Investigation of Minimum Number of Drop Levels and Test Points for FWD Network-Level Testing Protocol in Iowa Department of Transportation

아이오와 주교통국의 FWD 네트워크 레벨 조사를 프로토콜을 위한 최소 하중 재하 수와 조사지점 수의 결정

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ABSTRACT

In 2007, Iowa department of transportation (DOT) initiated to run the falling weight deflectometer (FWD) network-level testing along Iowa highway and road systems and to build a comprehensive database of deflection data and subsequent structural analysis, which are used for detecting pavement structure failure, estimating expected life, and calculating overlay requirements over a desired design life. Iowa’s current FWD network-level testing protocol requires that pavements are tested at three-drop level with 8-deflection basin collected at each drop level. The test point is determined by the length of the tested pavement section. However, the current FWD network-level program could cover about 20% of Iowa’s highway and road systems annually. Therefore, the current FWD network-level test protocol should be simplified to test more than 20% of Iowa’s highway and road systems for the network-level test annually. The main objective of this research is to investigate if the minimum number of drop levels and test points could be reduced to increase the testing production rate and reduce the cost of testing and traffic control without sacrificing the quality of the FWD data. Based upon the limited FWD network-level test data of eighty-three composite pavement sections, there was no significant difference between the mean values of three different response parameters when the number of drop levels and test points were reduced from the current FWD network-level testing protocol. As a result, the production rate of FWD tests would increase and the cost of testing and traffic control would be decreased without sacrificing the quality of the FWD data.
1. INTRODUCTION

The Iowa department of transportation (DOT) manages about 16,000-km highway using a pavement management information system (PMIS), which provides pavement history, detailed project history, and pavement surface condition data. Recently, non-destructive testing (NDT) using falling weight deflectometer (FWD) was added to the PMIS to provide a measure of the structural capacity of highway and road systems. The FWD is one of the primary NDT tools and it has been used to determine the modulus of the pavement layer. Several state agencies have performed the FWD test as part of their network-level pavement management system (Alam et al., 2007; Damnjanovic and Zhanmin, 2006; Hossain and Chowdhur, 1999; Zhang et al., 2003; Zaghloul et al., 2005).

In 2007, Iowa DOT initiated to run the FWD test at the network level and to build a comprehensive database of deflection data. The subsequent structural analysis was used for detecting pavement structural failure, estimating expected life, and determining an overlay thickness. Iowa’s current FWD network-level testing protocol requires that pavements are tested at three-drop level corresponding to 9,000-lb, 12,000-lb, and 15,000-lb with 8-deflection basin collected for each drop level. The FWD test points are determined by the length of the pavement section. However, the current FWD network-level testing protocol can cover only 20% of Iowa’s highway system per year. Therefore, the current FWD network-level test procedure is being simplified in order to test more pavement sections annually. The main objective of this study is to investigate if the reduced number of drop levels and test points would affect the quality of FWD data and the pavement structural analysis.

2. LITERATURE REVIEW

The falling weight deflectometer (FWD) is one of the most widely used devices to measure pavement deflections and provides information related to layer stiffness and material properties. In 2002, it was reported that twenty-eight highway agencies used the FWD device at the project level and seven highway agencies used it at both project- and network-level. Twenty-two highway agencies tested up to 800 roadway lane-km per year (Piyatrapommi et al., 2003). The FWD device has become an extremely valuable tool for the pavement evaluation of bearing capacity on the existing, rehabilitated, and newly constructed pavements (Nazef and Choubane, 2002; Zaghloul et al. 2005).

FWD deflection measurement procedure was standardized by AASHTO T 256 and ASTM D 4695 (AASHTO 2006; ASTM 2003). The FWD testing procedure normally recommends: 1) for a network level, a testing interval should be at from 190m to 500m with a minimum of seven tests per pavement section, 2) for a general project level, a testing interval should be at from 50m to 190m with a minimum of fifteen tests per pavement section, and 3) for a detailed project level, a testing interval should be at from 10m to 50m.

In New Jersey DOT, Zaghloul et al. (1998) selected three-drop level (6,700-lb, 9,000-lb, and 13,000-lb) for the FWD network-level program. For Kansas DOT, Hossain and Chowdhury (1999) recommended that the FWD test interval for the network-level structural evaluation would be two test points per kilometer. Noureldin et al. (2003) proposed two test points per kilometer in the driving lane of one direction by using one-drop level (9,000 lb) for the Indian DOT network-level pavement evaluation. For Virginia DOT, Alam et al. (2007) recommended three test points per kilometer by using three-drop level (9,000-lb, 12,000-lb, and 16,000-lb) with two deflection basins. Martin (2005) recommended the optimal sampling as 100m/km section or 500m/km section in Australia and New Zealand.

2.1. Minimum Number of Drop Levels

Freeman and Alexander (2001) studied to determine whether the number of drop levels from FWD test could be modified to reduce cost, without losing a significant amount of information and determined that a reduction in replicate drops from four to two and an increase in spacing from 8m to 15m would not cause a substantial loss in information. Alam et al. (2007) found that Virginia DOT’s four-drop level (6,000-lb, 9,000-lb, 12,000-lb, and 16,000-lb) test protocol can be changed to a one-drop level (9,000-lb) test protocol without sacrificing the quality of data.

2.2. Minimum Number of Test Points

The minimum number of test points is selected to determine the representative value of pavement strength parameters while taking account of the variability of pavement strength (Martin, 2005). Kestler (1997) addressed that adjustment of optimal test point configuration would optimize the FWD testing process by eliminating both underestimating and overestimating and recommended that FWD test point spacing for network inventory ranges from 30m to 300m, with outliers in reaching 900m. Lytton et al. (1990) determined a minimum of three test points...
points per kilometer to provide accurate structural capacity of the pavement section at the network level. Piyatrapoomi et al. (2003) stated the optimum test spacing would be the longest interval showing an acceptable variation from the representative structural condition based on a 50m to 100m measurement. Alam et al. (2007) indicated that the FWD network-level test should be conducted with one test point per kilometer without reducing the quality of deflection data or subsequent analysis.

3. IOWA’S CURRENT FALLING WEIGHT DEFLECTOMETER NETWORK-LEVEL TESTING PROTOCOL

As shown in Figure 1, currently, Iowa DOT uses JILS-20 FWD, which is manufactured by Foundation Mechanics. JILS-20 FWD unit is trailer mounted devise that record half deflection bowls at discrete test points on the pavement surface by measuring surface deflection at distance ranging from 0 to 150 cm from the center of the load plate. Figure 2 illustrates the location of the deflection sensors to measure the deflection from nine points. JILS-20 FWD unit has load plate with 15-cm diameter and nine displacement-measuring sensors. Nine sensors place at -30cm, 0cm, 20cm, 30cm, 45cm, 60cm, 90cm, 120cm, and 150cm from the center of the loading plate.

Iowa’s current network-level testing protocol requires that pavements be tested at three-drop level corresponding to 9,000-lb 12,000-lb, and 15,000-lb with 8-deflection basin collected at each drop level. The measured deflection data at 12,000-lb and 15,000-lb was normalized to a standard load of 9,000-lb. As illustrated in Figure 3, the FWD test is performed in the outer wheel paths, 60cm from the outer edge, in both directions for 2-lane road and one direction for 4-lane road. It may be appropriate to measure a deflection from the wheel paths where the traffic is significantly heavier than in the adjacent lane. The number of test point for measuring the pavement deflections is determined by the length of recommended pavement section as shown below:

1) Less than 0.8 kilometer: do not test.
2) 0.8 kilometer~3.2 kilometers: 5 test points in the outer wheel paths with opposite sides staggered.
3) 3.2 kilometers~8.0 kilometers: 10 test points in the outer wheel paths with opposite sides staggered.
4) Over 8 kilometers: 1 test point per 800m in the right outer wheel paths with opposite sides staggered.

4. FALLING WEIGHT DEFLECTOMETER NETWORK-LEVEL TESTING PROGRAM

4.1. Data Collection

As shown in Figure 4, the FWD network-level tests were conducted on approximately 310 kilometers of Interstate Highway 29, 35, 80 and 380 in Iowa. Eighty-three composite pavement sections were selected and tested at three-drop level corresponding to 9,000-lb 12,000-lb, and 15,000-lb with 8-deflection basin at each drop level. A total of 610 deflection data sets were collected. The information of existing pavement thickness was obtained from Iowa DOT’s pavement management information system (PMIS).
4.2. Backcalculation

Iowa DOT uses an artificial neural network (ANN)-based backcalculation model, which provides a rapid and accurate prediction of critical responses and deflection profiles of rigid, flexible, and composite pavements. ANNs backcalculation models are capable of predicting the modulus of pavement layers from the FWD deflection basin data and are used in the field for rapidly assessing the condition of the pavement sections during the FWD testing (Bayrok et al., 2005; Ceylan et al., 2004). Eighty-three composite pavement sections were modeled as a three-layer pavement system. The moduli of asphalt surface layer and concrete base layer and coefficient of subgrade reaction were selected as representative response parameters for a comprehensive statistical analysis in this study.

4.3. Statistical Analysis

A statistical analysis was conducted to investigate if the response parameters were significantly different from the combinations of number of drop levels and test points at the FWD network-level program as shown below:

- Seven cases of drop levels: 1) 3-drop: 9,000-lb, 12,000-lb, and 15,000-lb; 2) 2-drop: 9,000-lb and 12,000-lb; 3) 2-drop: 9,000-lb and 15,000-lb; 4) 2-drop: 12,000-lb and 15,000-lb; 5) 1-drop: 9,000-lb; 6) 1-drop: 12,000-lb; and 7) 1-drop: 15,000-lb.

- Three cases of test points: 1) total test points (as-is); 2) 30% reduction of total test points; and 3) 50% reduction of total test points.

Dependent t-test allows researcher to obtain a more powerful test of false null hypothesis and a shorter confidence interval for samples which are obtained by matching. (Kirk 1999). One of assumptions associated with the t-statistics for dependent samples is that if pairs of matched samples are used, the participants in each pair are randomly assigned to the experimental and control conditions. SPSS (version 12.0) was used for the statistical analysis of all FWD test data sets.

To simply the multiple hypothesis testing requirements, Bonferroni correction was employed in this study. For example, if \( k \) tests are to be conducted and the over Type I error rate (i.e., the probability of making at least one Type I error in \( k \) tests) is to be no more than \( \alpha \), then a rule of thumb is to conduct each individual test at a Type I error rate of \( \alpha/k \). If two tests are performed on the FWD test point data, the significance level for the number of drop and deflection basin data which was performed 6 times is 0.0083 (\( \alpha/k = 0.05/6 \)). The null hypothesis is \( H_0: \mu_1 = \mu_2 \) (i.e., there are no differences between means) and the alternative hypothesis is \( H_1: \mu_1 \neq \mu_2 \) (the means of two sets are unequal),
which signifies a two-tailed test, were used to determine if there was a statistical difference.

SPSS provides an estimate of differences as an output along with the confidence intervals and the correlation coefficient. The test results provide the \( t \)-value, the \( p \)-value, and degree of the freedom which the test is conducted. The null hypothesis cannot be rejected if the estimated means is within the calculated confidence intervals that signify that the \( p \)-value is higher than the level of significance.

5. ANALYSIS RESULTS AND DISCUSSION

A statistical analysis was performed to investigate if there was a significant difference in mean values of HMA modulus (\( E_{\text{HMA}} \)), PCC modulus (\( E_{\text{PCC}} \)) and coefficient of subgrade reaction (\( k_s \)) when comparing three-drop level against fewer drop levels with 8-deflection basin collected at each drop level. In addition, the hypothesis was performed if there was a significant difference in mean values of those three response parameters when comparing the data set from whole FWD test points versus one from 30% or 50% reduction of whole FWD test points at three-drop level with 8-deflection basin.

5.1. Minimum Number of Drop Levels

To find out the strength of the relationship between the compared variety FWD test sets of three response parameters, correlation coefficient values are presented with plots of whole data points. Figure 5 shows plots of backcalculated HMA modulus, PCC modulus and coefficient of subgrade reaction, for 2-drop level (or 1-drop level) versus 3-drop level with 8-deflection basin. As shown in Figure 5, three response parameters obtained from 3-drop level matched very well with those obtained from 2-drop level or 1-drop level.

Table 1 summarizes the correlation coefficients of six-pair of number of drop levels for three different response parameters. As summarized in Table 1, correlation coefficients of three response parameters ranged from 0.935 to 0.994. It is interesting to note that correlation coefficients of 3-drop level versus 1-drop level were below 0.95, which may be considered unacceptable. There is a strong correlation between 3-drop level and 2-drop level for all HMA modulus, PCC modulus, and coefficient of subgrade reaction. Therefore, it is recommended that the current FWD network-level test with 3-drop level would be changed to 2-drop level.

![Figure 5](image)

Fig 5. Plots of HMA modulus, PCC modulus and coefficient of subgrade reaction at 2-drop level (or 1-drop level) against 3-drop level.

To ensure the possibility of reducing number of drop levels for the FWD network-level test, dependent \( t \)-test analysis are conducted on six-pair of drop level to compare for three response parameters. Table 2 summarizes the dependent \( t \)-test analysis results for HMA modulus and PCC modulus and coefficient of subgrade reaction with six-pair of drop levels. For the pair of number of drop level, the significant level was selected as 0.0083 using Bonferroni correction to avoid the Type I
error. As summarized in Table 2, for the number of drop level, the results show no significantly difference in mean values of three different response parameters of 2-drop level (9,000-lb and 15,000-lb) when compared against the 3-drop level (9,000-lb, 12,000-lb, and 15,000-lb). This signifies that 2-drop level (9,000-lb and 15,000-lb) can be used instead of 3-drop level for the FWD network-level test.

| Table 1, Results of correlation coefficient for three response parameters with six-combination of drop level |
|--------------------------------------------------|--------------------------------------------------|
| **No. of Drop Level** | **Response Parameter** | **Correlation Coefficient (r≈0.95)** |
| 3-drop (9,000-lb, 12,000-lb, and 15,000-lb) vs. 2-drop (9,000-lb and 12,000-lb) | $E_{\text{HMA}}$ | 0.988 |
| | $E_{\text{POC}}$ | 0.994 |
| | $k_0$ | 0.988 |
| 3-drop (9,000-lb, 12,000-lb, and 15,000-lb) vs. 2-drop (9,000-lb, and 15,000-lb) | $E_{\text{HMA}}$ | 0.983 |
| | $E_{\text{POC}}$ | 0.993 |
| | $k_0$ | 0.992 |
| 3-drop (9,000-lb, 12,000-lb, and 15,000-lb) vs. 2-drop (12,000-lb, and 15,000-lb) | $E_{\text{HMA}}$ | 0.988 |
| | $E_{\text{POC}}$ | 0.994 |
| | $k_0$ | 0.980 |
| 3-drop (9,000-lb, 12,000-lb, and 15,000-lb) vs. 1-drop (9,000-lb) | $E_{\text{HMA}}$ | 0.965 |
| | $E_{\text{POC}}$ | 0.973 |
| | $k_0$ | 0.940 |
| 3-drop (9,000-lb, 12,000-lb, and 15,000-lb) vs. 1-drop (12,000-lb) | $E_{\text{HMA}}$ | 0.949 |
| | $E_{\text{POC}}$ | 0.978 |
| | $k_0$ | 0.970 |
| 3-drop (9,000-lb, 12,000-lb, and 15,000-lb) vs. 1-drop (15,000-lb) | $E_{\text{HMA}}$ | 0.935 |
| | $E_{\text{POC}}$ | 0.977 |
| | $k_0$ | 0.952 |

5.2. Minimum Number of Test Points
As shown in Figure 6, correlation coefficient values are presented with plots of two-pair of FWD data points for three response parameters. Three response parameters obtained from whole FWD test points (610 points) matched very well with those obtained from 30% (427 points) or 50% (305 points) reduction where the correlation coefficients of three response

![Figure 6](image_url)

(a) $E_{\text{HMA}}$
(b) $E_{\text{POC}}$
(c) $k_0$

Fig 6. Plots of HMA modulus, PCC modulus and coefficient of subgrade reaction at 30% and 50% reduction of whole FWD test points against whole FWD test points.
parameters ranged from 0.947 to 0.988. Dependent $t$-test analysis was then conducted on two-pair of FWD test points for three response parameters. Table 3 summarizes the dependent $t$-test analysis results for HMA modulus, PCC modulus and coefficient of subgrade reaction with two-pair of FWD test points. As explained before, for the pair of FWD test points, the significant level of 0.025 following Bonferroni correction was selected to avoid the Type I error. As summarized in Table 3, all $p$-values are within non-significant levels as shaded such that the current number of FWD test points can be reduced by 50% without sacrificing the quality of the FWD data.

5.3. Benefits of Minimum Number of Drop Levels and Test Points

Based on a statistical analysis using the limited FWD network-level testing data, dependent t-test results showed no significant difference in the mean values of the three response parameters of 2-drop level (9,000-lb and 15,000-lb) when compared against 3-drop level. In addition, there was no significant difference in mean values of the three response parameters of 30% and 50% reduction from the current FWD test points.

Assuming the FWD test at each test point takes approximately 45 seconds to measure the deflection and, on average, 640 test points can be tested each working day for the FWD network-level program. As summarized in Table 4, the adoption of 2-drop level instead of 3-drop level will allow FWD data to be collected from 960 test points per day. If the number of FWD tests is reduced up to 50%, current FWD network-level program could cover 30% of Iowa highway and road system per year.

### 6. SUMMARY AND CONCLUSIONS

The falling weight deflectometer (FWD) has been widely used in pavement engineering to evaluate pavement structural condition for pavement rehabilitation projects, research, and pavement structure failure detection. Iowa department of transportation (DOT) initiated to perform the FWD network-level test on Iowa highway and road system and to build a comprehensive database of deflection data and subsequent structural analysis to be used for detecting pavement structure failure, estimating expected life, and calculating overlay requirements. Iowa’s current FWD network-level testing protocol requires that pavements are tested at 3-drop level with 8-deflection basin collected at each drop level. The test point is determined by the length of the tested pavement section.

This paper discussed the minimum number of drop levels and test points for the FWD network-level test protocol without compromising the quality of the collected data. Based on the statistical analysis using FWD test data obtained from eighty-three composite pavement sections, the following conclusions are derived:

1. There are strong correlations of backcalculated HMA moduli, PCC moduli, and coefficients of subgrade reaction between 3-drop level and 2-drop level.

2. Based upon the dependent t-test results, there is no significant difference in mean values of three different response parameters of the 2-drop level (9,000-lb and 15,000-lb) when compared against the 3-drop level.

3. Based on the statistical analysis results, the current FWD test points can be reduced by 30% or 50% without sacrificing the quality of the FWD.

4. The reduction of number of drop level significantly increases the FWD test production rate up to 1.5 times for the FWD network-level program.

5. Overall, the reduction in number of drop levels and test points of the FWD would result an increase in FWD test production rate and decrease in cost of testing and traffic control without sacrificing the quality of the FWD data.
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REFERENCES


