

Implementation of TONN2010

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Executive Summary

This report describes the combined efforts of the project team to merge two tools developed under separate research contracts to help users make informed decisions when posting allowable axle loads on roads within their jurisdiction. The two tools include the Falling Weight Deflectometer (FWD) Viewer Tool (originally developed by MnDOT, and subsequently enhanced under contract with Minnesota State University, Mankato) and the TONN 2010 analysis method (developed under contract with the University of Minnesota). The effort included two primary objectives: to combine the two tools into one, and to develop a training program to demonstrate the tool's advantages and inform of its limitations.

Assisted by MnDOT's State Aid Division, the project team was able to pre-load the combined FWD Viewer Tool and TONN 2010 method with FWD and other data from the Tier 1 roadways in the County State Aid Highway system. The complete dataset was then divided by county and exported to unique spreadsheet tools for use by each of the counties in the state.

The training program was developed as part of this project, and presented throughout the state to various engineers and technicians in the counties and MnDOT districts. The training program was delivered under a separate contract with Minnesota State University, Mankato. The program contains sections on the tool's operation, basic technical background of the TONN 2010 method and how it is used in the FWD Viewer Tool, case studies, and an installation guide.

Chapter 1. Introduction

This report describes the implementation of the Allowable Axle Loads on Pavements analysis method and associated computer software developed by Dr. Lev Khazanovich [1] at the University of Minnesota (the TONN 2010 analysis method). The implementation activities included the incorporation of the Allowable Axle Loads on Pavements computerized routine into the existing Falling Weight Deflectometer (FWD) Viewer Tool. The FWD Viewer Tool was developed by Minnesota State University (MSU) under separate contract with the Minnesota Department of Transportation (MnDOT). This report includes a basic description of the FWD Viewer Tool, the TONN 2010 routine, and the steps involved in combining them (a spreadsheet and computational routine) into one tool that may be used by local agencies to analyze pavement structures within their areas of responsibility.

The TONN 2010 analysis is an improvement over the TONN program that was developed by the Minnesota Department of Roads and reported by Kruse and Skok [2] in 1968 (and revised in 1983). While the details of the TONN 2010 development are reported by Bly, Tompkins and Khazanovich [1], a short summary is included in this introductory chapter.

In addition, this report presents the set of training presentation and case studies developed under this project, and delivered under a separate contract.

Content of the Report

As this report is organized primarily to chronicle the implementation and incorporation of the TONN 2010 analysis routine, there is no specific technical content but a summary of the activities undertaken by the project team. The report includes the following sections.

- Incorporation of the TONN 2010 analysis into the FWD Viewer Tool, including testing and revisions, and
- Development of training materials, including a PowerPoint presentation, installation instructions, case studies, and a troubleshooting guide.

Chapter 2. Incorporation of TONN 2010 into FWD Viewer Tool

This chapter describes the incorporation of TONN 2010 into the existing FWD Viewer Tool (developed under contract #94288 – Integrated Tools for Pavement Design and Management). The original FWD Viewer Tool displayed the load ratings for the Tier 1 roadways on the state aid highway system tested by consulting firms in 2010 and 2011. The TONN 2010 analysis method was developed by Dr. Lev Khazanovich and others at the University of Minnesota, and is described in full in their report [1]. The MSU project team worked with Dr. Khazanovich to make minor corrections in the TONN 2010 analysis code, and to conduct an analysis of the statewide data.

Data Requirements

Since the TONN 2010 computation routine can take about one second per FWD drop, some road segments included in the FWD Viewer Tool can take several minutes to complete. For this reason, the TONN 2010 analysis was conducted on all of the FWD tests in the analysis tool database across the state. This required a computer about six days, running 24 hours per day to conduct the full analysis. There are almost 370,000 FWD drops recorded in the analysis tool database. The TONN 2010 analysis was conducted only for the those drops where all required user input data is available. These include some data acquired directly from MnDOT and some from the individual agencies throughout the state, as discussed below.

• Design ESALs

Traffic data was obtained from the Traffic Data Analysis group at MnDOT for individual segments requested by the agencies when they identified which roads would be tested. The Average Annual Daily Traffic (AADT) was extracted and included in the Statewide FWD database.

- Subgrade soil type
- Existing bituminous thickness (obtained from county engineers), and
- Existing base thickness (obtained from county engineers). The soil type and layer thickness of the bituminous and base layers were obtained from the individual counties (Plastic, Semi-Plastic, or Non-Plastic for soil type, and inches of thickness for bituminous and base layers).
- Previous day temperature

The average temperature $(T_{max} - T_{min})$ for the day prior to the FWD testing. This was obtained from the Minnesota Climatology Working Group web site [3]. For each county, a location on the web site's map of the state was selected at approximately the geographical center of the county. The hourly temperatures were then downloaded for the range of dates when the FWD testing occurred.

- Number of lanes
- Locale

The number of lanes on the roadway segment and the locale (urban or rural) were used in the calculation of 20-year ESALs. These values were obtained from the MnDOT State Aid web site [4] in the CSAH Segment Reports section.

The MnDOT State Aid Office conducted an extensive data collection program with the counties to complete the set of required data for TONN 2010 computations (soil type, bituminous thickness, and base thickness). Of all FWD tests included in the database, about 73% have a complete set of soil type and layer thickness data. The other required data were obtained from data sets with 100% coverage.

Comparison of Analysis Methods

The TONN 2010 analysis method was compared with the other analysis methods that have been used to design pavements and to determine their appropriate allowable axle loads, including the AASHTO, TONN, INV-183 and Soil Factor methods. These methods are described in more detail in a report by Lukanen [5].

The information shown in Figures 1 and 2 provides distribution curves of allowable axle load for the more than 250,000 FWD tests conducted in 2009 and 2010, and allows a comparison between them. In these figures, the distributions of the results of the four methods used in the initial FWD Analysis Tool (AASHTO, TONN, INV 183, and Soil Factor) are made up of over 293,000 FWD basins from across the state. The TONN 2010 distributions are made up of 263,000 basins. The different numbers of analyses included are related to some information missing that is required for the various methods to compute load rating.

The graphs only show results up to 20 tons, although each of the traditional analysis methods computed some load ratings up to 100 tons. This is not to say that some sections should be rated to that level, but that it is more likely that the limits of the analysis methods were exceeded, and the results should not be used above reasonable values. The TONN 2010 method gave a maximum value of only 37 tons over the 263,000 basins. It can be seen in the figures that the original TONN method is the least conservative (suggesting that more roadways have a higher allowable axle load) and the INV-183 method is the most conservative (more roadways have lower allowable axle load). The TONN 2010 analysis method lies somewhere between. For example, in Figure 2 TONN 2010 suggests that about 10% of the locations are at 10 tons or less, whereas INV-183 suggests that about 30% of the segments are at 10 tons or less. The original TONN method indicates that about 7% are at 10 tons or less. Figure 3 shows the same information as in Figure 1, but extended to display data up to 40 tons. At most, in each analysis method, there are only 0.25% of basins with a calculated load rating greater than 40 tons.



Figure 1. Frequency of Load Ratings using various Analysis Methods.



Figure 2. Cumulative Distribution of Load Ratings using various Analysis Methods.



Figure 3. Frequency of Load Ratings using various Analysis Methods, up to 40 tons.

TONN 2010 Implementation

Figure 4 shows a screen capture of the revised FWD Analysis Tool with the TONN 2010 analysis method incorporated. It has taken the place of the original TONN method from LRRB INV-603 [2].



Figure 4. Sample of Updated FWD Analysis Tool.

As mentioned previously, in order to reduce computation time whenever the user desires to view the data, the entire data set was processed using the data collected by the project team and the MnDOT State Aid office. This processed data is included in the individual spreadsheets supplied to each county. If the user desires to evaluate the allowable axle loads with increased traffic volumes or a different classification scheme over the design period, the TONN 2010 values must be recomputed. This can take several minutes, depending on the speed of the computer.

In Figure 5, the series plotted with smaller, yellow circles is the original, precomputed TONN 2010 values. The larger, red circles in the second series in that figure is the TONN 2010 rating for the same FWD data but with an increased traffic prediction. When changes to the traffic estimate are made (using the "Modify Default Traffic" button) the current ADT value can be entered with a predicted growth rate, and the tool computes a new design ESAL value and allows the user to recompute the TONN 2010 ratings for the segment or segments selected. The traffic modification screen in shown in Figure 6 and the user settings window is shown in Figure 7.



Figure 5. Sample of Updated FWD Analysis Tool with TONN 2010.

Enter Custom Traffic Infor	mation for th	nis Segment		x
General Information Annual Growth, % Design Period, yrs ADT # Lanes, 2-way	1 20 462 2 •	ocale — Us O Urban (Rural (er or Default Values	
Vehide Classification	/ehicle Class	Default ESAL		
Vehicle Class	Percent	Factor		
Cars, Pickups	86.56	0.0007		
2 ax 6 tire SU	3.44	0.25		
3+ ax 50	2.17	0.58		
3 ax TST	0.39	0.39		
4 ax TST	0.69	0.51		
5+ ax TST	5.32	1.13		
T w/tr, buses	1.4	0.57		
Twin Trailers	0.03	2.40		
Total:	100.0		OK Cancel	

Figure 6. Traffic Update Window.

User Settings	X
Summary Worksheet C Switch to Summary Sheet when clicking 'Summarize'. Return to Analysis Sheet after clicking 'Summarize'.	File Locations TONN 2010 Computation Files C:\TONN2010 Select
TONN 2010 Calculation Speed Test Begin S5.4 FWD Drops Don't warn me per minute about calculation times.	Maximum Axle Load Y-Axis O Automatic Image: Set Max Value 20 tons
(Speed tests can take several minutes.)	Display lines between points in graphs.
	OK Cancel

Figure 7. User Settings Window.

Chapter 3. Training Development

This chapter discusses the development of the training materials for the FWD Viewer Tool with TONN 2010 and a new overlay design module. The overlay design component was added to the tool under a Contract #94288. Additionally, this report includes the development of the training materials only. The delivery of the materials in terms of training sessions and other meetings is included in the other contract.

Some highlights of the training materials included in Appendix A are as follows.

- Basic operation of the revised FWD Viewer Tool
- Basic operation of the newly-added overlay method
- A simple technical background of the TONN 2010 routine and the overlay method
- Several case studies highlighting specific uses of the tool
- A troubleshooting guide for solving common problems relating to the tool's installation and operation

Other topics that are addressed in the training materials include:

- Statewide FWD testing on Tier 1 Roadways
- Basic definitions of reliability and appropriate levels, and how these are incorporated into the tool
- Discussion of satisfactory performance and design periods

The training materials will be presented under Contract #94288 during the fall and winter of 2013-2014.

References

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Appendix A. Training Materials









Statewide Data			
ADT	% ≥ 10 Ton	Miles*	
< 300	84	1,341	
301 – 750	83	2,435	
751 – 1,500	84	1,311	
1,500 - 5,000	78	968	
> 5,000	77	557	
*Locations without complete	ete pavement information	n are not included.	























































Overlay Method What is the Proper Reliability Level?					
Basic Tool Operation Overlay Method Technical Background	AASHTO Levels	of Reliab	ility		
Case Studies Troubleshooting		Recommended Level of Reliability			
	Functional Classification	Urban	Rural		
	Interstate and other Freeways	85-99.9	80-99.9		
	Principal Arterial	80-99	75-95		
	Collector	80-95	75-95		
	Local	50-80	50-80		
	Guide for Design of Pavement Structures, AASHTO, 1993				
				O	



































