Use of Track Strength Data in the Determination of Future Crosstie Requirements

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The new generation of objective track strength measurement systems, which measure the lateral deformation (and associated strength) of the tie/fastener systems in track, is currently being used by a number of railroads, to measure the track strength from a safety point of view. As such, it serves as an effective means of locating weak spots, particularly clusters of poor or inadequate ties, in track. However, this new generation of data also offers the potential for developing maintenance parameters for ties and fasteners, based on the same level of objective information.

A recent U. S. Department of Transportation, Federal Railroad Administration Next Generation High Speed Rail Program sponsored project [1] was specifically aimed at the development of "maintenance" criteria for track strength based on the use of track strength measurement data for both conventional and high speed railroad track. A focus of this project was to use objective track strength data to define track upgrade and maintenance requirements for track being upgraded from conventional train operations to a combination of conventional and high speed passenger operations. This project made use of track strength data taken by CSX Transportation's GRMS[1] track inspection vehicle. As part of this maintenance criteria development, an assessment of the "minimum" level of upgrade necessary to allow for the operation of both heavy axle load freight traffic and high speed passenger trains on existing tracks was made. This activity also addressed the definition of suitable track strength maintenance criteria for existing wood tie track and the determination of a relationship between these criteria and the rate of degradation (and maintenance) of the track strength.

The focus of this study was the CSX Transportation line segment between Richmond VA and Washington DC. Track 3, between MP 4 and MP 109, was selected for analysis because of data availability and history of recent tie installations. This line segment sees regularly scheduled GRMS vehicle tests and supports a mix of freight traffic to include coal, intermodal, and mixed traffics. The line segment is also a potential site for increased speed passenger operations.

For this study, CSX provided two years of GRMS (track strength) measurement data, tie installation data (1996, 1997, 1998) and tonnage data for the study line segment. The GRMS vehicle measurements included:

[1] The GRMS car is the Gage Restraint Measurement System that measures the widening of the track gage under controlled lateral and vertical loading.

- Unloaded Gage
- Loaded Gage
- Delta Gage (Loaded Gage – Unloaded Gage)
- Gage Widening Ratio (GWR)
- Projected Loaded Gage (PLG 24)

Data was received for this line segment corresponding to two GRMS inspections: the first performed in August 1996 prior to the start of a recent series of tie replacement activities (1996, 1997, and 1998) and the second taken in May 1998 after the conclusion of the Spring 1998 tie insertion program. In addition, two on the ground, tie by tie inspections were performed by ZETA-TECH personnel using the *TieInspect* recording system (March 1998 and November 1998).

Development of Track Strength Quality Indices

After analysis of the track strength data, it appeared that a Track Strength Quality Index (TSQI) could be developed which would be an indicator of the tie/fastener (track strength) maintenance condition for an extended stretch of track. Because tie data is often stored on a per mile basis, a one mile[2] unit of track was initially defined as the baseline length for calculating the TSQI. This index is envisioned as a parallel index to the Track Quality Indices (TQIs) currently used to summarize and evaluate track geometry data from conventional track geometry recording cars.

Initial examination was made of the statistical mean of five GRMS output values:

- Unloaded Gage
- Loaded Gage
- Delta Gage (Loaded Gage – Unloaded Gage)
- Gage Widening Ratio (GWR)
- Projected Loaded Gage (PLG 24)

where:

$$PLG24 = UTG + A * (LTG - UTG)$$

$$GWR = (LTG - UTG)/L * 16000$$

and

UTG is the unloaded gage
LTG is the loaded gage
A is a constant of the order of 1.6 for the GRMS vehicle [2]
L is the lateral load applied by the GRMS.

[2] Since not all railroad miles are 5280 feet, the full length of the mile was used and normalized to 5280'.

Note that the Projected Loaded Gage (PLG 24) corresponds closely to the loaded gage, and combines both the tie lateral (gage) strength and the gage itself. It is thus sensitive to both wide gage and weakened track strength. The GWR corresponds closely to the Delta Gage (normalized for applied load) and is sensitive primarily to the track strength itself (by design it is not sensitive to wide gage).

Because of inconsistencies in the 1996 GWR data results [1], the subsequent analysis focused on the loaded gage directly (which is completely unaffected by the unloaded gage) and the PLG24 which is not as strongly effected by the observed problem with the data.

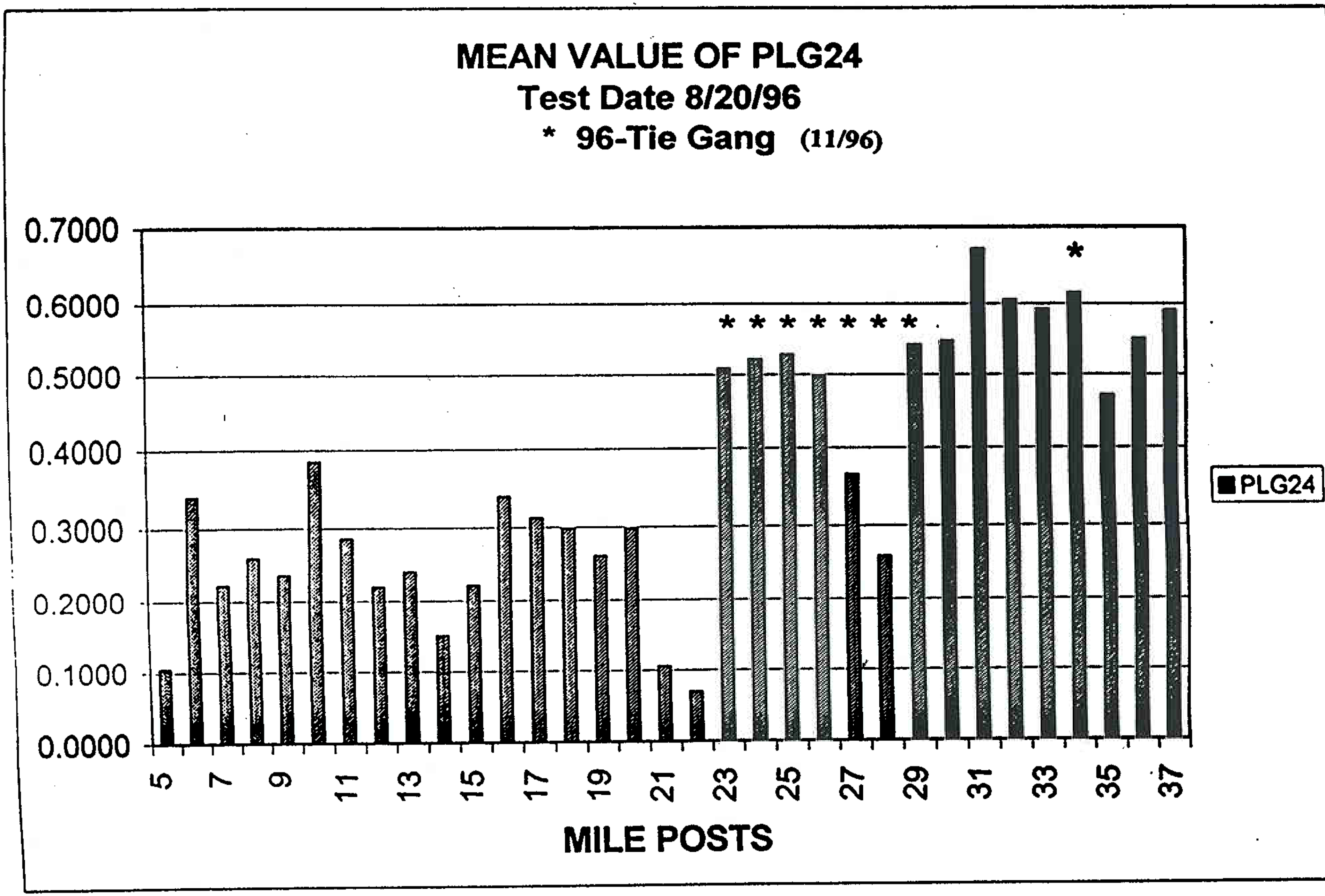
Analysis of Track Strength Data

Initial evaluation of the TSQI data was performed using the August 1996 data in a mode corresponding to that of a maintenance planning officer, i.e. to help utilize the data for planning tie programs. As such this data was compared to the follow up CSX tie programs. Figure 1A presents the mean value of the PLG24 output for the segment CFP MP 5 to CFP MP 37, with the locations of the November 1996 tie program superimposed. Examination of this Figure indicates that the region between MP 23 and MP 37 shows significant higher mean PLG value than does the region between MP 5 and 22. Noting, that MP 30 through 37 was scheduled for tie work in 1998, this data suggests an initial correlation between CSX timbering and GRMS PLG 24 measurements.

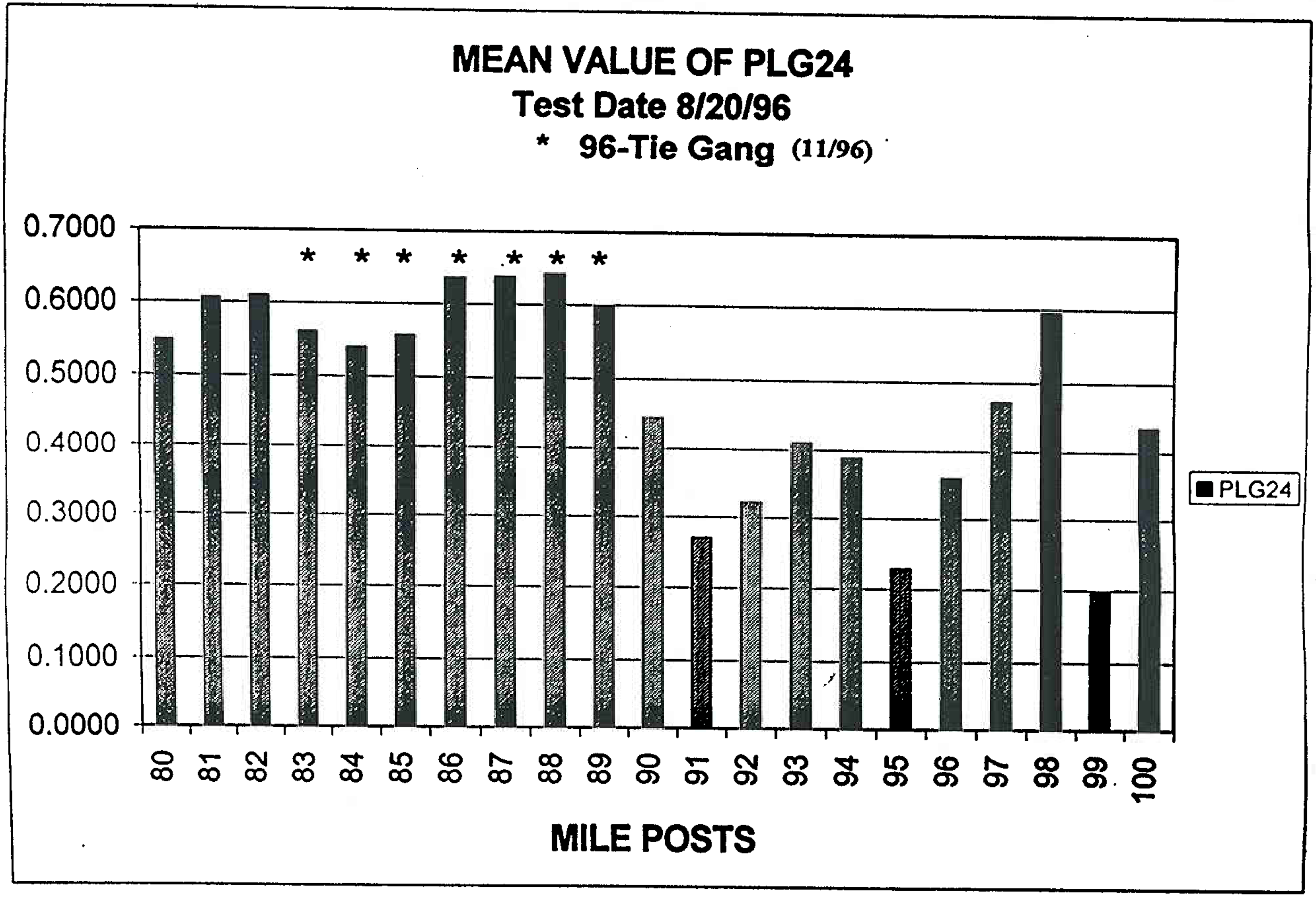
Examination of the tie data for CFP MP 80 through 100 showed similar behavior. Examination of the mean PLG24 data (Figure 1B) shows that the miles timbered had for the most part the highest PLG24 values measured prior to the timbering operation, and, significantly higher than the adjacent miles 90 – 97 which were not timbered. This again suggests a good correlation between PLG measurements and actual tie counts (on which the timbering program was based).

Examination of the standard deviations for all five parameters together with the mean + standard deviation (mean + sigma) values show significantly less sensitivity to the actual tie program [1].

In order to attempt to achieve a better correlation with the actual CSX timbering program experience, a bottom up approach was also attempted. This analysis approach was based on a threshold in which the number of ties (or feet of track) above a define threshold were summed (on a per mile basis) and compared to actual tie insertions. Figure 2 compares such a threshold based approach (using a threshold for PLG24 of 0.5) and compares this parameter to actual tie gang activity in 1996 (following the GRMS inspection). These threshold based values did not appear to have the same level of consistency as did the mean values presented in Figure 1A.

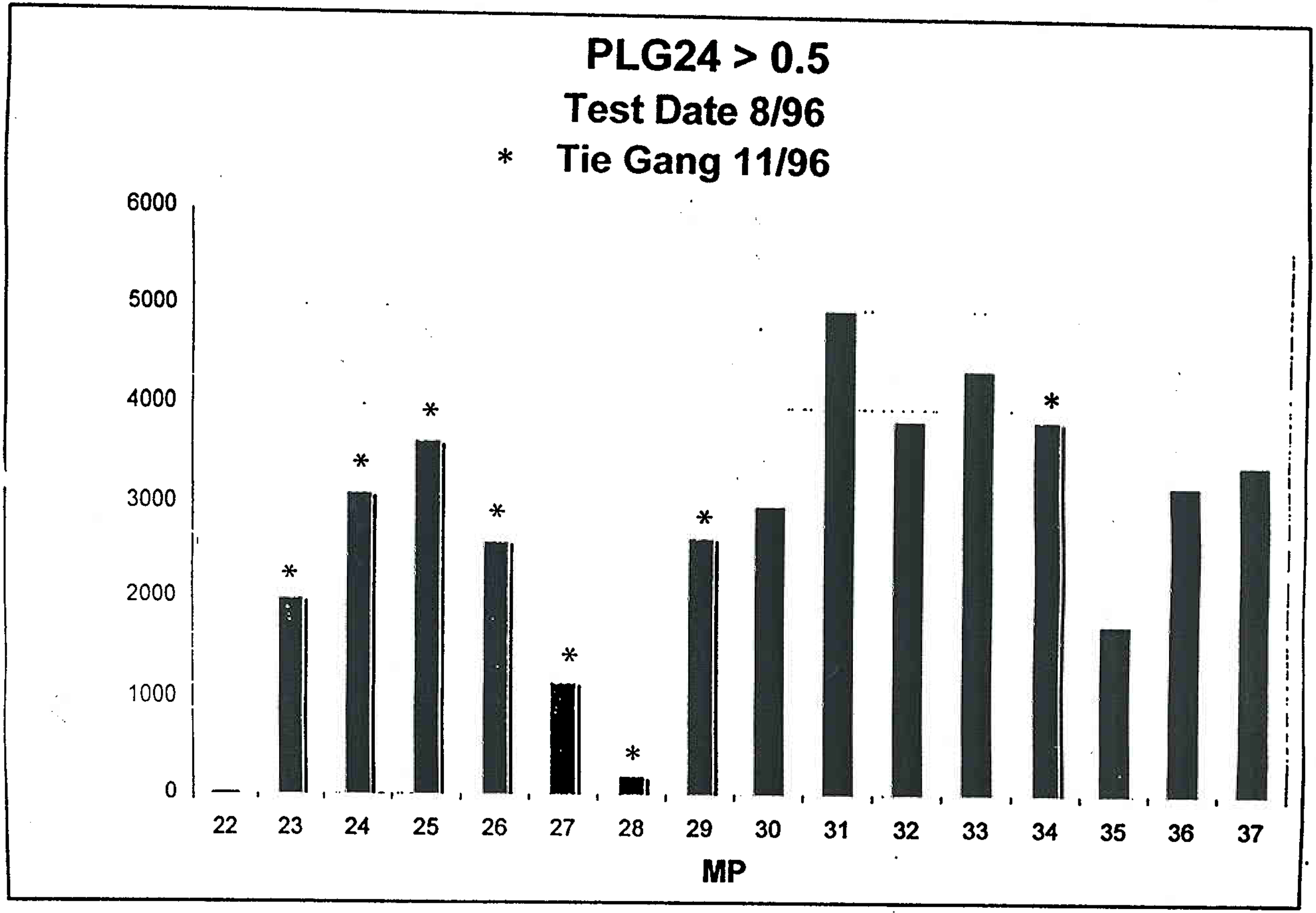


MEAN VALUE OF PLG24



MEAN VALUE OF PLG24

FIGURE 2



PLG24 > 0.5

When the 1998 GRMS data became available, a more intensive analysis of this data was performed using both the 1996 and 1998 GRMS data together with 1996, 1997, and 1998 tie insertion data (which included actual ties inserted per mile). This analysis focused on the following two TSQI indices:

- Mean Loaded Gage; the statistical mean (average) of all loaded gage measurements in the mile.
- Mean PLG24; the statistical mean (average) of all PLG24 measurements in the mile.

Figures 3 and 4 present a mile by mile summary of the mean loaded gage and mean PLG24 for both the 1996 and 1998 GRMS runs for the entire study segment (MP 4 through 109). Also presented are the location of tie gang activity (by year) and the corresponding number of ties inserted between the two measurement cycles (right hand axis of graphs). Note: the data set includes segments of track where significant tie replacement occurred during the period 1996 through 1998 as well as areas where no tie replacement had occurred. Thus, for the mean loaded gage (Figure 3):

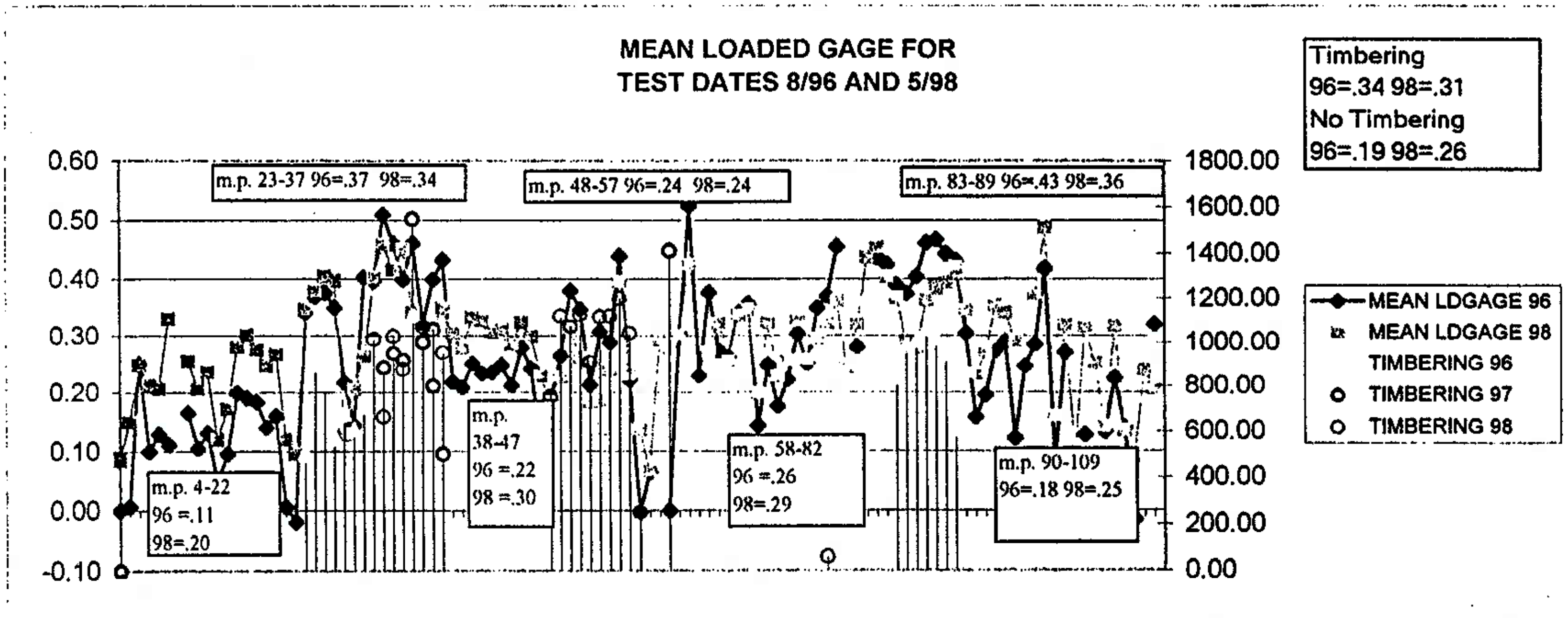
Zones where tie insertion occurred:

- For MP 23 through 37, the mean loaded gage for 1996 was 0.37. For 1998, the mean loaded gage was 0.34
- For MP 48 through 57, the mean loaded gage for 1996 was 0.24. For 1998, the mean loaded gage was 0.24
- For MP 83 through 89, the mean loaded gage for 1996 was 0.43. For 1998, the mean loaded gage was 0.36
- For all miles where ties have been inserted; the mean loaded gage for 1996 was 0.34. For 1998, the mean loaded gage was 0.31

Zones where no tie insertion occurred:

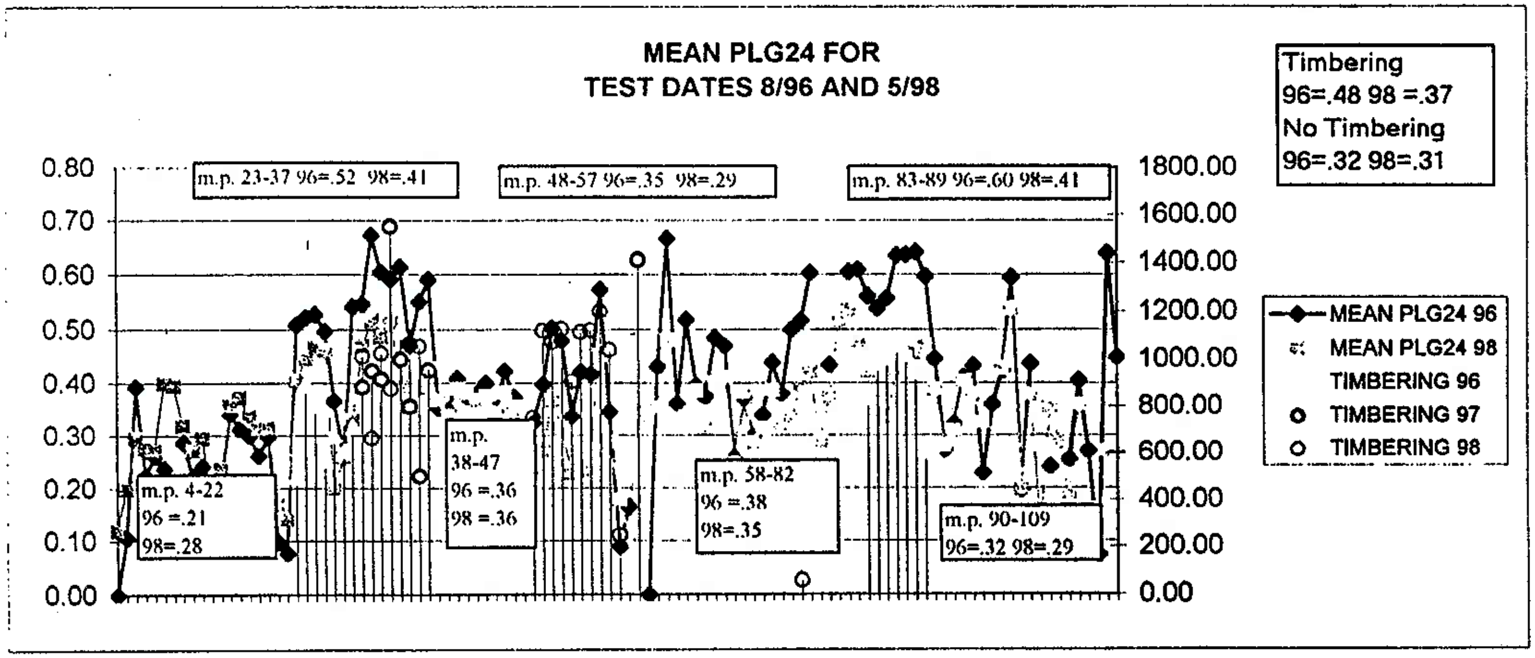
- For MP 4 through 22, the mean loaded gage for 1996 was 0.11. For 1998, the mean loaded gage was 0.20
- For MP 38 through 47, the mean loaded gage for 1996 was 0.22. For 1998, the mean loaded gage was 0.30
- For MP 58 through 82, the mean loaded gage for 1996 was 0.26. For 1998, the mean loaded gage was 0.29
- For MP 90 through 109, the mean loaded gage for 1996 was 0.18. For 1998, the mean loaded gage was 0.25
- For all miles where no ties have been inserted; the mean loaded gage for 1996 was 0.19. For 1998, the mean loaded gage was 0.26

FIGURE 3


MEAN LOADED GAGE FOR
TEST DATES 8/96 AND 5/98
Timbering
96=.34 98=.31
No Timbering
96=.19 98=.26
m.p. 23-37 96=.37 98=.34
m.p. 48-57 96=.24 98=.24
m.p. 83-89 96=.43 98=.36
m.p. 4-22
96 =.11
98=.20
m.p.
38-47
96 =.22
98 =.30
m.p. 58-82
96 =.26
98=.29
m.p. 90-109
96=.18 98=.25
MEAN LDGAGE 96
MEAN LDGAGE 98
TIMBERING 96
TIMBERING 97
TIMBERING 98
0.60
0.50
0.40
0.30
0.20
0.10
0.00
-0.10
1800.00
1600.00
1400.00
1200.00
1000.00
800.00
600.00
400.00
200.00
0.00

8

FIGURE 4


MEAN PLG24 FOR
TEST DATES 8/96 AND 5/98
Timbering
96=.48 98 =.37
No Timbering
96=.32 98=.31
m.p. 23-37 96=.52 98=.41
m.p. 48-57 96=.35 98=.29
m.p. 83-89 96=.60 98=.41
m.p. 4-22
96 =.21
98=.28
m.p.
38-47
96 =.36
98 =.36
m.p. 58-82
96 =.38
98=.35
m.p. 90-109
96=.32 98=.29
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
1800.00
1600.00
1400.00
1200.00
1000.00
800.00
600.00
400.00
200.00
0.00
MEAN PLG24 96
MEAN PLG24 98
TIMBERING 96
TIMBERING 97
TIMBERING 98

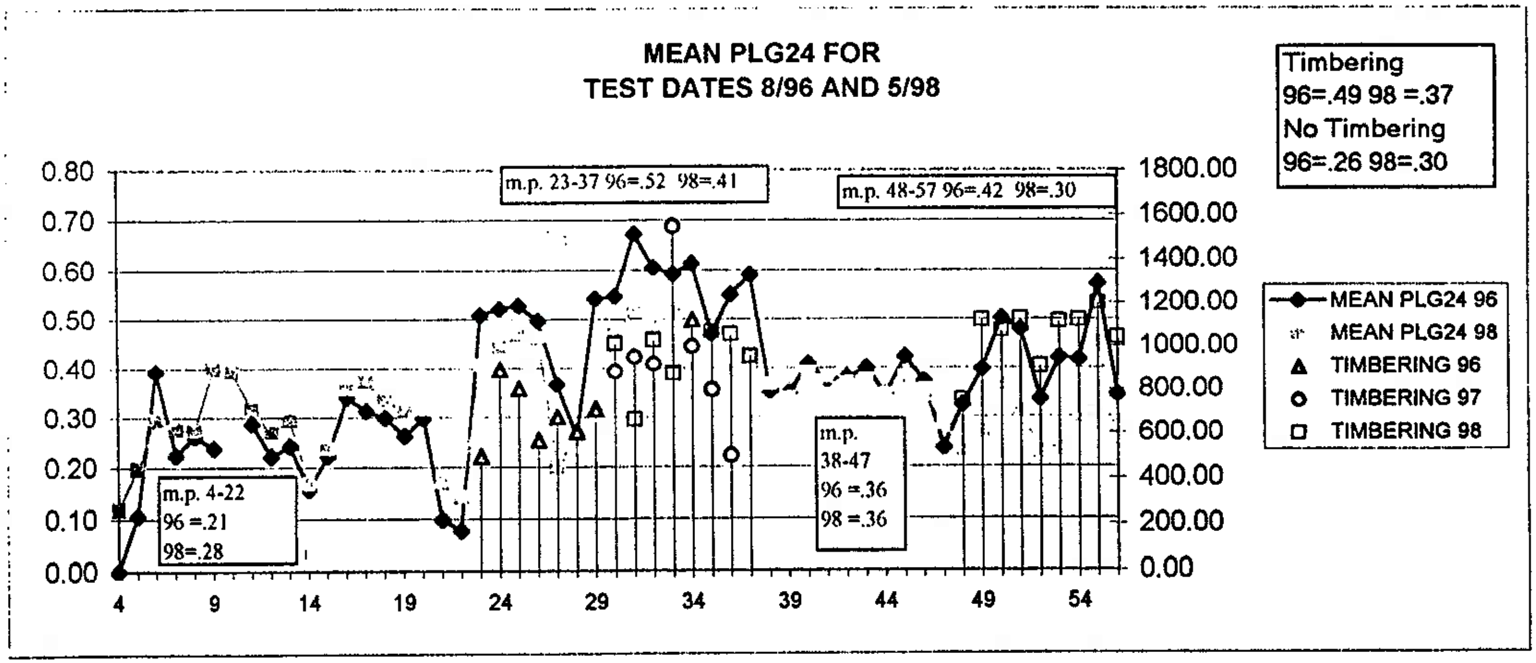
Analysis of this data showed that in those zones where no ties were inserted (4 zones), the mean loaded gage increased in all cases, corresponding to a degradation of tie condition with time (2 years) and traffic (between 40 and 100+ MGT depending on MP, [1]). Furthermore, the zone with the greatest traffic density, MP 4 through 22, had the largest increase in mean loaded gage, an increase of 80%. Overall, for all zones, the loaded gage increased from 0.19 to 0.26, an increase of 37%. *Based on an average tonnage of 65 MGT over the two years, this corresponds to an increase in loaded gage of 0.0011 per MGT.*

Analysis of the zones where ties were inserted showed that in these cases, the average loaded gage decreased, corresponding to the improvement in track strength due to the new ties and fasteners. (The only exception to this was MP 48 through 57 where the mean loaded gage remained at 0.24. However, in this zone, the value of the mean loaded gage, which corresponded to the tie condition, was significantly lower than those of the adjacent two zones, which were of the order of 0.34 to 0.43, significantly higher.)

Finally, it should be noted that in general, the mean loaded gage for the miles that had ties inserted was measurably higher than those for which no ties had been inserted (with the exception of the track between MP 48 and 57). This is in agreement with the railroad practice of installing ties only in those miles where the track strength is inadequate and additional ties to upgrade the track strength is required. This was clearly the case for the zones MP 23 through 37 and 83 through 89.

Figure 5 presents the PLG24 data in the same format. As can be seen in Figure 5 through 57, those miles where ties were inserted had a measurable reduction in PLG24 with the average decreasing from 0.48 to 0.37. However, for the case of those miles where no ties were inserted, the data was more erratic. This appears to be due to the effect of the problem 1996 unloaded gage data noted earlier.

FIGURE 5


MEAN PLG24 FOR
TEST DATES 8/96 AND 5/98
Timbering
96=.49 98 =.37
No Timbering
96=.26 98=.30
m.p. 23-37 96=.52 98=.41
m.p. 48-57 96=.42 98=.30
m.p. 4-22
96 =.21
98=.28
m.p.
38-47
96 =.36
98 =.36
MEAN PLG24 96
MEAN PLG24 98
TIMBERING 96
TIMBERING 97
TIMBERING 98
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
1800.00
1600.00
1400.00
1200.00
1000.00
800.00
600.00
400.00
200.00
0.00
4
9
14
19
24
29
34
39
44
49
54

Development of Correlation Equations

As was noted above, there appeared to be a distinct correlation between the change in track strength quality indices and the number of ties installed. In order to confirm this correlation and to obtain a specific correlation equation, statistical regression techniques were applied to this data set.

Figure 6 presents the results of the correlation between the change in loaded gage (Delta LDGAGE) and the ties inserted. This was performed for the entire data set. A separate analysis for each of the two insertion years was also performed to separate out the two year time change and associated change in track strength. ([1]). As can be seen in this figure, an acceptable (and valid) statistical correlation was obtained.

The corresponding relationship for the improvement in loaded gage with number of inserted ties was found to be given by:

$$LDGAGE_{new} = LDGAGE_{old} + a^{*}\ TIES + b$$

Where:

$LDGAGE_{new}$ is the predicted mean (per mile) loaded gage after ties are inserted

$LDGAGE_{old}$ is the measured mean (per mile) loaded gage prior to ties insertion

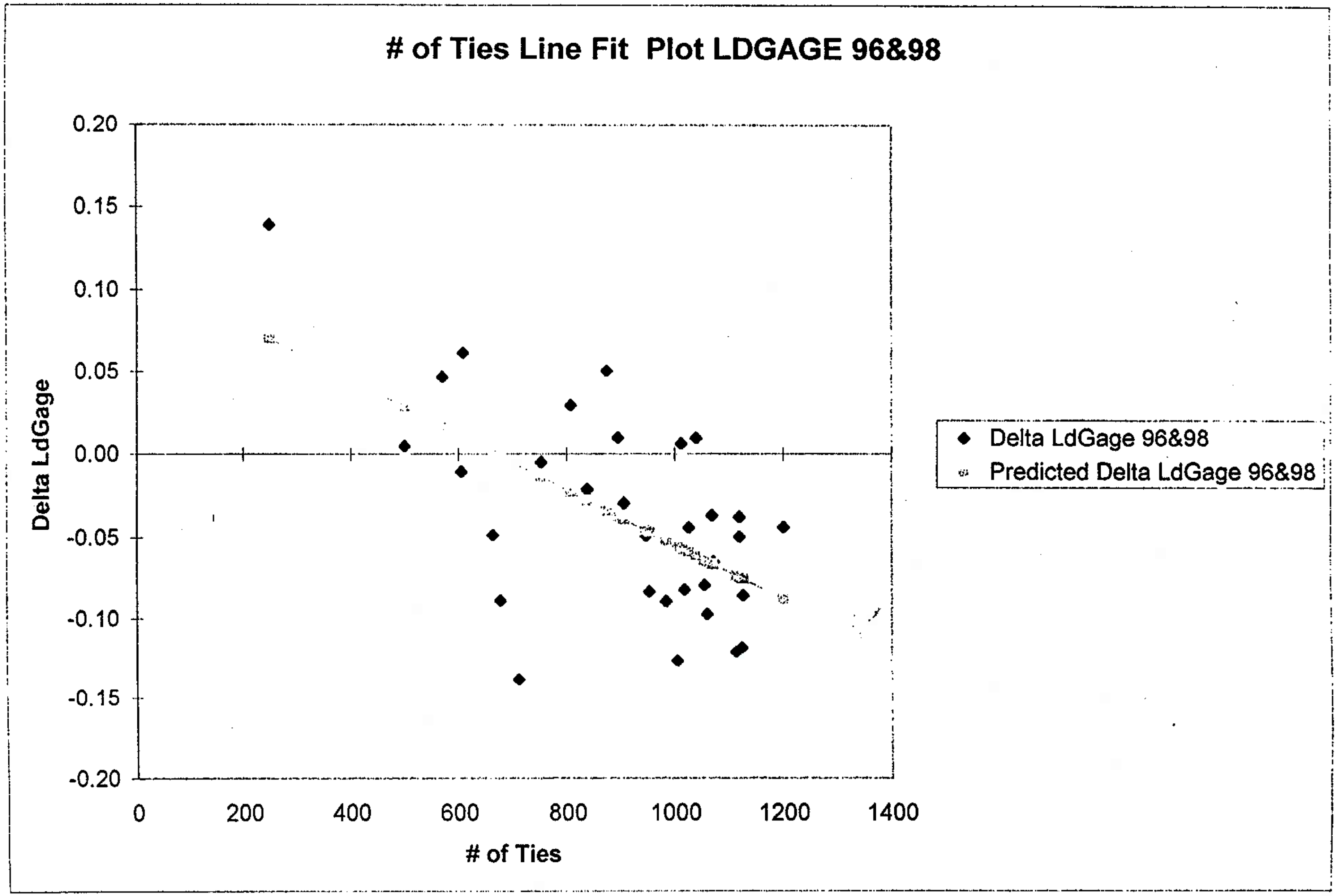
TIES is the number of ties inserted in the mile

a is a constant (slope) equal to –0.0002

b is a constant (intercept) equal to the additional degradation that occurs between the time of the first measurement (before) and the second measurement. Note, if the constant value of 0.11 is used, then the relationship is valid only for insertions greater than 600 ties per mile.

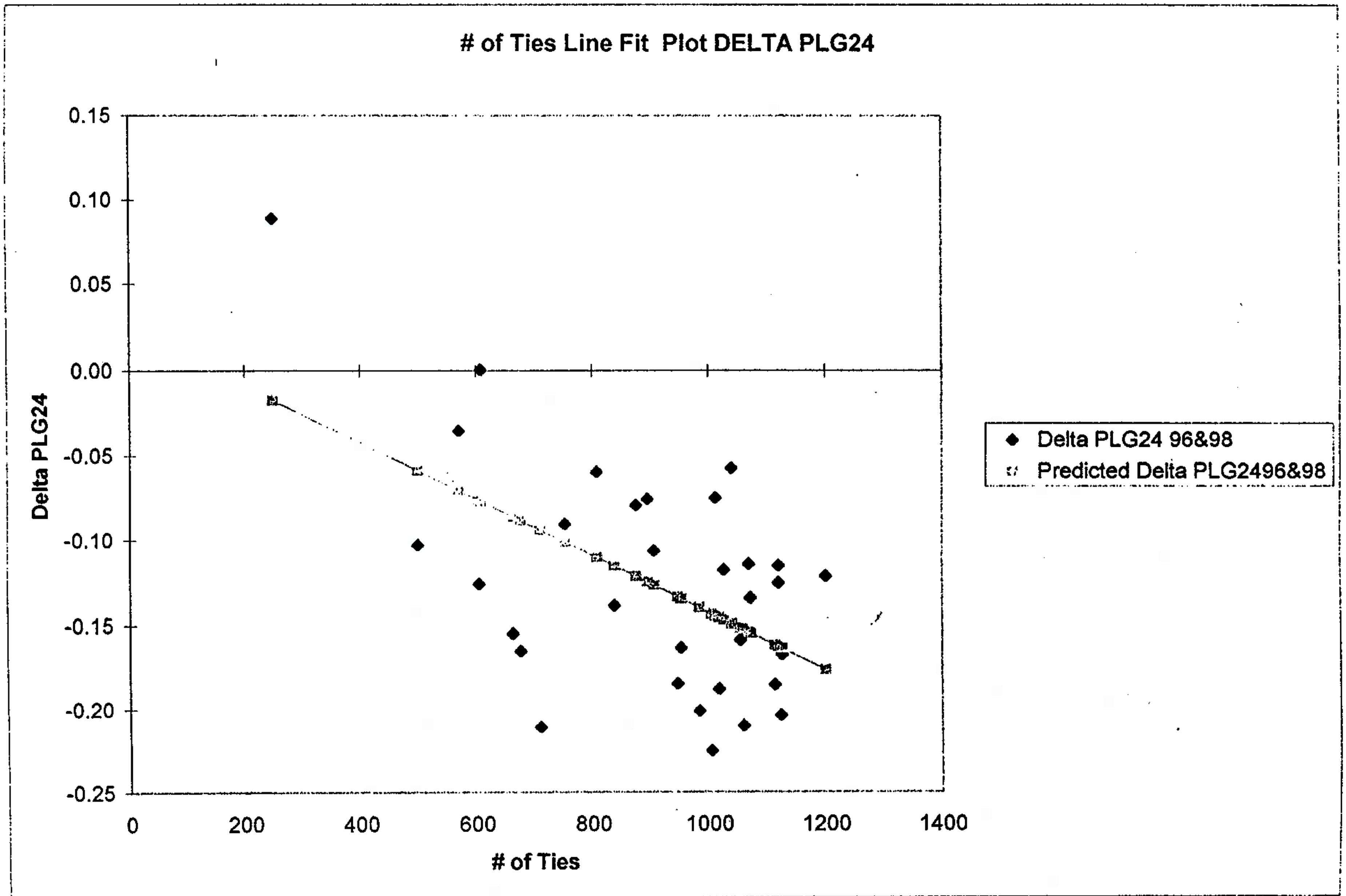
Figure 7 present the results of the correlation between the change in PLG24 (Delta PLG24) and the ties inserted. As with the case of loaded gage, this was performed for the entire data set. Again, valid statistical correlation was obtained.

FIGURE 6



# of Ties Line Fit Plot LDGAGE 96&98
0.20
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
-0.20
Delta LdGage
0
200
400
600
800
1000
1200
1400
# of Ties
Delta LdGage 96&98
Predicted Delta LdGage 96&98

FIGURE 7



# of Ties Line Fit Plot DELTA PLG24
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
-0.20
-0.25
Delta PLG24
0
200
400
600
800
1000
1200
1400
# of Ties
Delta PLG24 96&98
Predicted Delta PLG2496&98

The corresponding relationship for the improvement in PLG24 with number of inserted ties is given by:

$$PLG24_{new} = PLG24_{old} + a' * TIES + b'$$

Where:

PLG24 (new) is the predicted mean (per mile PLG24 after ties are inserted)

PLG24 (old) is the measured mean (per mile PLG24 prior to ties insertion)

TIES is the number of ties inserted in the mile

a' is a constant (slope) equal to –0.0002

b' is a constant (intercept) equal to the additional degradation that occurs between the time of the first measurement (before) and the second measurement. Note, if the constant value of 0.025 is used, then the relationship is valid only for insertions greater than 35 ties per mile.

Thus, it appears that a relationship can be developed that related changes in the TSQI with tie insertions.

In addition to the relationship between improvement of TSQI with tie insertions, a relationship was also obtained for the *degradation* of TSQI with tonnage. This was noted previously, for the loaded gage TSQI to be of the order of 0.0011 per MGT (corresponding to 0.11 per 100 MGT). The corresponding relationship for PLG24 was found to be of the form

$$PLG24_{new} = PLG24_{old} + 0.001*MGT.$$

Correlation of Track Strength data with Anticipated Load Environment

The next issue addressed was the definition of proper TSQI values for the maintenance of track for the range of equipment under consideration. This includes the freight traffic, for which the line is currently being maintained, and future high speed passenger traffic.

Figure 8 presents previous TSC sponsored tests of track strength [2] which indicates that a GWR of 0.52 represents weak cut spike track, a value of 0.32 represents good wood tie track, and a value of 0.15 represents good concrete tie track. Corresponding GWR data taken during these CSX GRMS runs showed a mean GWR values of 0.25 to 0.38 corresponded to track that CSX determined as needing ties [1]. Noting that the data in Figure 8 corresponds to a spot (local) measurement while the mean (TSQI) data presented here-in corresponds to a per mile mean, it is necessary to calibrate the spot measurement data (used primarily for safety measurement) to the more general TSQI data (used in maintenance planning).

Based on the two sets of data [1], an initial estimate for a "per mile" mean TQSI value was found to be 50 to 75% of the "spot" TQSI value.

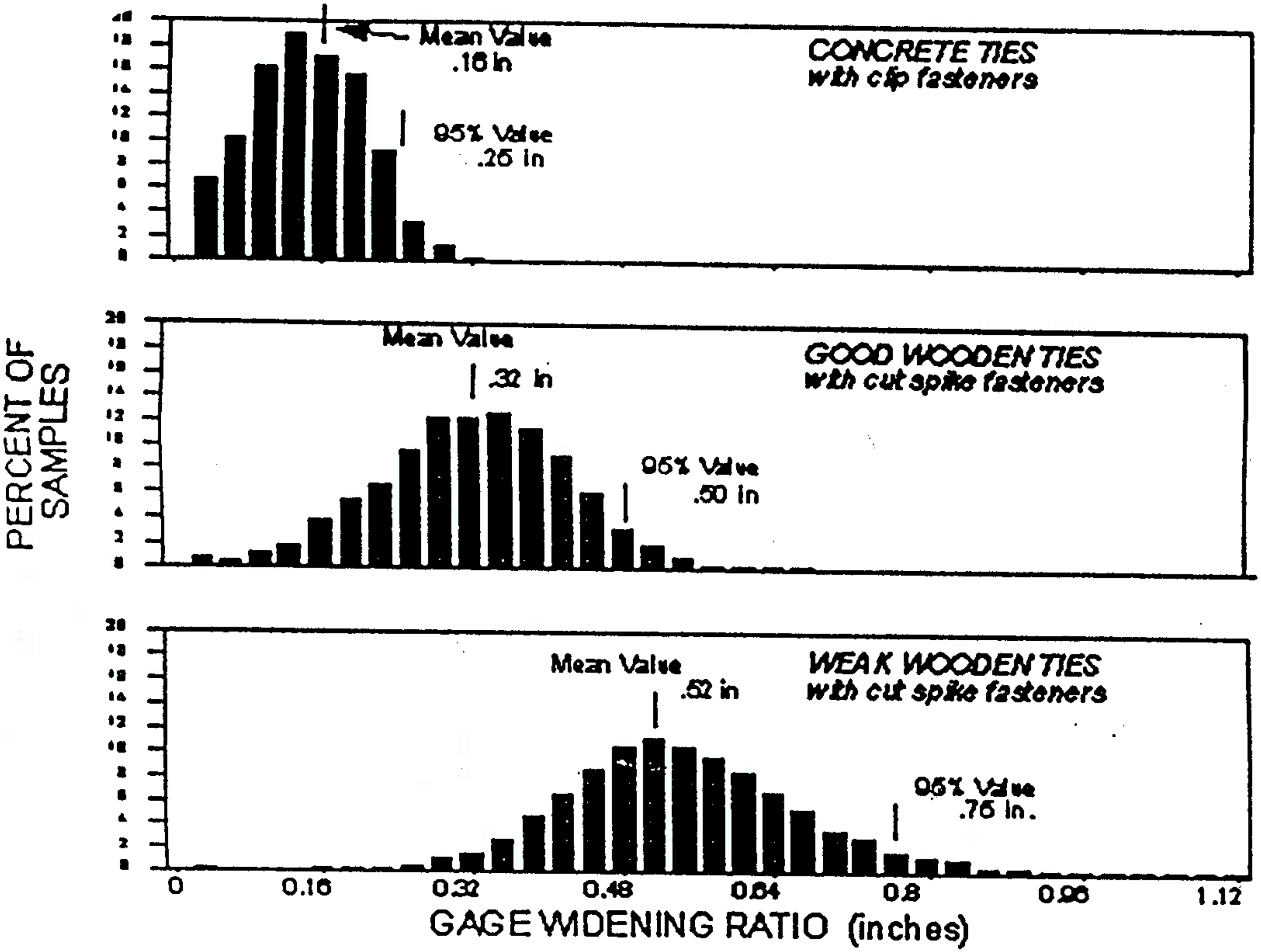
In the case of PLG24, Figure 1A shows that the range of mean PLG24 for track requiring timbering (based on CSX standards for freight traffic) is of the order of 0.35 to 0.70 with an average value of 0.48. The corresponding range of mean loaded gage for track requiring timbering (based on CSX standards for freight traffic) is of the order of 0.24 to 0.50 with an average value of 0.34.

The new FRA standards [3] require the following gage widening restrictions:

Class of Track	Maximum Speed (mph)		Maximum Gage Widening*
	Freight	Passenger	
Class 3	40	60	1.25"
Class 4	60	80	1.00"
Class 5	80	90	1.00"
Class 6	N/A	110	0.75"**

* from nominal gage of 4' 8 ½"
** maximum change of 0.5" within 31 feet

FIGURE



Mean Value
.16 in
95% Value
.25 in
CONCRETE TIES
with clip fasteners
Mean Value
.32 in
95% Value
.50 in
GOOD WOODEN TIES
with cut spike fasteners
Mean Value
.52 in
95% Value
.76 in.
WEAK WOODEN TIES
with cut spike fasteners
PERCENT OF SAMPLES
0
0.16
0.32
0.48
0.64
0.8
0.96
1.12
GAGE WIDENING RATIO (inches)

These are for "spot" inspection, they are too restrictive for a maintenance planning index (TSQI). However, taking 50% of this spot value (the bottom of the range noted above), a corresponding per mile mean limit for PLG24 (the "maintenance" PLG24) would now be as follows:

	"Maintenance" PLG24
Low Speed Freight (Class 3)	0.625
Moderate/High Speed Freight Track (Class 4)	0.5
Passenger (Class 6)	0.375

Note: the limit of 0.5 corresponds to the measured average of the mean PLG24 on the track that was actually timbered by CSX (thus determined by the railroad inspectors as requiring ties).

These limits allow for the determination of the number of ties to be inserted per mile, by calculating the difference between the "actual" (measured) mean PLG24 for the mile and the above defined limit. This difference is then divided by the "slope" of the PLG 24 equation presented previously to calculate the number of ties to be inserted.

Determination of Ties Required to Reach Maintenance Threshold

By using the "maintenance" PLG24 levels defined above as a guide, the number of ties needed to reach these maintenance levels can be determined using the actual GRMS values, per mile, and the regression equations. Using these results, it is possible to extrapolate the forward to examine the potential for maintenance for high speed track. Noting that the "Maintenance" PLG24 for high speed (Class 6) track was set at 0.375" (corresponding to 56 7/8"), the previously defined equation can be used to determine the number of ties necessary to bring the track to the higher strength standard associated with high speed operations. The results of such an analysis is presented in Table 1 which shows, for the selected mileposts, the number of ties that would have to be installed to reach the more restrictive PLG24 level required for high speed track. (Note, these values are based on the regression equation presented previously). Thus, for the case of MP 34, 1431 ties would be required (as opposed to the 1124 ties actually inserted which brought the track to a level of 0.41).

Thus, it can be seen that the number of ties that are required to achieve a defined level of track strength (as defined by the PLG24) can be determined using this methodology. This, in turn, supports the approach of an analytical methodology to define

Table 1

MilePost	96 GRMS MEAN PLG24	98 GRMS MEAN PLG24	Total Equ. Ties	GRMS Ties PLG24>.4	GRMS Ties PLG24>.5	GRMS Ties PLG24>.6	GRMS Ties PLG24>.7	GRMS Ties PLG24>.8	# of Ties Installed	Predicted PLG24 W/O Constatnt PLG24>.4	Predicted PLG24 W/O Constatnt PLG24>.5	Predicted PLG24 W/O Constatnt PLG24>.6	Predicted PLG24 W/O Constatnt PLG24>.7	Predicted PLG24 W/O Constatnt PLG24>.8	# of Ties (Equation) Mean PLG24 = .375
23	0.51	0.41	3198	1452	467	218	123	37	500	0.27	0.43	0.47	0.49	0.50	802
24	0.52	0.45	3192	2290	564	76	14	0	895	0.14	0.43	0.51	0.52	0.52	877
25	0.53	0.47	3190	2355	1157	274	34	7	808	0.13	0.33	0.48	0.52	0.53	916
26	0.50	0.46	3152	1817	944	467	316	233	571	0.19	0.34	0.42	0.44	0.46	732
27	0.37	0.20	3148	66	7	0	0	0	677	0.36	0.37	0.37	0.37	0.37	0
28	0.26	0.26	3176	175	13	1	0	0	609	0.23	0.26	0.26	0.26	0.26	0
29	0.54	0.33	3211	629	186	44	15	7	711	0.44	0.51	0.53	0.54	0.54	1000
34	0.61	0.41	3147	1458	739	292	79	15	1124	0.37	0.49	0.57	0.60	0.61	1431

"mean" track strength and corresponding tie insertion requirements, based on that strength. Furthermore, the above strongly indicates that *the use of the GRMS data as part of the tie installation decision making process can result in a potential reduction of ties needed to be installed in order to achieve an acceptable level of track strength[1] from both the safety and maintenance points of view.*

Summary

The results of this study indicates that Track Strength Quality Indices, TSQIs, can be developed which relate the GRMS output data to the general condition of the tie-fastener system. Furthermore, these TSQIs can be correlated to the number of ties installed, to develop a predictive relationship between improvements in TSQIs and ties installed.

The TSQI parameters that were found to be most meaningful in representing the track condition were "mean" values, calculated over a mile length of track, of the following key GRMS outputs:

- Loaded Gage
- Projected Loaded Gage (PLG 24)
- Delta Gage (Loaded Gage – Unloaded Gage)[2]
- Gage Widening Ratio (GWR)[2]

Analysis of the GRMS degradation data (between the 1996 and 1998 GRMS runs) showed that in those zones where no ties were inserted, the mean loaded gage increased in all cases, corresponding to a degradation of tie condition with time and traffic. The overall degradation relationship for PLG24 was found to correspond to:

$$PLG24_{new} = PLG24_{old} + 0.001 * MGT.$$

Analysis of the GRMS data for the zones where ties were inserted, showed that in these cases, the average loaded gage decreased, corresponding to the improvement in track strength due to the new ties and fasteners. Using statistical regression techniques, this data resulted in the development of a correlation between the Track Strength Quality Index parameters and the number of ties inserted of the form:

$$PLG24_{new} = PLG24_{old} + A' * TIES + b'$$

[1]Note, this does not necessarily include ties needed for vertical support, which may not be identified by the GRMS data.

[2]Only limited results were obtained from these parameters due to an apparent data problem with the unloaded gage measurements taken from the August 1996 GRMS run.

A similar relationship was obtained for Loaded Gage.

Based on the results of the measurements and data collected on this line, together with earlier FRA and TSC test data for track strength values, a set of maintenance thresholds for the TSQI planning index were developed. These, per mile mean limit for PLG24 (the "maintenance" PLG24) were set as follows:

	"Maintenance" PLG24
Low Speed Freight (Class 3)	0.625
Moderate/High Speed Freight Track (Class 4)	0.5
Passenger (Class 6)	0.375

Note: the limit of 0.5 corresponds to the measured average of the mean PLG24 on the track that was determined by CSX track inspectors as requiring ties.

These limits allow for the determination of the number of ties to be inserted per mile, by calculating the difference between the "actual" (measured) mean PLG24 for the mile and the above defined limit. This difference is then divided by the "slope" of the PLG 24 equation presented previously to calculate the number of ties to be inserted.

Furthermore, it appears that the use of GRMS data as part of the tie installation decision making process can result in a *potential* reduction in ties needed to be installed in order to achieve an acceptable level of *track strength* from both the safety and maintenance points of view.

The "next" step in the process is the determination of whether such a track strength based approach to tie replacement provides a more economical track maintenance policy than the "convential" tie replacement approach.

Based on the above results, it appears that the GRMS data, when developed in the form of TSQI values, on a mile by mile or segment by segment basis, can be used as part of the maintenance planning process.

Acknowledgment

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