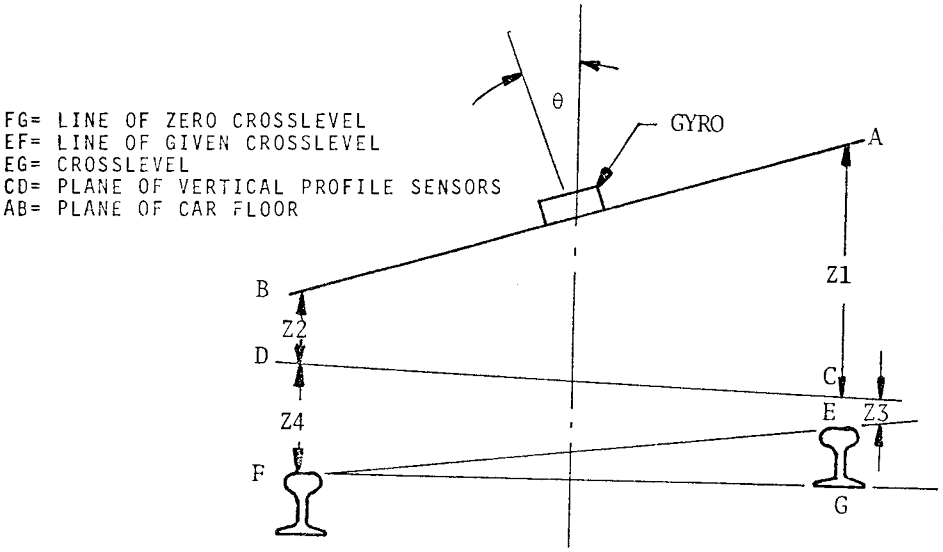


Figure 5-14. Relationship of Gyroscope, Displacement Transducers and Car Body



$$\text{Crosslevel} = (Z2+Z4)-(Z1+Z3)+K\sin\theta$$

Figure 5-15. Crosslevel Computation Technique

5.6 TRACK CURVATURE MEASUREMENT SUBSYSTEM (Figure 5-16)

The Track Curvature Subsystem measures the curvature of track in degrees per 100 feet. The system employs an inertial rate gyroscope to measure the yaw rate of the car, a speed signal from the Speed and Distance Processor, and two velocity transducers to measure relative yaw motions between the car and the trucks.

The curvature signal is digitized and recorded on magnetic tape, and is displayed in analog form on a strip chart recorder to provide a visual display and permanent record of the measurement.

5.7 AUTOMATIC LOCATION DETECTOR SUBSYSTEM (Figure 5-17)

The Automatic Location Detector (ALD) subsystem is used to detect physical features which are unique to a particular section of track roadbed. The detected features are used to correlate track geometry data with specific physical location. The ALD sensor

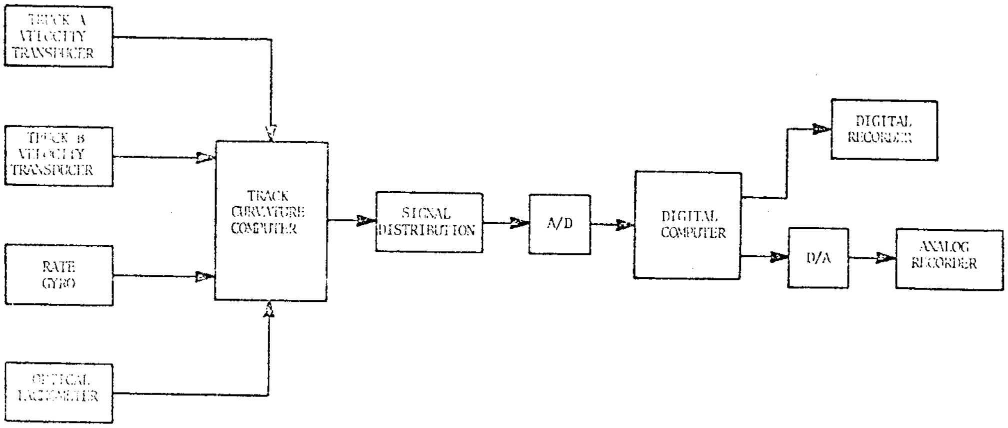


Figure 5-16. Curvature Measurement Subsystem Block Diagram

is located on a frame approximately in the center of the "A" truck on Car T-3 (Figure 5-18), and detects the proximity of physical objects in the centerline of the track roadbed.

The ALD signal is sensed and recorded simultaneously with the track geometry data. The signal is then digitized, displayed on a strip chart recorder, and stored on magnetic tape (Figure 5-19).

There are several types of ALD indications displayed on the strip chart recorder. These are as follows:

MILEPOST:	Indication that appears as a small negative pedestal when initiated by the control operator.
LOCATION:	Indication that appears as a positive signal excursion superimposed on a computer-generated pedestal. The positive pedestal is initiated by the control operator. This indication is used to locate a specific geographic position on the track.

ROAD CROSSING and TURNOUT:	Indications that appear as positive signal excursions on the ALD trace. The two are differentiated by the shape of the waveform.

In planning a test run, objects such as road crossings, turnouts, etc., are assigned three-digit codes. As these objects are approached during a test run, an identifying code is entered in the remote control unit by sequentially depressing the three numerical digits of the code. As the object of interest passes under the leading vehicle, the code is keyed into the computer. When detection of the object is made by the ALD sensor, the code is recorded on the digital tape.

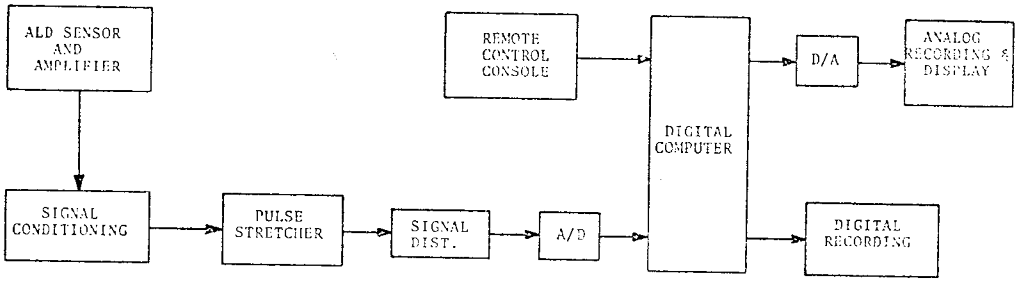


Figure 5-17. ALD Subsystem Block Diagram

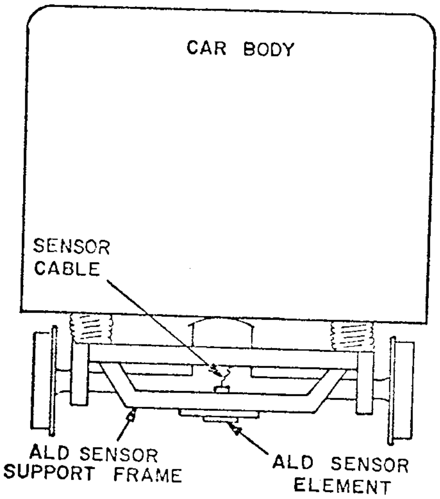


Figure 5-18. Location of ALD Sensor on Measurement Car

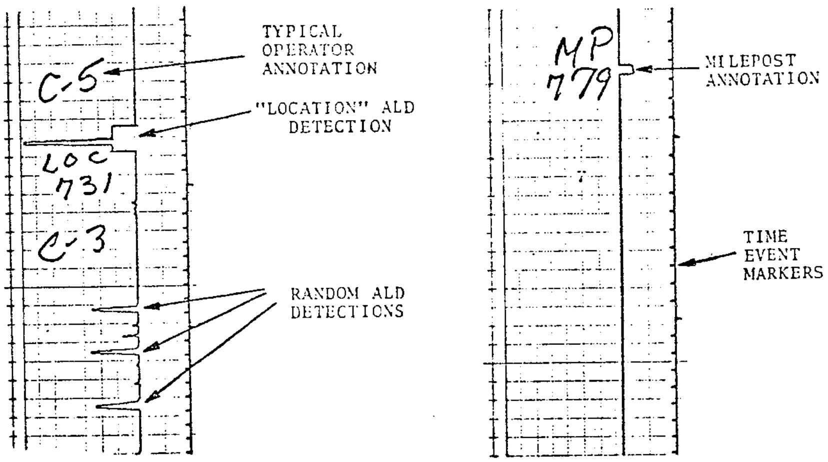


Figure 5-19. Typical ALD Strip Chart Trace

5.8 SPEED AND DISTANCE MEASUREMENT SYSTEM

An optical tachometer, chain-driven by the car axle, produces one thousand pulses during each revolution of the train wheel. The pulses produced by the tachometer are counted over a fixed time interval by the speed and distance processor to indicate instantaneous vehicle speed, and are accumulated by the same unit to indicate total distance of vehicle travel. The speed and distance processor provides the primary timing signals which control data acquisition, computer sampling, and data recording. Speed and timing signals are also distributed throughout the entire track geometry measurement system where measurement functions are related to vehicle speed. A functional block diagram of the speed and distance subsystem is shown in Figure 5-20.

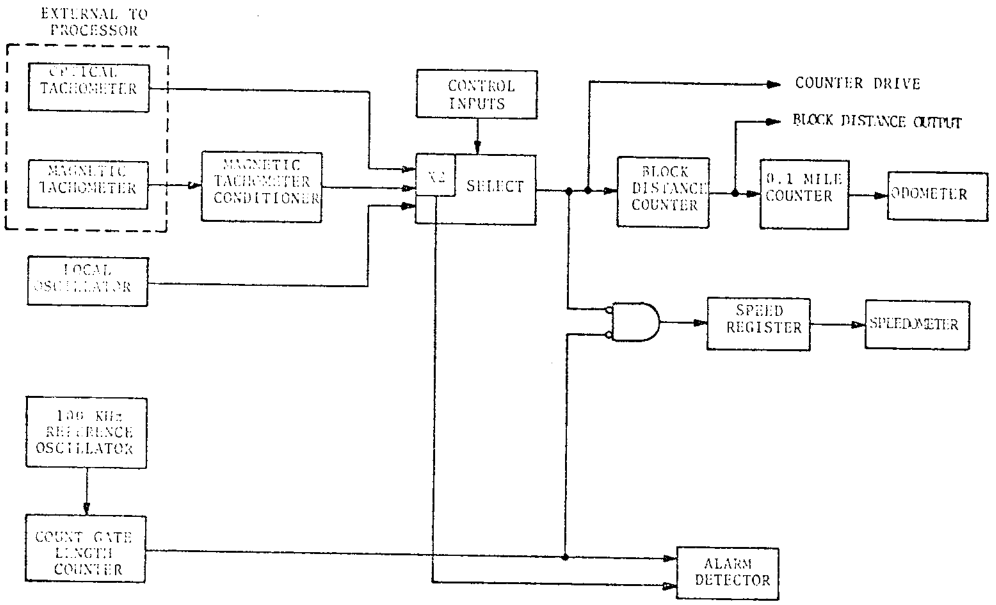


Figure 5-20. Speed and Distance Processor Block Diagram

5.9 ANALOG DISPLAY SUBSYSTEM

The Analog Display Subsystem consists of two strip chart recorders, associated preamplifiers, and data channel selection equipment.

The analog signal from each measured track geometry parameter can be displayed on a strip chart recorder to provide a real-time visual display and a permanent record of data in an analog form. The eight-channel recorder resides with the computer and associated data acquisition units to allow for monitoring incoming geometry data (Figure 5-21). The movable six-channel recorder is placed in the rear vestibule of the final car in the consist to allow visual correlation between strip chart data and significant track features by railroad personnel during a test run.

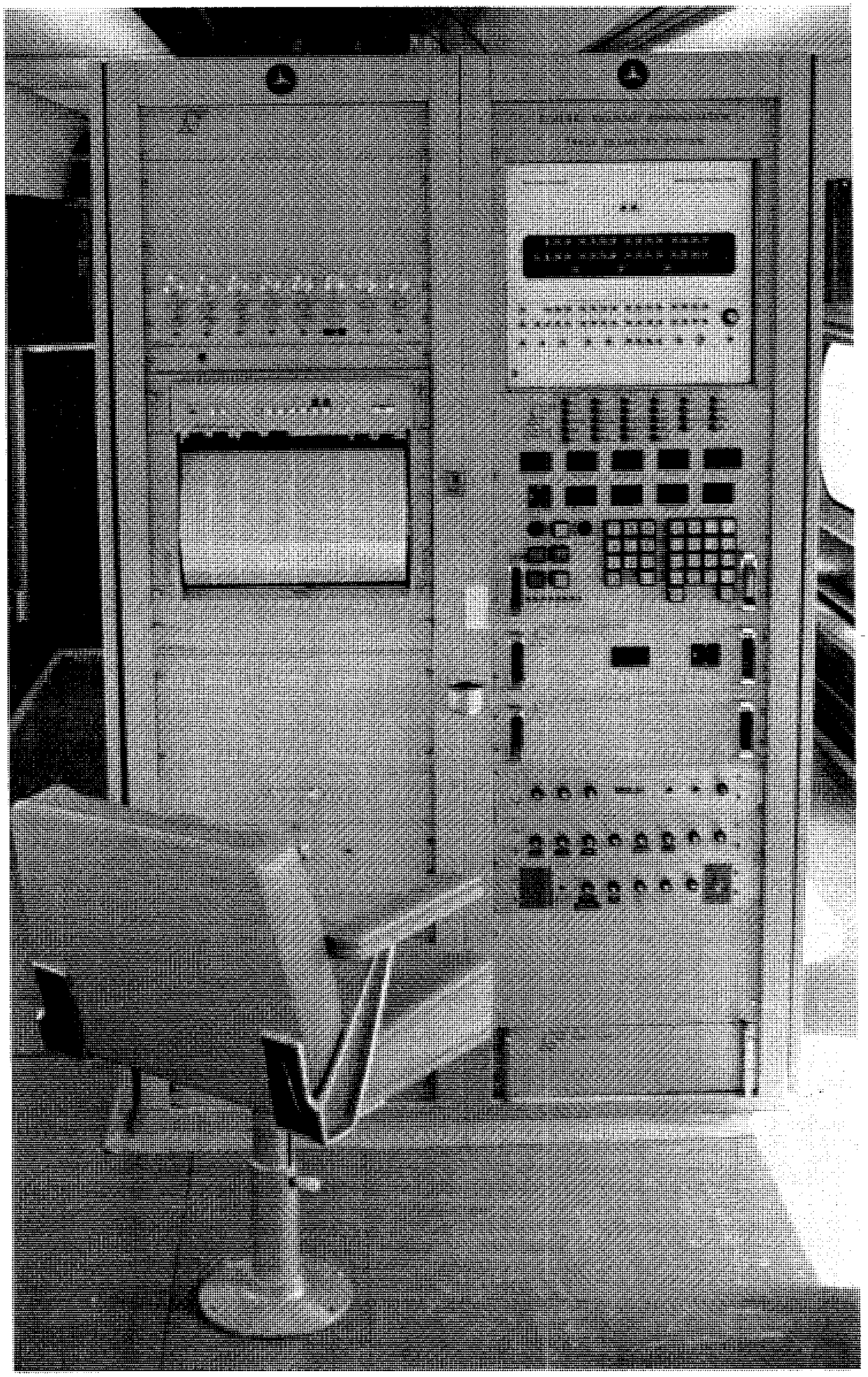


Figure 5-21. Track Geometry Computer System

5.10 DIGITAL RECORDING SUBSYSTEM

The Digital Recording Subsystem records all pertinent track geometry data in digital form on magnetic tape to provide a permanent record, and provides data for off-line processing on a large computer system. Such off-line processing results in reports and data tabulations for further analysis of specific aspects of track geometry.

As track geometry data are measured, the primary measurement signals produced are analog voltages. The analog voltages are scanned, digitized, and stored temporarily in the digital computer. When 80 scans of data have been digitized and stored, the data are then transferred to magnetic tape in a complete block. One scan of data is initiated by each block distance pulse, which is supplied by the speed and distance processor each 2.41 feet of vehicle travel.

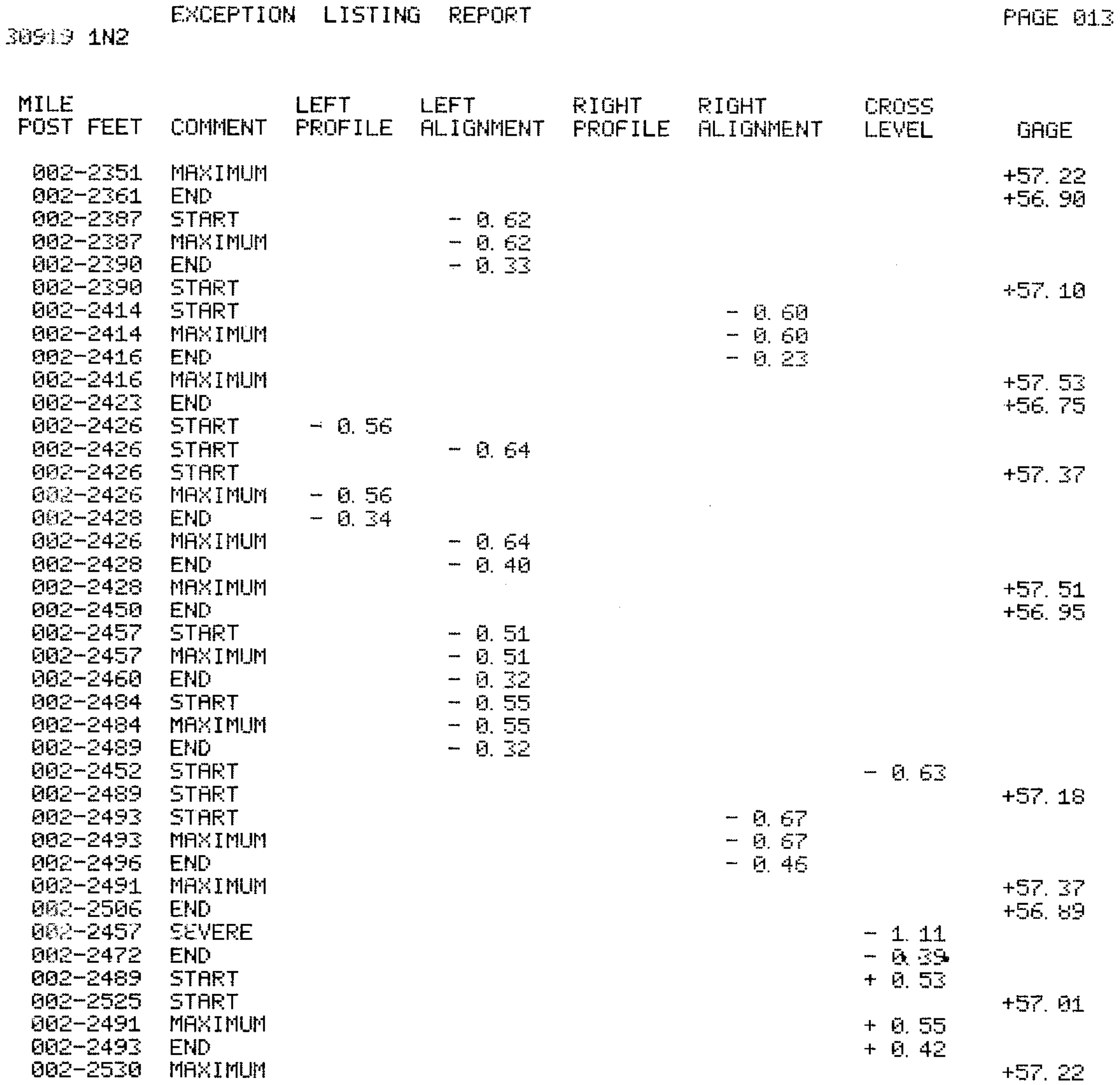
A maximum of 32 channels are used as analog inputs to the data collection system. The channels are digitized before being input to the computer.

Fifteen of the analog inputs are committed to proximity sensors of the measurement system; twelve channels are assigned to the profile and alignment sensors; two channels are assigned to the Gage sensors; and one channel is assigned to the ALD sensor. Five additional signals, including crosslevel, curvature, speed, and left and right inertial profile, are also input to the computer. The remaining channels are available for special test data collection needs.

5.11 ON-LINE REPORTS

The Track Geometry Measurement System presently generates three separate types of reports for operating personnel and has the capability of supplying additional types of reports as required. The following reports are presently provided.

The Exception Listing Report (Figure 5-22) contains information on track geometry parameters which exceed a predetermined range of acceptable values. The first, last, and maximum variations in excess of acceptable limits are printed and marked with respect to the last milepost and distance in feet from that milepost. The report also includes a summary of the mean and standard deviation of the values since the last summary, and an index value associated with each value. The index value is proportional to the product of the variation from the mean multiplied by the length of variation.



```
                 EXCEPTION  LISTING  REPORT                                           PAGE 013
30919 1N2

MILE                   LEFT       LEFT         RIGHT      RIGHT         CROSS
POST FEET   COMMENT    PROFILE    ALIGNMENT    PROFILE    ALIGNMENT     LEVEL        GAGE

 002-2351   MAXIMUM                                                                 +57. 22
 002-2361   END                                                                     +56. 90
 002-2387   START                   - 0. 62
 002-2387   MAXIMUM                 - 0. 62
 002-2390   END                     - 0. 33
 002-2390   START                                                                   +57. 10
 002-2414   START                                           - 0. 60
 002-2414   MAXIMUM                                         - 0. 60
 002-2416   END                                             - 0. 23
 002-2416   MAXIMUM                                                                 +57. 53
 002-2423   END                                                                     +56. 75
 002-2426   START       - 0. 56
 002-2426   START                   - 0. 64
 002-2426   START                                                                   +57. 37
 002-2426   MAXIMUM     - 0. 56
 002-2428   END         - 0. 34
 002-2426   MAXIMUM                 - 0. 64
 002-2428   END                     - 0. 40
 002-2428   MAXIMUM                                                                 +57. 51
 002-2450   END                                                                     +56. 95
 002-2457   START                   - 0. 51
 002-2457   MAXIMUM                 - 0. 51
 002-2460   END                     - 0. 32
 002-2484   START                   - 0. 55
 002-2484   MAXIMUM                 - 0. 55
 002-2489   END                     - 0. 32
 002-2452   START                                                       - 0. 63
 002-2489   START                                                                   +57. 18
 002-2493   START                                           - 0. 67
 002-2493   MAXIMUM                                         - 0. 67
 002-2496   END                                             - 0. 46
 002-2491   MAXIMUM                                                                 +57. 37
 002-2506   END                                                                     +56. 89
 002-2457   SEVERE                                                      - 1. 11
 002-2472   END                                                         - 0. 39
 002-2489   START                                                       + 0. 53
 002-2525   START                                                                   +57. 01
 002-2491   MAXIMUM                                                     + 0. 55
 002-2493   END                                                         + 0. 42
 002-2530   MAXIMUM                                                                 +57. 22
```

Figure 5-22. Typical Exception Listing Report

APPENDIX A

TRACK QUALITY MEASURES

x_i = Gage in inches at point i on the track

n = Number of gage measurements made over section of track

GAGE:

1. Mean:

$$\text{Mean} = \frac{1}{n}\sum_{i=1}^{n} x_i = \overline{x}$$

2. Standard deviation:

$$\text{Standard deviation} = [\text{variance}]^{1/2}$$

where

$$\text{variance} = \frac{1}{n-1}\left[\sum_{i=1}^{n}(x_i-\overline{x})^2\right] = \frac{1}{n-1}\left[\sum_{i=1}^{n}(x_i)^2-n\overline{x}^2\right]$$

3. Slopes:

$$\text{Slopes} = \sum_{i=1}^{n} F(x_i)$$

$$\text{Where } F(x_i) = 0 \quad \text{if } |x_i-x_{i-1}|<0.1$$

$$= 1 \quad \text{if } |x_i-x_{i-1}|\geq 0.1$$

4. Index (-):

$$\text{Index } (-) = \sum_{i=1}^{n}[F(x_i)\cdot SI]$$

$$\text{Where } F(x_i) = x_i - 56.5 \text{ inches}$$

$$SI = \text{Sample Interval} = 2.41 \text{ feet}$$

5. Index (0):

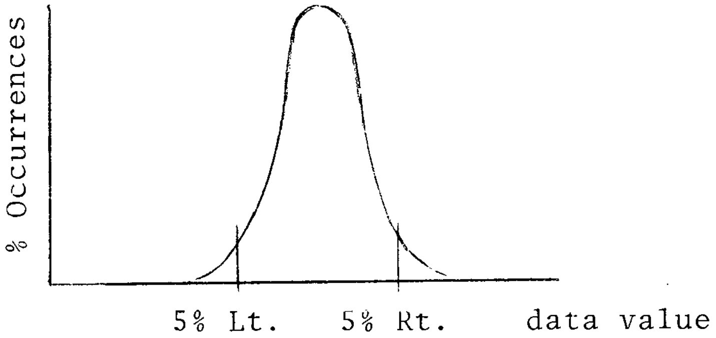
$$\text{Index }(0) = \sum_{i=1}^{n} [F(x_i) \cdot SI]$$

$$\text{Where } F(x_i) = 0 \quad \text{if } x_i \leq 56.5 \text{ inches}$$

$$= x_i - 56.5 \text{ if } x_i > 56.5 \text{ inches}$$

$$SI = \text{Sample Interval} = 2.41 \text{ feet}$$

A histogram of gage data is used for calculating the 5% Lt. and 5% Rt. measures.



6. 5% Lt.:

5% of the gage data lies below this gage value.

7. 5% Rt.:

5% of the gage data lies above this gage value.

x_i = Profile in inches offset from 14.5-foot chord at point i on the track

n = Number of profile measurements made over section of track

PROFILE:

1. Mean:

$$\text{Mean} = \frac{1}{n} \sum_{i=1}^{n} x_i = \overline{x}$$

The Informative Message Report lists Forward Observer commands, information related to tape starts, parity errors, and location detections. The report also lists abnormal sensor voltages and extreme track geometry parameter exceptions. Each message entry on the list is tagged with the last milepost number and the distance in feet from the milepost.

The Urgent Message Report is designed to inform operating personnel of unusual, abnormal, or extreme system operating conditions. Such conditions include abnormal sensor voltages, abnormal voltage changes, and extreme geometry exceptions.

2. Standard deviation:

Standard deviation = $[\text{variance}]^{1/2}$

Where:

$$\text{variance} = \frac{1}{n-1}\left[\sum_{i=1}^{n}(x_i-\bar{x})^2\right] = \frac{1}{n-1}\left[\sum_{i=1}^{n}(x_i)^2-n\bar{x}^2\right]$$

3. Slopes:

$$\text{Slopes} = \sum_{i=1}^{n} F(x_i)$$

Where: $F(x_i) = 0$ if $|x_i-x_{i-1}|<0.1$

$= 1$ if $|x_i-x_{i-1}|\geq 0.1$

4. Index:

$$\text{Index} = \sum_{i=1}^{n}[F(x_i)\cdot SI]$$

Where $F(x_i) = |x_i|$

SI = Sample Interval = 2.41 feet

Histogram of profile data is used for calculating the 5% Lt. and 5% Rt. measures.

5. 5% Lt.:

5% of the profile data lies below this profile value.

6. 5% Rt.:

5% of the profile data lies above this profile value.

7. SIGMA = Measured value of profile corresponding to 0.26% on the cumulative histogram.

8. DM/0.375 = Average number per mile of profile measurements less than -0.375 inch.

APPENDIX B

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