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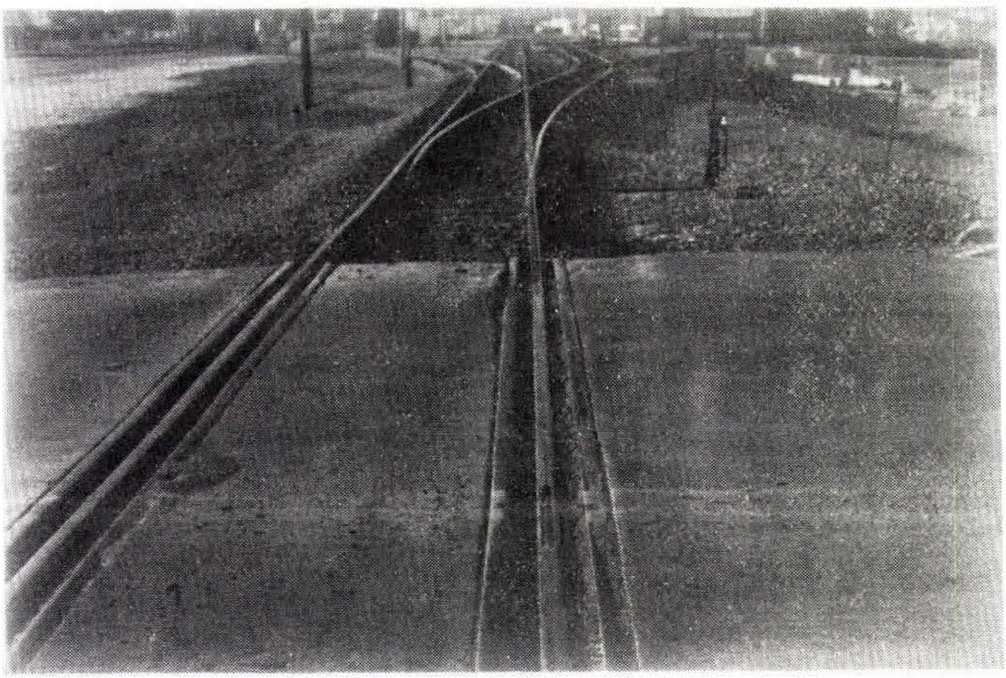

Railroad Crossing Study

Study SD90-14
Volume I: Final Report

Prepared by
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SD School of Mines & Technology
Rapid City, South Dakota

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16. Abstract

This report presents the results of the survey of 54 railroad grade crossings in South Dakota. Three basic types of crossings were studied: rubber, asphalt, and timber. The crossings were studied for the effect on roughness of highway and rail traffic, soil conditions, drainage, and age. Construction of five crossings was also observed, in order to evaluate the adequacy of the construction procedures and practices applied in South Dakota.

The results of the study indicate that the main factors leading to the deterioration of railroad crossings include: differential settlement between crossings and the approaches, surfacing material breakdown, inadequate maintenance, and poor construction procedures regarding the foundation materials for the crossings.

Based on the results of the surveys and inspections, conclusions regarding modes of distress and the adequacy of construction practices were formed. Recommendations were given in regard to measures that should be implemented to improve the performance of railroad crossings in South Dakota. The report stresses the need for semiannual cleaning and inspection of crossings, as well as repair and maintenance of items needing attention.

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CHAPTER I

EXECUTIVE SUMMARY

This report presents the results of the research project SD-90-14, "Railroad Crossing Study", performed for the South Dakota Department of Transportation by the South Dakota School of Mines & Technology. The project was performed during the period May 1, 1990 through January 31, 1992.

The objective of the research was twofold:

1. To identify design, construction, and maintenance factors which contribute to crossing roughness;
2. Recommend design or construction changes based upon the findings.

The project was divided into several tasks, including a literature study, crossing categorization, field investigation, observation of crossing removal and construction, and the development of conclusions and recommendations.

The field investigation included a detailed study of 25 randomly selected crossings throughout South Dakota. The crossings were surveyed and photographed, and the condition of the crossings described. Vibration measurements during highway and rail traffic and deflection measurements during rail traffic was also obtained. Soil borings were taken at each crossings by the South Dakota Department of Transportation (SDDOT), and the soil samples were tested at the SDDOT laboratories in Pierre, South Dakota. Following the completion of the study of the initial 25 crossings, a condition survey of an additional 29 crossings were performed. The condition survey included describing the condition of the crossings and taking of photographs.

Following the field study, the data obtained was analyzed, and distress and failure patterns for the different crossings identified. These patterns were then correlated with crossings age, and soil and drainage conditions. The results showed that the primary cause of crossing roughness and distress is differential settlement between the railroad track and the highway approaches to the crossing, and that the loads from the rail traffic is the primary cause of the settlement. The bulk of the settlement also appear to take place within the first two years. Once the initial roughness is initiated, impact loading from highway traffic is increased which contributes to the breakdown of the surfacing materials used in and at the approaches to the crossings. It was also noted that frost heave of the highway approaches to the crossings contributed to considerable winter roughness, and that frost action also contributes to pavement breakup and permanent approach damage. Snowplow damage, especially at rubber crossings ranged from minimal to severe. Based on the observations, snowplow damage appeared to be of considerably greater importance than wear from highway traffic.

The observation of the removal and construction of five railroad crossings were also part of this study. The observations showed that little consideration is given to subgrade preparation under the crossing, and that little or no compaction is performed on neither the subgrade nor the ballast. No measures to assure quality control by independent personnel were implemented at any of the crossings installed, and inspectors from state or city agencies ~~was~~ were only present for a short period of time at one of the sites. Installation of the crossing surfacing material was found to be satisfactory and in accordance with the manufacturers' recommendations.

Based on the observations made during this study, it is recommended that several changes in construction practices, inspection and maintenance be implemented. Prior to construction, a baseline geotechnical investigation should be performed such that information on the soil and groundwater levels can be obtained, and that the information obtained be used to determine the necessary depth of excavation and replacement of unsuitable material, and the need for subsurface drains. In order to minimize crossing settlement, it is also recommended that the exposed subgrade be proofrolled and compacted, and that the ballast be compacted with a heavy vibratory roller before the ties are placed. The thickness of the highway base material under the approaches to the crossing should be tapered such that the thickness of the base material adjacent to the crossing is of the same thickness as the ballast. The base should consist of non-frost susceptible material, and underlain by a fabric if the subgrade is soft. The ballast thickness used under the crossing should be carried at least 15 feet beyond the ends of the crossing, and then tapered until it adjoins the bottom of the ballast under the track. The fabric under the ballast in the crossing should also be carried to a distance of at least 15 feet beyond the ends of the crossing. Headers should be avoided where possible.

Inspection and quality control needs to be implemented throughout the construction. Inspection during construction should be concentrated on subgrade preparation under both the track and the approaches to the crossing, fabric and ballast placement, placement of base material under the approaches, and installation of drains.

Crossing maintenance also needs to be performed. The investigation revealed that the railroads attempt to perform maintenance at their crossings twice a year, however, shortage of personnel often prevent maintenance items from being carried out. Since many maintenance items are essential to prolonging crossing service life, it is recommended that the proposed maintenance schedule be upheld.

Snow plow damage to rubber crossings was observed to be a serious problem. It is recommended that representatives from the railroad and the respective highway departments meet to discuss and find solutions to this problem.

CHAPTER II

BACKGROUND

II-1 INTRODUCTION

There are six major railroad companies operating in South Dakota, with railroads spanning most of the state. At each location where the railroad crosses a highway, a railroad grade crossing has been constructed. Several types of railroad grade crossings are available today, including timber, asphalt, rubberized panels and, as of the last few years, concrete panels. In South Dakota, three of these types of railroad grade crossings are used, namely timber (often railroad ties), rubber pads, and asphalt.

With time, the railroad crossings deteriorate, and the crossings become rough. Such is also the case with a large portion of the public railroad crossings within the state of South Dakota. Since damage to railroad crossings is partially caused by vehicles impacting on the crossing surface because of elevation differences between the crossing and the highway approaches, the deterioration of the railroad grade crossings has a tendency to be progressive, and the rate of damage accelerates with time. This results in excess costs for maintenance, premature failure and eventual reconstruction. The roughness of the crossings does not only cause discomfort to the traveler, but may also cause tear and wear on the vehicles and contribute to increased maintenance cost, and possibly derailments.

Although both rail and highway traffic loads on the railroad crossings are the primary cause of damage, numerous other factors also contribute to additional damage, such as caused by snow plows, road graders and dragging and faulty railroad equipment. Increase in both railroad and truck traffic and allowable axle loads beyond those designed for are also important. In addition, inadequate installation procedures, design, poor construction material performance, and extended service life are also contributing factors to railroad grade crossing failures. Subsurface material failure, swelling soils, drainage conditions and frost action are also factors which should be recognized, especially since such conditions are likely to contribute to a high degree of strength loss under repetitive and cyclic loads. Failure to recognize poor subsurface conditions is one of most important factors leading to failures in highway construction industry and, in all likelihood, could be equally important in the construction and installation of railroad grade crossings.

II-2 OBJECTIVES

The principal objective of the proposed research project was to:

1. Identify design, construction and maintenance factors which contribute to crossing roughness;

2. Recommend design or construction changes based upon the findings from (1).

It is important to recognize that studies with similar objectives have been performed in the eastern portion of the United States. However, the soil and climatic conditions existing in South Dakota are often vastly different from the eastern portion of the country. The main thrust of this research program was therefore to be approached in view of the conditions which are specific and unique to South Dakota.

In addition to design, construction and maintenance factors, it was felt that the natural factors leading to railroad grade crossing roughness such as subsurface conditions, climactic factors, and natural terrain and drainage characteristics at and near the railroad crossings needed to be studied. Age of the crossings was also considered. These are principal factors which should be taken into account when selecting a specific railroad crossing design.

In order to fulfill the objectives of the research project, the existing conditions of selected railroad crossings were studied. Although the objective of project was not to map crossing conditions, a condition study was necessary to identify what type of design and what types of crossings performed the best as well as which would be most suitable for specific traffic conditions and locations in South Dakota.

II-3 SCOPE

The project was divided into five separate tasks:

1) Review of literature relevant to the study;
2) Categorization of both rural and urban rail road crossings according to ADT, rail traffic, type of surface material used in the crossing, subgrade soil types and drainage;
3) Field investigation of randomly selected crossings within each category to identify

those factors which contribute to railroad crossing roughness;

4) Development of design and maintenance standards for railroad crossings based on the following factors: rural and urban crossings, ADT, rail traffic, and subgrade soil type;

5) Preparation of the final report summarizing the relevant literature, research methodology, data, findings, and conclusions (Report).

At the end of the field investigation and surveying of the selected crossings, it was decided that the data collected was insufficient for a complete categorization and evaluation of the problems associated with the different types of crossings investigated. A complete condition survey of 29 additional crossings was therefore performed on crossings in Rapid City, Sioux Falls, Blunt, Northville, Redfield, Aberdeen and Watertown.

CHAPTER III

LITERATURE STUDY

III-1 GENERAL

A detailed literature search and review was performed using the facilities at the SDSM&T Devereaux Library and pertinent literature was ordered when not available locally. Manufacturers of railroad crossing surfacing materials were also contacted to obtain information about their products, specifications and information on recommended installation procedures. Railroad companies serving South Dakota and major railroad companies serving the western United States were also contacted and interviewed. In addition, installation guidelines and recommendations were also obtained from the American Railway Engineering Association.

III-2 FACTORS CONTRIBUTING TO ROUGHNESS

In accordance with Maurer (1978) the presence of railroad grade crossings has always been a problem of inconvenience to the highway users, and the problem is enhanced when the crossings become rough. Even though the predominant causes for the roughness of crossing have been recognized as excessive loading of the subgrade and inadequate drainage, the problem of roughness still remains dominant.

Further, Maurer, and Burns (1988) state that traditional surface material for railroad grade crossings like timber and asphalt deteriorate due to repetitive loads of traffic and with passage of time. These factors cause the crossings to become rough, resulting in excessive cost of maintenance, premature failure and eventual need for reconstruction. Improvement in crossing performance is being achieved, however, as the traditional type railroad crossings (like timber and asphalt), which represent most crossings constructed in the past, are being replaced by more durable, pre-manufactured rubber type surfaces.

Ahmad, Lytton, and Olson (1976) state that permanent differential deformation between the crossing and the adjacent highway pavement is the main factor leading to crossing roughness. Due to differences in wheel loadings, material properties, and the track and pavement structures, each will deform differently. It was observed that with increases in differential deformation, dynamic loads will increase, however, increased motor vehicle speed appears to decrease dynamic loads. On the other hand it was observed that the dynamic loads will increase with higher train speed. With the passage of time and repeated traffic load the crossing roughness will increase, hence it is essential to minimize the difference in elevation between the approach pavement and the crossing.

In addition to the above factors, various other factors (Maurer, 1978) which contribute to the crossing failures are listed below.

a) Inadequate compaction of subgrade and/or ballast;

b) Failure to install header boards or improperly installed header boards;

c) Failure to seal or maintain pavement/crossing joint with rubberized asphalt sealant;

d) Insufficient removal of old pavement and base;

e) Inadequate ballast;

f) Inadequate or improperly installed drainage system;

g) Inadequate geotextiles used for trackbed stabilization;

h) Dragging of railroad equipment and snowplows;

i) The accumulation of excessive debris and road dirt along the rail flange causing poor drainage due to improper maintenance;

j) Too light rails at the crossing;

k) Presence of bolted rail joints within the crossing and at a distance of 6 feet beyond the ends of crossing;

l) Pumping of track bed under train traffic;

m) Loosening of fasteners;

n) Tilting and failure of apron;

o) Settlement of rail approaches.

In accordance with Morgan and Olson (1987), looking at grade crossing history, lack of adequate drainage and improper crossing design was observed. Such flaws, resulting in an abrupt change of subgrade at the ends of the crossing and at the sides where the crossing adjoins the highway pavement, were the primary factors leading to the crossing failures. This problem was proposed to be minimized by gradually tapering the depth of pavement (a distance of over 100 to 150 ft from the crossing) and maintaining constant depth throughout the crossing. The tapering was thought to significantly reduce the stress concentration and, combined with adequate drainage, minimize crossing failures and roughness.

Lack of geometric design standards have resulted in unsatisfactory rideability of many crossings. According to the Transportation Institute (1977), maintaining initial geometric characteristic at the crossings is of utmost importance.

III-3 DYNAMIC ASPECTS

In accordance with Ahmad, Lytton, and Olson (1976), grade crossing performance criteria is measured by the following factors:

a) Dynamic load profile

b) Roughness index

c) Permanent differential deformation

The factors are related to each other; i.e., an increase in one will increase any of the other two variables.

Dynamic load experienced by a vehicle depends on the interactions between the roughness characteristics of the riding surface, the vehicle characteristics, and the vehicle speed.

Roughness index is defined as the ratio of the sum of the rear-axle excursions of a vehicle (in centimeters or in inches, as recorded by Mays Ride Meter) to the distance it travels.

Repetition of wheel loads causes permanent differential deformation between the railroad track and the adjacent pavement structures. This differential deformation causes surface roughness.

The Texas Transportation Institute has successfully conducted research on railroad grade crossings through computer analysis. The programs developed consider the flexibility of the pavement and the number of wheel load repetitions for highway and railway traffic separately. Further, it is claimed that this program can be effectively used to find the most effective ballast depth in different climatic and soil conditions. Material properties, such as resilient modulus and permanent strain of grade crossing materials, are considered in the design.

III-4 FAILURE MODES

According to Newton, Lytton, and Olson (1975) tracks generally fail either due to pumping or cumulative bearing capacity failure. The pumping failure is due to the presence of fine slurry at or above the level of base of the ties whereas cumulative bearing capacity failure is due to the overstressing of the subgrade soil.

Improper drainage and poor subgrade soils have been claimed to be the predominant causes leading to the failures of railroad grade crossings. In accordance with published literature on the railroad crossings (FHWA, 1985), deficiency in compaction of the subgrade and the backfilling material were felt to be major causes of failure. Significant improvements in the drainage conditions at the crossings can be made by providing drainage trenches parallel to the rails. Further, recent methods to reduce settlement of subgrade and to improve and maintain the subsurface drainage have been to install geotextile fabrics along the entire width of the crossing. The main function of these fabrics is to separate the subgrade and ballast, such that the flow of water can be maintained, and to provide tensile reinforcement.

III-5 SELECTION CRITERIA

The selection of surface material for a particular crossing mainly depends on the soil type, climatic conditions and the traffic loads. In addition to the above factors (FHWA, 1985, and Burns, 1990) the following were also found to be of importance in selection:

a) Type of highway surface on the approaches to the crossing;

b) Volume of highway traffic, with particular attention to truck movements;

c) General classification of the railroad;

d) Volume and type of railroad traffic;

e) Nature of the subgrade at the crossing and the climatic conditions;

f) Estimated cost, initial construction cost, replacement cost and maintenance cost.

Based on studies of grade crossing construction and performance history (FHWA, 1985) these criteria were clearly not given due importance for traditional surface material like asphalt and timber. With the replacement of traditional material by high type surfaces like rubber panels to bring about an improvement in drainage, a high initial cost of construction can be justified when considering reduced maintenance cost. Regardless of the type of surface material used, however, construction procedures such as adequate preparation of the track structure and the subgrade, including adequate drainage, are essential for better performance and longer service life of a grade crossing surface.

III-6 BALLAST AND TRACK SETTLEMENT

Strain in granular material under vibratory and cyclic loading was first studied in the late 1960's and early 1970's by Silver (1971), and others. Static and dynamic triaxial tests on ballast have been performed since the late 1970's by researchers such as Raymond et al (1978, 1983) and Janardhanam and Desai (1982). These studies established that strains in granular soil and ballast increase linearly with the logarithm of the number of load cycles, with the magnitude of the rate of increase of strain dependent on the stress level and the type of material. Stewart (1986), working under the direction of Dr. Ernest Selig, confirmed the findings of Raymond (1978) that the ballast undergoes large amounts of strain during the first load cycle, and thereafter deforms following a linear increase with the logarithm of number of load cycles. Stewart also proposed simple relationships for the permanent strain of ballast under different loads and number of load cycles.

Material degradation (particle breakdown) was also studied in conjunction with some of the cyclic testing on ballast (Raymond and Williams) and it was shown, based on field studies over a period of 13 years, that ballast breakdown continues unabated with time. Tests on Coteau Dolomite showed that the portion of the ballast finer than 10mm increased almost linearly with time from approximately one percent to nearly 8 percent over the study period of 13 years.

III-7 CONSTRUCTION PROCEDURES

Based on the literature study and interviews with the railroads it was observed that the design details for railroad grading crossings are insufficient. This appears to be a general problem, and therefore applies to South Dakota as well. Design details suitable for a particular site, with consideration given to soil type, climate, and type of traffic, are also inadequate. Design drawings are virtually nonexistent. Further, the installation and inspection procedures were also found to be lacking. Design detail suitable for a particular site, given with consideration for soil type, climate, and type of traffic, is insufficient.

III-8 TYPES OF CROSSINGS USED IN SOUTH DAKOTA

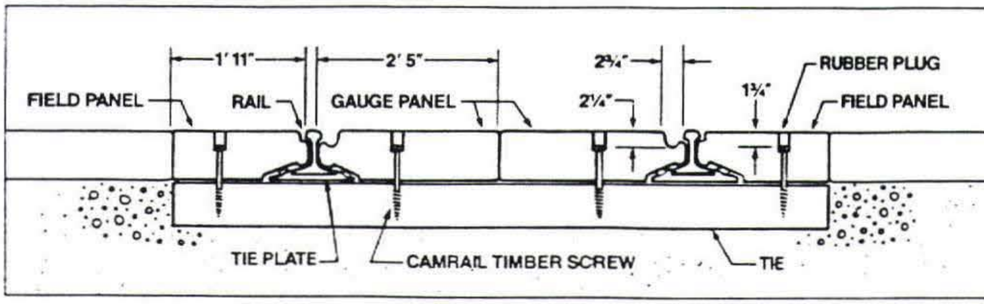
From grade crossing histories, it was observed that the most common surfacing materials which have been used in South Dakota are rubber, asphalt and timber.

III-8.1 Rubber Crossings

The most commonly used rubber crossings are GOODYEAR, PARKCO, OMNI, REDHAWK, and SAF&DRI. Generally two types, full depth and partial depth rubber panels are used. Partial depth panels are used with timber shims and header boards, while for full depth panels, timber shims and header boards are not used. Typically, all of the rubber crossings manufactured by the above companies are similar in geometrical characteristics, but strength varies with specifications and material properties. Examples of full depth and partial depth rubber panels are shown in Figures III-1 and III-2.

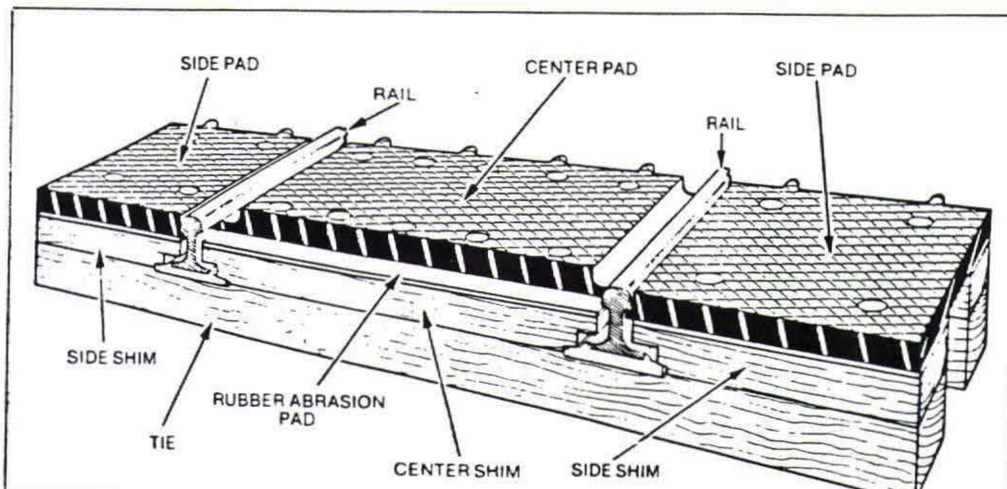
The Goodyear crossing surface is manufactured by Goodyear Tire & Rubber Company of Akron, Ohio (Goodyear & Co., Instruction Manual). The rubber panels are 3 feet long, each spanning two tie spaces. Center panels extend from rail web to rail web, with 2 and 3/8 of an inch flangeway openings provided. Side panels are 21 inches wide at the top and fit against the head of the running rail. Panels require pre-framed wood shims on top of the ties which are held in place by eight light spikes driven into the ties. A diamond pattern antiskid surface is molded into the rubber. The transverse joints between panels can be sealed against water penetration by applying pressure to compress a 1/8 inch by 1/4 inch protrusion at the top edge before the panels are fastened to the ties.

The ParkCo crossing was manufactured by Park Rubber Company of Lake Zurich, Illinois, however, Park Rubber Company no longer manufactures railroad crossings. It has two unique features. The steel reinforcement plate in each panel has a slightly arched form and the panels are not individually fastened to the ties. The assembly of panels forming an individual crossing are held



(Omni, 1990)

Figure III-1. Full Depth Rubber Crossing



(Goodyear, 1990)

Figure III-2. Partial Depth Rubber Crossing together by eight post tensioned steel rods which pass through pipe-formed channels in each panel, two per panel. The anchor rods are fastened at each end of the crossing to steel plates which are bolted to one tie. The panels rest on timber shims on top of each tie. The top surface of the panels has a molded antiskid pattern of small protruding circles. Normal panel length is 6 feet.

The SAF&DRI panels are produced and marketed by Structural Rubber Products Company of Springfield, Illinois. The panels are formed of rubber encapsulated 4-inch by 8-inch steel tubes. The crossing consists of two center panels with tubes and one side panel with two tubes. The interfaces of all panels have tongue and groove design to stop water from passing through into the ballast and subgrade. The panels are furnished in 6-foot lengths to accommodate crosstie spacings up to 20 inches. The panel depth is 4-13/16 inches requiring the use of timber shims on top of the ties.

The Omni panels are manufactured and distributed by Reidal Omni Products, Inc., Portland, Oregon. The Reidal Omni Products and Redhawk Rubber Co., Inc. have recently merged. The panels are generally 6 feet long and are manufactured to fit various rail and tie plate dimensions and any length tie. No shims are provided on the ties and the panels are full depth. The crossing consists of two gauge panels in the center while two side panels fit the shoulders. For positive water control, rubberized flangeways are provided. The Omni crossing has been studied in detail by the Oregon State University (Allen, 1987).

The Redhawk crossing surface is manufactured by Redhawk Rubber Co., Inc. The panels are full depth, consisting of center panels (36"x59") and side panels (36"x21"), in plan dimensions. The steel reinforcing structure is completely encased in the 3" thick rubber panels, thus eliminating corrosion. Timber screw fasteners (5/8"x10") are required for the panels. The treaded design diverts moisture from the surface area, claiming to eliminate dangerous ice or water build up.

III-8.2 Asphalt Crossings

Several different types of asphalt crossings are currently in use in South Dakota. Among the categories encountered during this study were the single rail asphalt crossing, the ball-up mud rail crossings, and the ball-in mud rail crossings. The ball-in and ball-up type crossings are shown in Figures III-3 and III-4. The type of crossing used depends on the volume of highway and rail traffic. The most common type asphalt crossing is the ball-up type, which is mostly used for medium to low volume highway traffic. The ball-up crossing consists of a main rail, with an additional rail installed upright on the inside of the main rail, or one rail installed on both the inside and outside of the main rail. The ball-in type crossing consists of a main rail and an additional rail installed sideways with the ball towards the main rail. Ball-in rails may also be installed on both the inside and

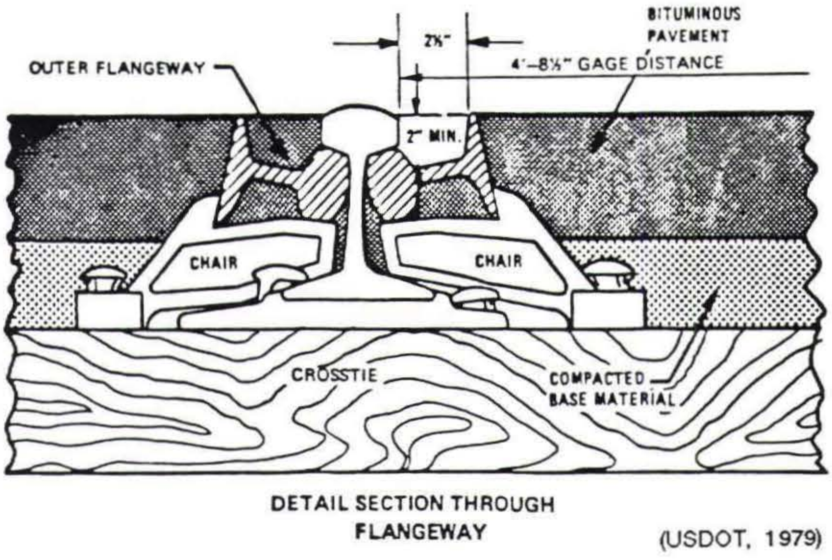


Figure III-3. Ball - In Type Asphalt Crossing

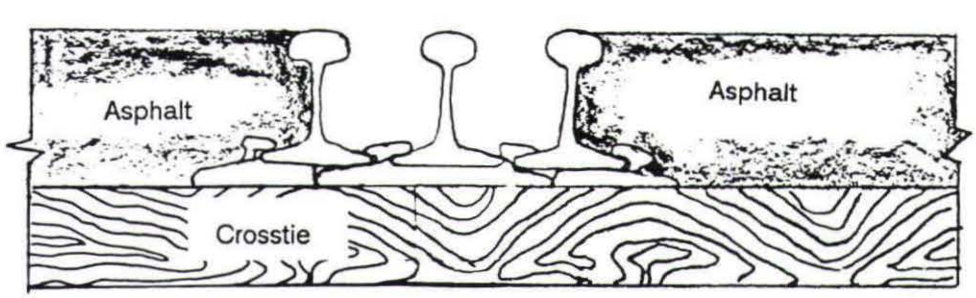
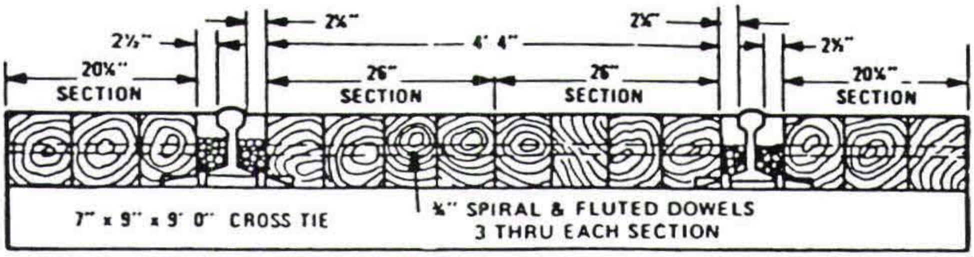


Figure III-4. Ball - Up Type Asphalt Crossing outside of the main rail. Rubber mud rails have also been used in South Dakota in recent years.

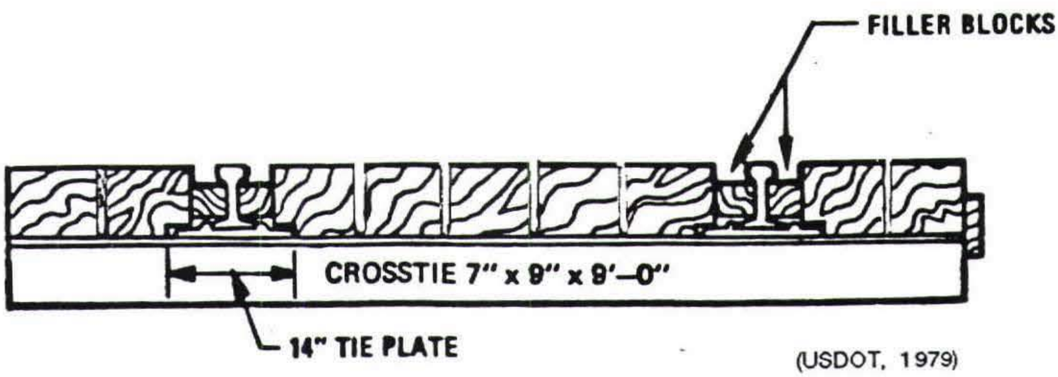
III-8.3 Timber Crossings

Two kinds of timber crossings are in use: Individual timbers and timber panels. Examples of individual timber type and timber type panel crossings are shown in Figures III-5 and III-6. Most frequently, the panels are full depth. The panels are prefabricated, and the sections are usually furnished in 8-foot lengths to accommodate 19.2 inches cross tie spacing. Washer-head drive spikes, or lag screws, with or without steel washers are used to secure the timber panels to the ties. Countersinking of the panels for either the spikes or lag screws is often done in order to provide a satisfactory riding surface. Rubber cushioning under the timber panels is a standard feature of the International Track Systems, Inc., while rubber capped timber modules are available from Oneida General Corporation.



(USDOT, 1979)

Figure III-5. Full Depth Timber Panels Crossing



(USDOT, 1979)

Figure III-6. Individual Timber Crossing

CHAPTER IV

FIELD INVESTIGATION

IV-1 CATEGORIZATION

Information on all railroad crossing locations, ADT, and soil conditions at the respective crossings was provided by the South Dakota Department of Transportation. This information was used to categorize and select railroad crossings in accordance with ADT, rail traffic, type of crossing and surfacing material, age, soil type, and drainage conditions. Otherwise, crossings surveyed were selected randomly without previous knowledge about their condition.

Categorization based on soil type could not be based on specific information about the subsurface conditions since the borings had to be performed after the crossing had been selected. Location, based on geological features including what soils were to be associated with land forms, flood plains, residual soil and glaciated areas, therefore had to be used for selection.

Originally, traffic volume was to be converted to E18 axle load equivalents, but due to lack of information on vehicle type breakdown and low traffic volumes on some roads, this was not feasible. Rather, traffic volume alone was used for this portion of the categorization. Whether a crossing was to be considered rural or urban was not only based on location but also by considering speed limit. In order to minimize the number of variables, categorization according to highway traffic was based on two categories for rural (ADT more and less than 1,000 vehicles). For urban areas, arterials and collector streets were considered.

Breakdown by type of crossing for rural areas seemed to relate to traffic, as rubber and asphalt crossings were used for both high volume and low volume highways. Timber crossings, however, seem mostly to have been used on low volume state and county highways. In urban areas on arterial streets, rubber crossings appear to be used in almost all cases, while asphalt crossings are most common on collector streets.

Selection of crossings as related to rail traffic proved difficult, as there are few coal lines left. However, two crossings were studied on the Burlington Northern coal line through Aberdeen. Crossings with a wide variety of rail traffic volume, however, were covered by the surveys.

With the number of crossings studied, age spanned over a period of up to 20 years. However, most crossings studied were installed between 1979 and 1990.

IV-2 FIELD SURVEYS

Based on traffic volume, crossing type and location, railroad crossings were selected and scheduled for investigation. Initially, 25 crossings located in eastern and western South Dakota were surveyed and studied in detail. At the end of the field investigation and survey of the selected crossings, it was decided that the data collected was insufficient for a complete evaluation of the problems associated with the different types of crossings investigated. A complete condition survey of 29 additional crossings was therefore performed on crossings in Rapid City, Sioux Falls, Blunt, Northville, Redfield, Aberdeen, and Watertown. The condition surveys are described and discussed in Section IV-3.

The field investigation for the initial 25 crossings, except for the crossing at Cottonwood, was performed from October, 1990 through March, 1991. The crossings in Rapid City were surveyed during the period of October through December, 1990, while the crossings in Aberdeen and Watertown were surveyed in February, 1991, and crossings in Sioux Falls in March of 1991. The crossing at Cottonwood was surveyed in June of 1991.

The field survey consisted of mapping the surface of the crossings. These results are presented in Appendix A and summarized in subsequent sections of this chapter. The mapping of the surface of the crossings was performed by dividing the surface into two square foot sections, and measuring the elevation within each of these squares by leveling. The data from the surveys was entered into a data file and contours of the crossing were plotted using a computer program. The main purpose of the surveys was to determine the overall geometry such that surface roughness of the crossings could be evaluated, and also to identify any patterns regarding crossing deterioration and failure. General conditions of the surfacing material and natural drainage were also recorded. Photographs were taken to show details and overall views of the crossings.

Cross-sections were drawn of the pavement at the shoulder of the road (outside the area generally subjected to traffic) in the wheel path of the highway traffic and in between the wheel paths. From the cross-sections so plotted, a roughness number was computed. The roughness number was defined as the height of a ridge or the depth of a depression over its length (in the direction of the highway traffic). A summary of roughness numbers for all crossings is given in Section VII-2.

IV-2.1 Vibration Monitoring

Vibration monitoring to determine dynamic loading conditions during both highway and railroad traffic was performed using the Instantel DS477 monitoring device. The results of the monitoring yielded little useful information, however, the results are discussed in subsequent sections of the report.

The Instantel DS477 records and plots the acceleration, peak velocity and frequency resulting from the highway and railroad traffic. Using the output from the vibration monitoring equipment, values of displacement amplitude of the track were calculated using a computer program. Measurements were taken at a distance of three feet from the wheel path at several locations along the crossing.

IV-2.2 Rail Deflection Measurements

The approach portion of the railroad bed was studied for deflections. Such deflections were measured using a cantilever beam device founded outside the railroad embankment. A pen was attached to the beam and a sheet of paper attached between the tie and the wall of the rail. As the rail deflected, a trace was recorded on the paper. During the measurements it was noted that the rails and ties deflected considerably under the rail traffic, however, no deformations were noted on the ballast between the ties. Deformations were therefore also measured by driving a spike under the rails at the end of the crossing and recording how far the spike was driven into the ballast relative to the rail.

IV-2.3 Soil Conditions

The soil conditions at the location of the crossings surveyed were obtained from borings and laboratory testing performed by crews from the South Dakota Department of Transportation. The soil conditions at the crossings are described under the results of the field surveys and the gradation analysis and water contents obtained from the laboratory testing are shown in the Appendix B of this report.

IV-3 RESULTS OF SURVEYS

Detailed descriptions of the crossings are presented in Volume II, Appendix A and B. The crossings are described under the main headings in accordance with the city or near the city where located, and in the order of which they were surveyed. Each crossing is named in accordance with the name of the street or highway it crosses. The location of each crossing also is shown on the location maps for each city.

VI-4 CONDITION SURVEYS

Following the survey of the originally designated 25 crossings, it was felt that the database for types of distress and failure modes connected with the different types of crossings inspected, especially with the many different types of rubber crossings, was inadequate. In order to obtain more information regarding failure and distress modes, an additional 29 crossings were inspected. The crossings are described in Volume II, Appendix A. The crossings were not surveyed, however, a complete condition survey including deflection and settlement measurements was obtained at selected locations. In addition, photographic records of the conditions at and near the crossings were obtained. In total, 29 crossings in Aberdeen, Rapid City, Watertown, Sioux Falls, Blunt, Redfield, Summit, and Northville were inspected between June and September, 1991. Each crossing is designated by street name. The crossings inspected are described under the main heading in accordance with the city or near the city where located. As with the crossings selected for surveying, the locations were selected at random, except in Rapid City where all but three crossings were inspected.

CHAPTER V

OBSERVATION OF CONSTRUCTION

V-1 GENERAL

During the course of this investigation, the construction of five railroad grade crossings was observed. The types of surfaces installed included individual timbers (1), timber panels (1), asphalt (1), and rubber(2). The installation of three different types of rubber panels (OMNI, Hi-Rail and Gen-Track), two of which were used in one location, was also observed.

V-2 SUMMIT

Highway 207

The crossing removed at Summit was a True Temper partial depth rubber panel type with steel wire mesh reinforcement (See Photo V-1). The panels were resting on rubber spacers. Some of the panels were cracked and actually punctured (See Photo V-2). The track was completely filled with mud and the panels were up to an inch above the rail at some locations (See Photo V-3). The thin wood headers were broken up and rotted and the asphalt in the crossing was uneven and rutted. The center portion of the asphalt was also quite worn and was up to an inch below the panels.

Drainage was good to fair along the northern and in the central portions of the site, but vegetative growth near the south spur indicated periods of standing water. Such indications were supported by excessively wet material excavated from the south side spur. There was little or no evidence of pumping near the

Photo V-1. Summit - Old True Temper Crossing. Panels Resting Rubber Spacers

Photo V-2. Summit - Cracked and Failed Panels.

Photo V-3. Summit - Panels Raised Relative to Rail.

Photo V-4. Summit - Drainage Trench with Drain Pipe.

end of the tracks, although there was evidence of track deflection under rail traffic, as the wheels appeared to have worn deeply into the edge of the panels.

At the time of arrival the south track had been excavated, both the drain pipe and the fabric had been placed (See Photo V-4), and the drain trench was partially backfilled. The excavation revealed that the asphalt pavement thickness at this crossing was between 12 and 13 inches. The asphalt was cut to full depth, thus minimizing the disturbance of the pavement outside the cut during excavation of the crossing. The old ballast had been removed and the subgrade was overexcavated to nearly 40 inches below grade. The material beneath the ballast was black, soft and wet clayey silt. The fabric was visible in the trench on the east crossing end and extended to a distance of nearly 30 feet past the end of the crossing. The fabric was wrapped around the drain pipe, but it was not placed up along the sides of the excavation. With the soft black soil in the sides of the trench there was no provision for the prevention of the ballast being forced into the sides of the excavation. The drain pipe, installed below the 40 inch excavation level of the trench, was extended out of the crossing area to the southeast toward a storm sewer (See Photo V-4). The excavated ties were in fair shape with no excessive wear at the rail support plates, and there was no significant fraying of the tie undersides from contact with the ballast.

Ballast was used for backfilling the entire 40 inch deep excavation. The ballast was placed by dumping from an end loader until the elevation of the trench was high enough for the preassembled track to be placed. Following the track placement, ballast was placed over the track by dumping from a freight car, and the track was then raised to the final elevation by jacking. No compaction of the ballast in the trench was performed, except for final vibratory tamping between the ties.

After raising the track to the desired elevation on the south track, the side spur immediately to the north of the main track was removed. Following removal of the old panels and spacers, mud could be seen packed in next to the rail (See Photos V-5 and V-6) and mud up to an inch thick was laying in between the bottom of the panels and on the top of the spacers. This most likely caused the lifting of the rubber panels above the rails (See Photo V-3). After removal of the ties, the ballast (Quartzite) appeared to have been contaminated by fines near the surface. After skimming off the upper 6 to 8 inches, however, the ballast was clean with little evidence of material breakdown or contamination with fines. Further excavation indicated that the ballast was approximately 24 inches thick and underlain by a 12 to 16 inch thick layer of very dense clean sand and gravel (See Photo V-7). The excavation profile is shown on Photo V-7. Underneath the gravel was hard, moist clay which showed little evidence of having infiltrated the sand and gravel. No water was encountered in the excavated trench.

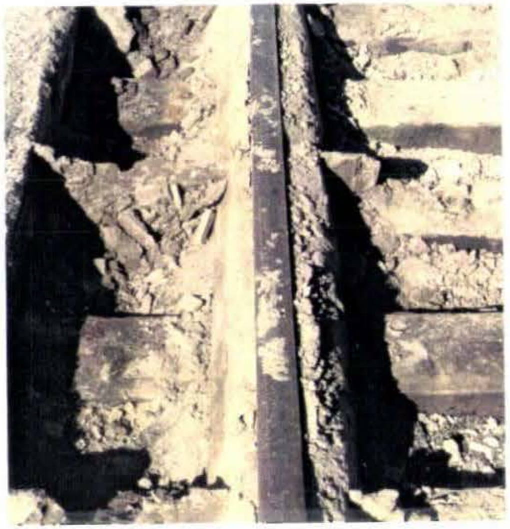


Photo V-5. Summit - Mud Packed Rail.

Photo V-6. Summit - Mud between Panels and Spacers.

Photo V-7. Summit - Old Ballast, Base Material and Subgrade.

Photo V-8. Summit - New Timber Panels.

Timber panels of the type observed at County 131 and east of Minnehaha County 131 near Sioux Falls were installed in the crossing at Summit. The panels, shown in Photo V-8, are full depth and rest directly on the ties. Each panel is fastened by eight camcar screws. The panels placed next to the rails also are grooved to allow for rail deflection without damage to the panels.

V-3 ABERDEEN

Fifth Street

The crossing at Fifth Street was inspected and surveyed and is described in Appendix A. The crossing was in very poor condition, as can be seen on Photo V-9. Removal of the old asphalt crossing commenced by cutting the asphalt at a distance of 6 to 8 inches from the end of the ties. The asphalt was not cut to full depth and, when the asphalt between the rails was removed, the pavement outside the cut was severely disturbed and raised several inches above the road base and subgrade in some places.

The ties in the crossing appeared to be in good condition, but the underside of the ties was considerably frayed from contact with the ballast (Photo V-10). Severe pumping had taken place at some locations (See Photo V-11) and the ballast was highly contaminated with fines and clay. Inspection of the exposed rail showed that the outside of the rail was completely filled with asphalt, while the space inside the rail was completely packed with asphalt and mud. The spikes holding the ties were partially

Photo V-9. Aberdeen, Fifth Street - Condition of Old Crossing.

Photo V-10. Aberdeen, Fifth Street - Tie Damaged by Contact with Ballast.

Photo V-11. Aberdeen, Fifth Street - Pumping.

Photo V-12. Aberdeen, Fifth Street - Mud Squeezed in between the Rail and the Bearing Plates.

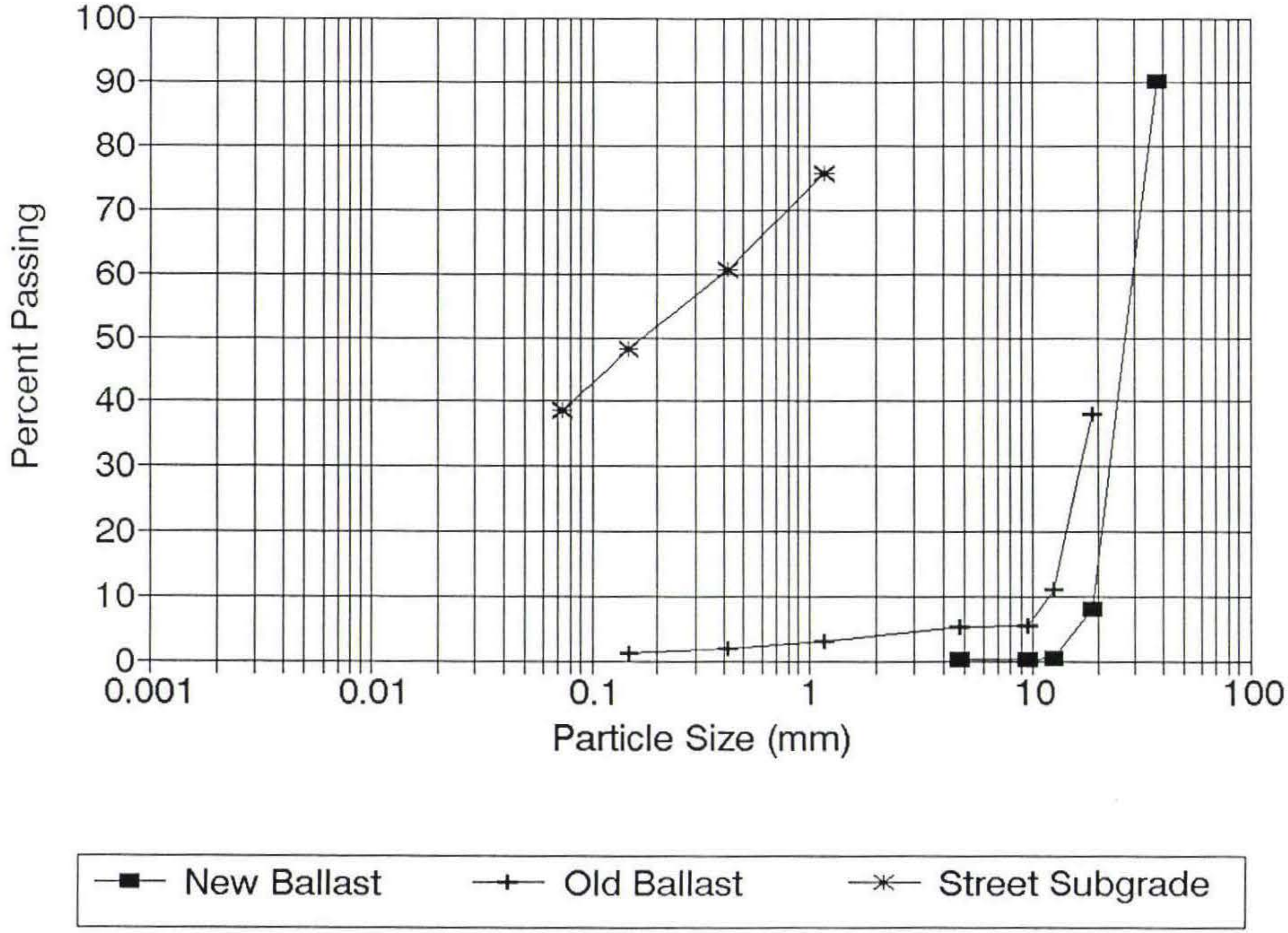
loose, hence up to one half of an inch of mud had been forced in between the rail and the bearing plate (See Photo V-12).

The old crossing was taken out to a depth of 16 inches below the pavement. The ballast consisted of natural sand and gravel and was at most 6 to 8 inches in thickness below the ties. Clay had also infiltrated in between the gravel and ballast at the bottom of the excavation. The exposed clay at the bottom of the excavation was locally very moist.

The excavation showed that the approach pavement was 4 to 5 inches thick and underlain by less than 6 inches of crushed rock. Located under the crushed rock was a greyish-brown moist silt. The gradation curves for new and old ballast as well as road base and subgrade material, shown in Figure V-1, indicate that the subgrade is highly frost susceptible.

Reconstruction commenced with leveling of the trench bottom. No compaction or proofrolling of the subgrade was performed and the fabric was placed directly on the clay and loose gravel subgrade. The subgrade was not strong, as the backhoe and front loader used in the construction made one to two inch deep ruts when passing over the exposed area. The exposed subgrade is shown in Photos V-13 and V-14. Placement of fabric is shown in Photo V-15. The fabric was 15 feet wide and the excess was folded back into the excavation. New ties were lain directly over the fabric. Ballast was then dumped over the finished track and packed under the ties. Except for the packing of the ballast no compaction

Figure V-1. Aberdeen - Fifth Street
Ballast and Subgrade Gradation



was performed. The fabric was not carried past the shoulders of the road (to the end of where the panels were to be placed) but ballast was placed well beyond the shoulders. The rail installed weighed 115 pounds and was welded, such that the nearest bolted joints were well beyond the crossing.

Two types of rubber panels were installed at this location, both previously used and removed from another location. At the portion of the crossing subjected to traffic, Hi-Rail-type panels were installed, while General Tire Gen-Track II were installed at the shoulders. Prior to installation of the panels, the ties and rails were thoroughly cleaned using compressed air (See Photo V-16). Installation of the full depth Hi-Rail panels and the partial depth Gen Track panels with shims is shown in Photos V-17 and V-18. Since the track at this crossing is in an eight degree curve, the contractor had trouble installing the panels such that they matched perfectly. The Gen-Track II panels did not match the Hi-Rail panels in height. In the final product, the shoulder panels were about one half to three quarters of an inch below the Hi-Rail Panels. In order to secure the panels on the outside of the rail, one to two camcar screws were installed in the Hi-Rail panels (See Photo V-18).

As close as the asphalt was cut to the track at this location, there was little room for compaction between the panels and the pavement. The asphalt should therefore have been cut out to a width sufficient to for a roller to recompact the subgrade obtain sufficient asphalt compaction. It is also felt that the asphalt

Photo V-13. Aberdeen, Fifth Street - Exposed Subgrade with Loose Cobbles.

Photo V-14. Aberdeen, Fifth Street - Exposed Clay Subgrade.

Photo V-15. Aberdeen, Fifth Street - Placement of Fabric.

Photo V-16. Aberdeen, Fifth Street - Cleaning of Ties before Placement of Rubber Panels.

Photo V-17. Aberdeen, Fifth Street - Placement of Gen-Track Panels.

Photo V-18. Aberdeen, Fifth Street - Placement of HI-RAIL Panels.

Photo V-19. Aberdeen, 12 Street - Corroded Rails.

Photo V-20. Aberdeen, 12 Street - Deteriorated Tie.

should have been cut to full depth to minimize the disturbance of the pavement. At this location, the pavement is also to be raised four inches. Care should therefore have been taken to adopt a procedure where adequate compaction of the asphalt could be achieved next to the track.

Twelfth Street South

Twelfth Street South is a low volume street with less than 300 vehicles per day. The old crossing was paved with asphalt, while the new crossing was constructed from timber. The street is paved with asphalt from the north to the crossing, but the road surfacing is gravel south of the crossing. The age of the crossing is not known but the contractor estimated that the crossing most likely dated to before World War II. The rails taken out at this crossing were severely rusted, with the base completely corroded away (See Photo V-19). The spikes were no longer holding the gauge; rather, the rail was held up by mud packed around it. The ties were in varying shape, from fairly good to completely rotted away. All ties were severely damaged from the rail traffic. An average tie is shown in Photo V-20.

The track bed was excavated to 14 inches below grade. The grade was raised about four inches, hence there was only about 6 inches of ballast beneath the track. No fabric was installed at this crossing. The soils taken out were moist, dark grey to black silty clay. Most of the subgrade was hard although no compaction or proofrolling was performed. Compaction was limited to packing of the ballast, however, with as little ballast as was used under the ties at this crossing, the tines of the machine penetrated the subgrade and brought soil up into the ballast.

The ties were thoroughly cleaned by brooming before placing the timbers. The timbers were laid by hand and fastened using camcar screws (See Photo V-21). Generally, two camcar screws were used to fasten each timber. The timbers installed in this crossing were of non-uniform thickness, and the difference in thickness ranged up to 3/4 inch. Some timbers were also warped, which made them difficult to fasten. Warped timbers were lain with the concave side down and bolted with camcar screws at every tie. This procedure in some instances, however, was not sufficient to bring the timbers flush with the crossing (See Photo V-22). Backfilling against the headers and in between the track consisted of dumping soil in with the backhoe and spreading by shovel (See Photo V-23). Compaction was limited to running over the soil with the wheels of the backhoe (See Photo V-24).

The drainage at this crossing was generally very poor and, with no fabric at this location, problems could arise. The rail used in this crossing was 70 pound weight with no welded joints, and a bolted joint was located within the crossings on the inner rail on the main track (See Photo V-24).

V-4 STURGIS

Ball Park Road

The crossing at Ball Park Road in Sturgis was of an inner and outer ball-up mud rail asphalt type and was replaced using Omni

Photo V-21. Aberdeen, 12 Street - Fastening of Timbers with Camcar Screws.

Photo V-22. Aberdeen, 12 Street - Completed Crossing Showing Uneven Timbers.

Photo V-23. Aberdeen, 12 Street - Placement of Soil Backfill.

Photo V-24. Aberdeen, 12 Street - Completed Crossing and Backfilling.

type rubber panels. The crossing, installed in 1981, was not part of the initial survey, nor was it examined during the condition survey. The crossing was replaced in conjunction with the reconstruction of Ball Park Road and, at the time of inspection, the road base was not yet brought to grade. The old track was removed and the ballast and subgrade excavated to a depth of up to 26 inches below the existing grade (See Photo V-25).

The removal of the old pavement revealed that the spaces between the mud rails and the main rail were packed with mud and that mud had been forced under the mud rails. Samples of the old limestone ballast were taken and a sieve analysis performed. The results, when compared to new ballast (Figure V-2), show that the portion smaller than 4 mm had increased from 0 to 16 percent during the 10 years of service assuming that the old ballast originally was of the same gradation as the new ballast. It is not known whether the increase in the portion smaller than 4 mm was caused by ballast degradation or infiltration from outside the crossing, however, degradation of ballast has been known to take place with

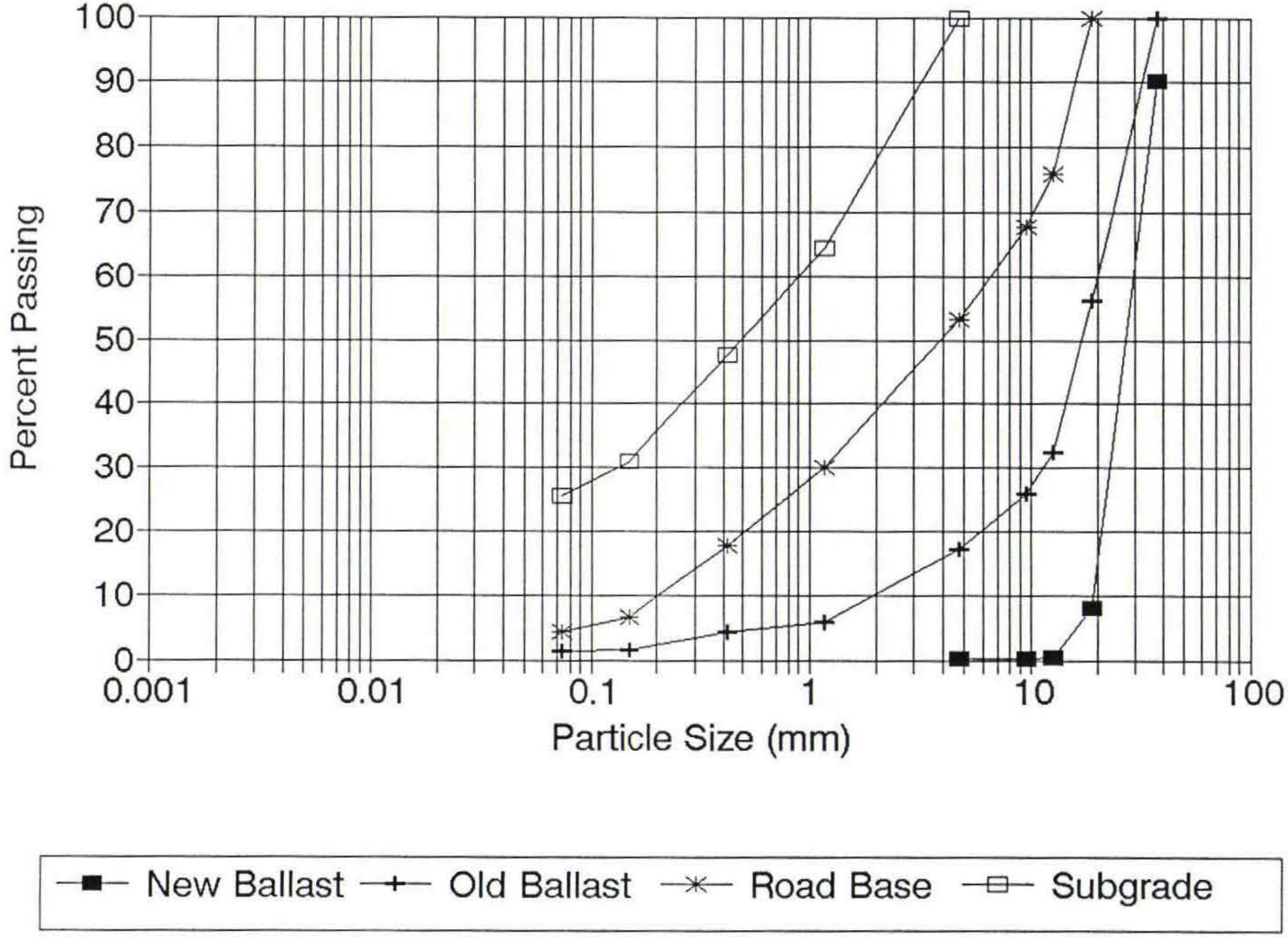
Photo V-25. Sturgis, Ball Park Road - Roadbase and Subgrade Exposed in Excavation.

Photo V-26. Sturgis, Ball Park Road - Tie Damaged under Bearing Plate.

Photo V-27. Sturgis, Ball Park Road - Overall View of Excavation.

Photo V-28. Sturgis, Ball Park Road - Close-up of Rutting form Frontloader Tires.

Figure V-2. Sturgis - Ball Park Road
Ballast and Subgrade Gradation



(Photo V-26). Such penetration would have contributed significantly to the settlement of the rails in the crossing.

The removal of the old ballast and excavation of the softened subgrade was performed by a frontloader. The exposed subgrade is shown in Photos V-27 and V-28. The excavation was nearly 2.5 feet deep at the center and tapered down to a depth of approximately 1.5 feet at the north and south ends of the crossing. As can be seen in the photos, the exposed subgrade consisted of dark brown to black, soft, silty clay and was severely disturbed and rutted by the frontloader tires. No proofrolling or compaction of the subgrade was performed and the fabric was rolled out over the subgrade as shown in Photo V-29. No drainage pipe was installed. Ballast was then placed to a depth of approximately 1.5 feet and the preassembled track was lifted into the crossing and bolted to the rails at both ends of the track. No compaction of the ballast was performed. After the placement of the track a ballast car was rolled onto the crossing and further ballast dumped over the track. The track was then jacked to its final grade and the ballast was packed under the ties.

Following leveling of the track, the rails were surveyed and the first train, consisting of four locomotives and fifty loaded freight cars, was allowed to pass over the crossing. The track was then resurveyed. The results are shown in Figure V-3, and reveals an initial settlement of up to .5 inches and an average settlement of .3 inches. Such settlements are on the same order

Photo V-29. Sturgis, Ball Park Road - Placement of Fabric.

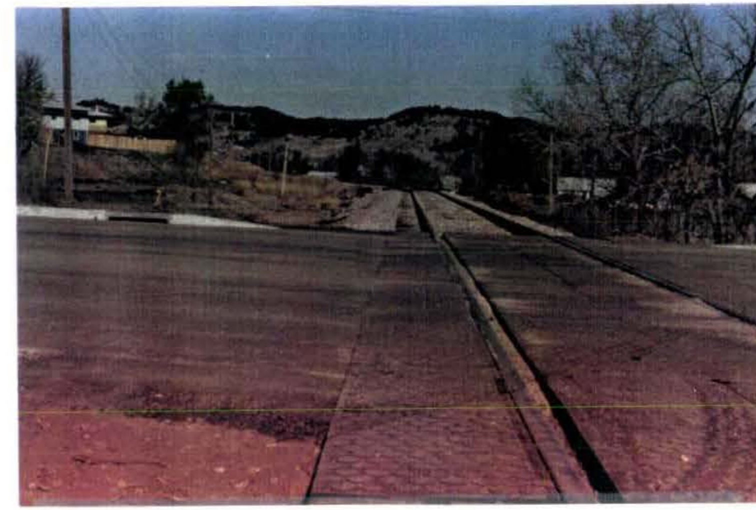
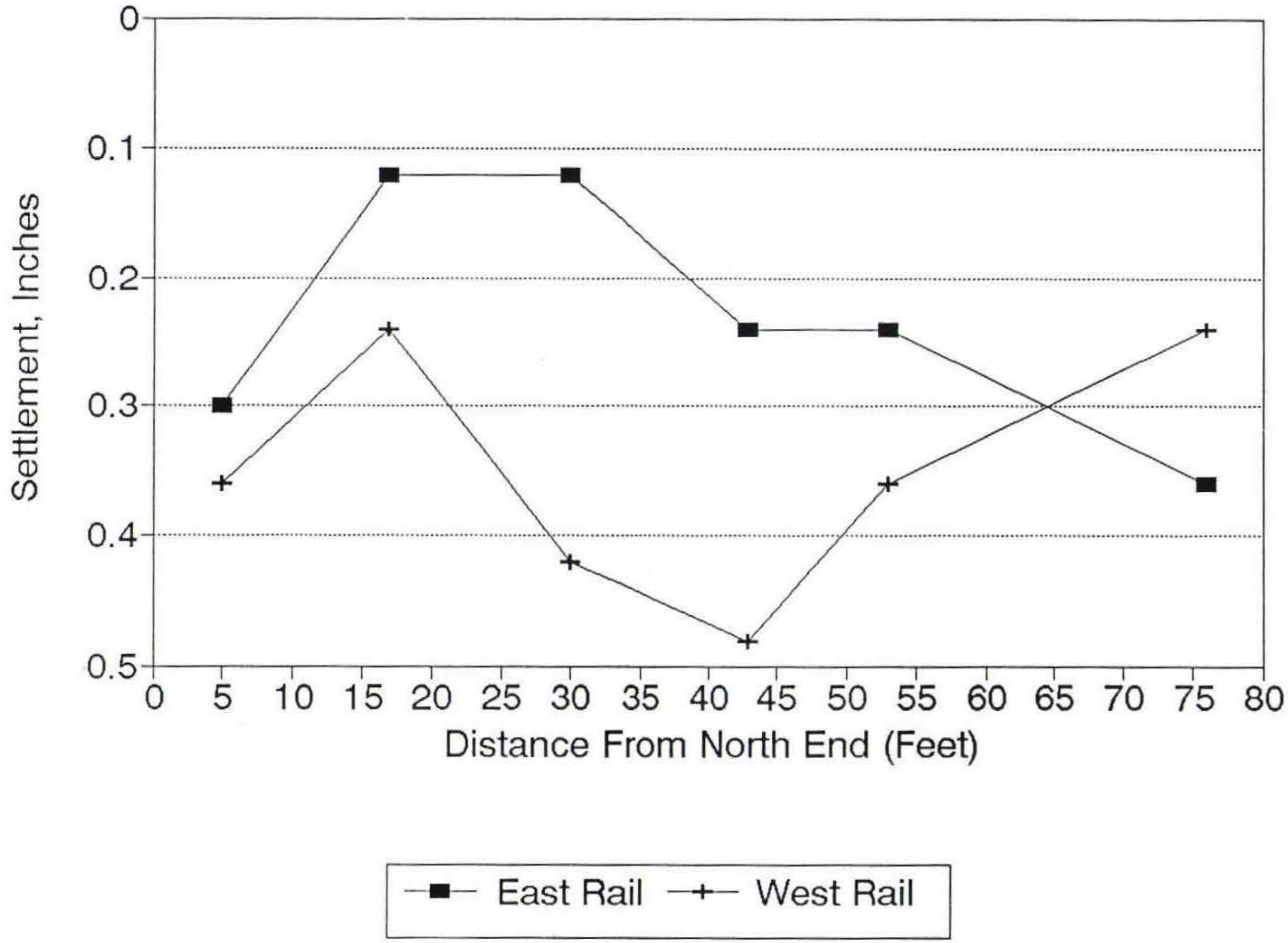


Photo V-30. Sturgis, Ball Park Road - Crossing One Month after Completion.

Photo V-31. Rapid City, Second Street - Pavement and Subsurface Soil Profile.

Photo V-32. Rapid City, Second Street - Ballast above Old Fabric and Subgrade Below Fabric.

Figure V-3. Sturgis - Ball Park Road
Track Settlement After First Train



of magnitude as those initially observed at Second Street in Rapid City. Ball Park Road was not paved for approximately three weeks following completion of the crossing and the Omni rubber panels were not placed until just before the road was paved. A considerable amount of track settlement was therefore allowed to take place prior to actual crossing usage.

Since the road base was no more than 6 inches thick at the sides of the crossing and nearly 30 inches of ballast was placed in the crossing, differential frost heave at this location is likely to occur.

At this location, an inspector from the SDDOT was present for a short period of time. However, the inspector stated that he was not certain about what to look for and what to inspect.

The crossing was inspected approximately one month after completion (Photo V-30). At this time there was a considerable amount of mud in between the rails and the center rubber panels and the crossing had settled approximately 1/4 to 1/2 of an inch in relation to the pavement, especially on the west side. It was also clear that the pavement was placed high relative to the crossing. It is likely that these factors could contribute to crossing roughness and crossing damage in the future.

V-5 RAPID CITY

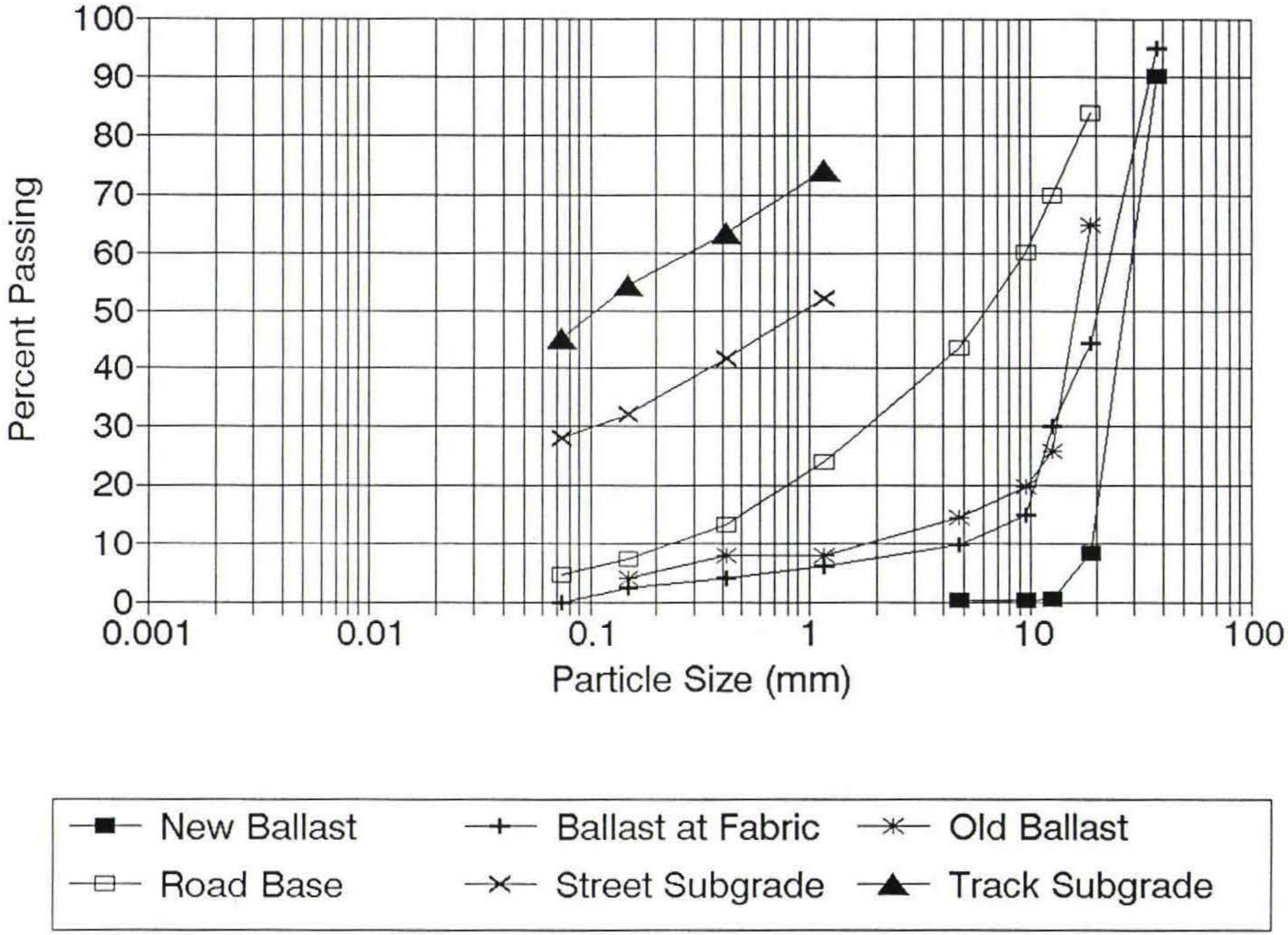
Second Street

The reconstruction of the crossing at Second Street was performed in conjunction with the installation of a new 72 storm sewer.

The sewer was installed on the west side of the street running parallel to the curb.

The excavation for the sewer allowed an excellent opportunity for detailed study of the soil condition under the crossing. Judging by the excavation, the crossing is at the location of an old creek crossing. Timbers from the old bridge at the location were encountered in the west end of the excavation and the fill soils under the crossing consisted of a brown to dark brown, medium stiff, wet, silty clay and clayey silt. The pavement thickness at the crossing was from 4 to 10 inches thick and underlain with 2 to 4 inches of crushed rock overfill. The cross-section and its foundation soils are shown in Photo V-31. Samples were also taken of the crushed rock base and the clay and silt subgrade under the asphalt apron on the sides of the crossing. A gradation analysis was performed on the samples, the results of which are shown in Figure V-4. The results indicate that the materials underlaying the asphalt aprons are very frost susceptible and are therefore likely to be subject to frost heave, especially with the amount of moisture available from the ballast trough and the underlying fill soils. Following placement of the storm sewer pipe, the trench was backfilled with flowable fill (Portland Cement and Fly Ash grout) to mid-height and allowed to set. The rest of the trench was then backfilled in lifts using the excavated soils. During the filling it was observed that the fill was pumping under the roller and that the roller would not walk out. Cement-treated soil was then brought

Figure V-4. Rapid City - Second Street
Ballast and Subgrade Gradation



in and compacted in lieu of using the soils excavated from the storm sewer trench. There were no field compaction tests performed during the backfilling process.

At the Second Street crossing two tracks were removed and the old ballast excavated and removed. Asphalt was cut to full depth at both the north track and the south track. On the north track there was six inches of ballast over approximately seven inches of crushed rock under the ties and no fabric was found. All of the old ballast and crushed rock was removed before fabric and new ballast was placed. At the south track there was approximately 12 inches of ballast under the ties and fabric was found at the bottom of the ballast trench (See Photo V-32, page 49). The fabric appeared to have performed excellently as no fines from the clay and silt under the fabric was seen to have infiltrated the ballast. There were no provisions for drainage and it was evident that water had been standing at times in the ballast trough since the limestone had cemented above the fabric on the south track. The ballast and crushed rock had also been contaminated with fines from the fill subgrade on the north track. In addition it is likely that, since the ballast under the crossing was generally thicker than the ballast under the track, water had accumulated in the ballast under the track and may have drained to the crossing. Conversations with construction crews from the railroad indicated that such water flow had been observed at other locations.

The removal of the pavement and exposure of the ties and rails showed that the spaces between the mud rails and the main rail were completely filled with hard-packed mud. Removal of the mud rails also showed that in excess of one inch of mud had been forced in between the bearing plate and the rail (See Photo V-33), lifting the mud rail well above the main rail, as also observed in the condition survey (See Appendix A). The excavations for both the north and south track revealed that the ballast was comprised of limestone and was highly deteriorated (See Photo V-34). A sieve analysis was run on the ballast showing that it had been subjected to degradation. The grain size analysis on the old and new ballast is shown in Figure V-4. Towards the bottom of the existing ballast, evidence of cementation could clearly be seen (See Photo V-35) and fines washed towards the bottom of the ballast trench had formed a conglomerate of calcite and ballast. This phenomenon is common and has been known to completely clog dam toe drains consisting of crushed limestone with more than 5 percent fines.

The old ballast and fabric were removed by a frontloader (See Photo V-36). In spots, the clay subgrade under the fabric and at the bottom of the trenches was soft, resulting in considerable rutting of the subgrade. Following completion of the excavation, the ruts were filled with loose soil (mostly clay clumps) and fabric was placed directly above the subgrade (See Photo V-37 and V-38). No compaction or proofrolling of the subgrade was performed. The track was lifted into place, covered with new

Photo V-33. Rapid City, Second Street - Mud Squeezed in between Bearing Plates and Mud Rail.

Photo V-34. Rapid City, Second Street - Deteriorated Ballast and Subgrade.

Photo V-35. Rapid City, Second Street - Degraded and Cemented Limestone Ballast.

Photo V-36. Rapid City, Second Street - Removal of Old Ballast.

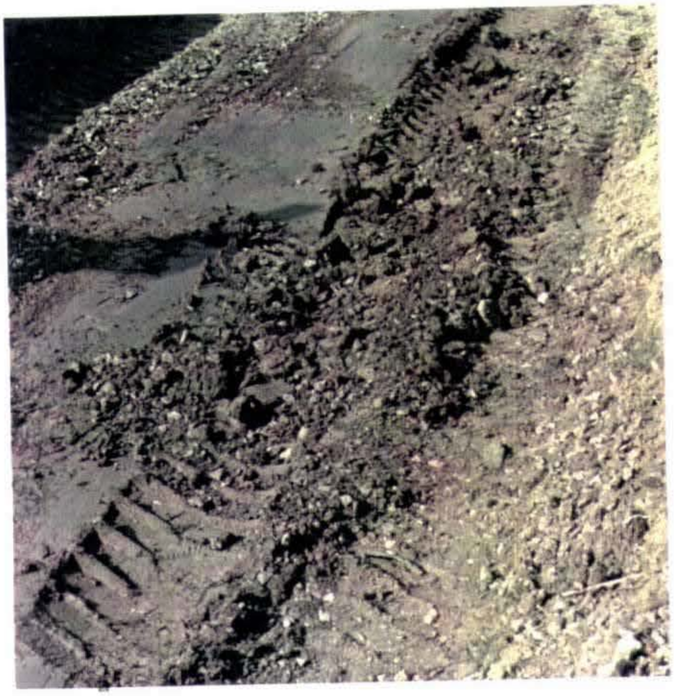


Photo V-37. Rapid City, Second Street - Finished Subgrade and Backfilled Rutting Marks.

Photo V-38. Rapid City, Second Street - Placement of Fabric.

ballast, and raised by jacking to allow the ballast to fall in place under the ties. The ballast dumping and track jacking was continued until the track and rails were brought to the desired elevation. The ballast was then packed with a hydraulic tamper. No ballast was placed or compacted prior to the track being lifted into place.

Since the crossing had to be open to railroad traffic immediately following construction, and since the road would not be open to traffic until completion of the storm sewer and paving, the track was not to be releveled and welded until just prior to street paving. The ballast and subgrade was therefore subject to repeated loading from railroad traffic for a period of two weeks. During this period the south track was repeatedly surveyed at ten locations along the rails and the settlements were calculated. The track was surveyed after the first day of rail traffic, after the sixth day, and on the eleventh day. The results of the surveys in terms of settlement are presented in Figures V-5 and V-6. It can be seen that the settlement was greatest under the section where the pipe was laid. Figure V-6 also shows that the settlements decrease linearly with the logarithm of the number of days of rail traffic. In other words, the same settlement which occurred between the first day and the fifth day of rail traffic would also be expected to occur over the next 50 days, and over the next five hundred days as well. For this crossing, approximately 0.4 inches settlement is expected to take place within the next year, and another 0.4 inches over the following

Figure V-5. Second Street
Track Settlement

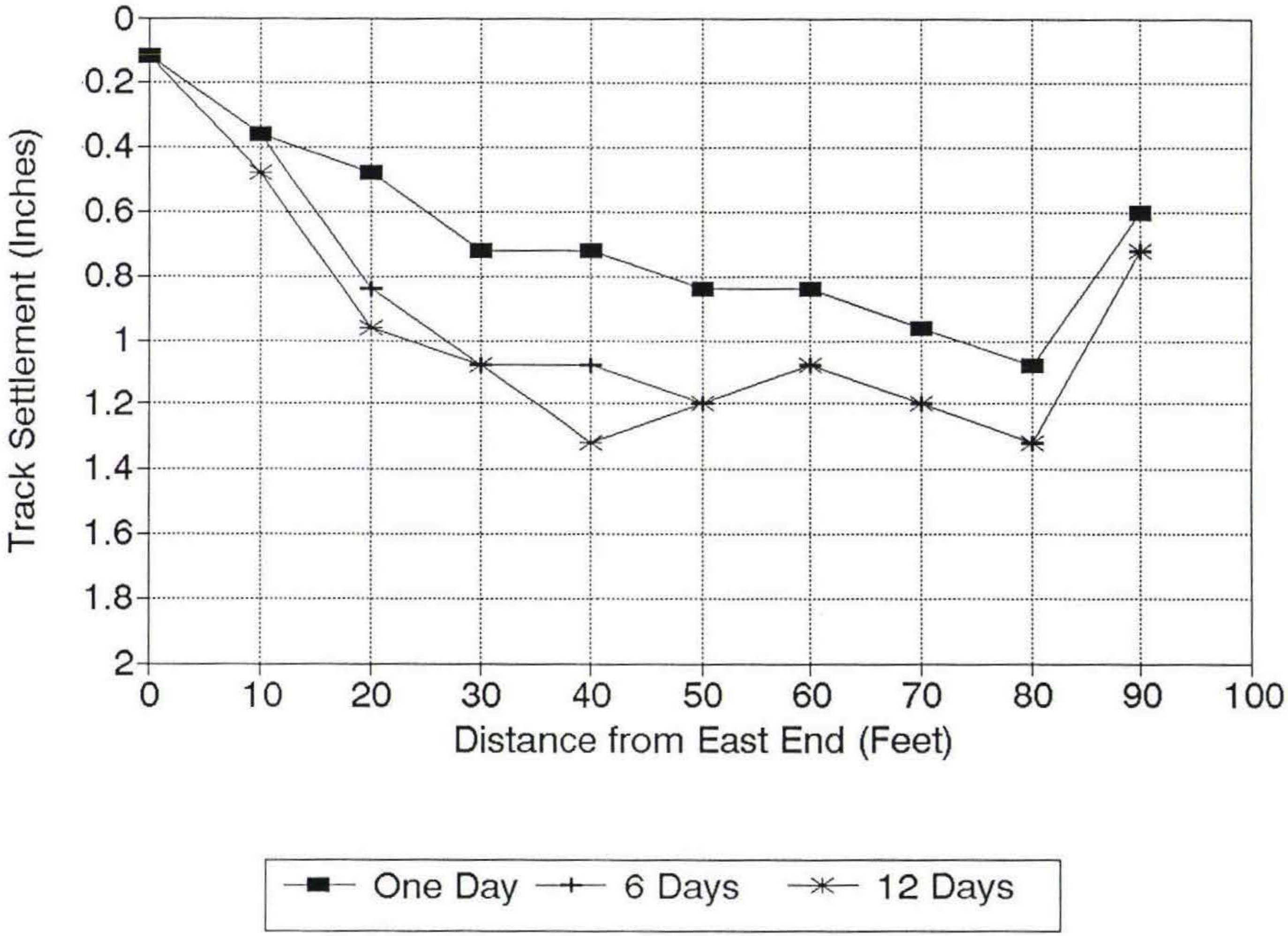


Figure V-6. Second Street
Average Settlement Versus Time

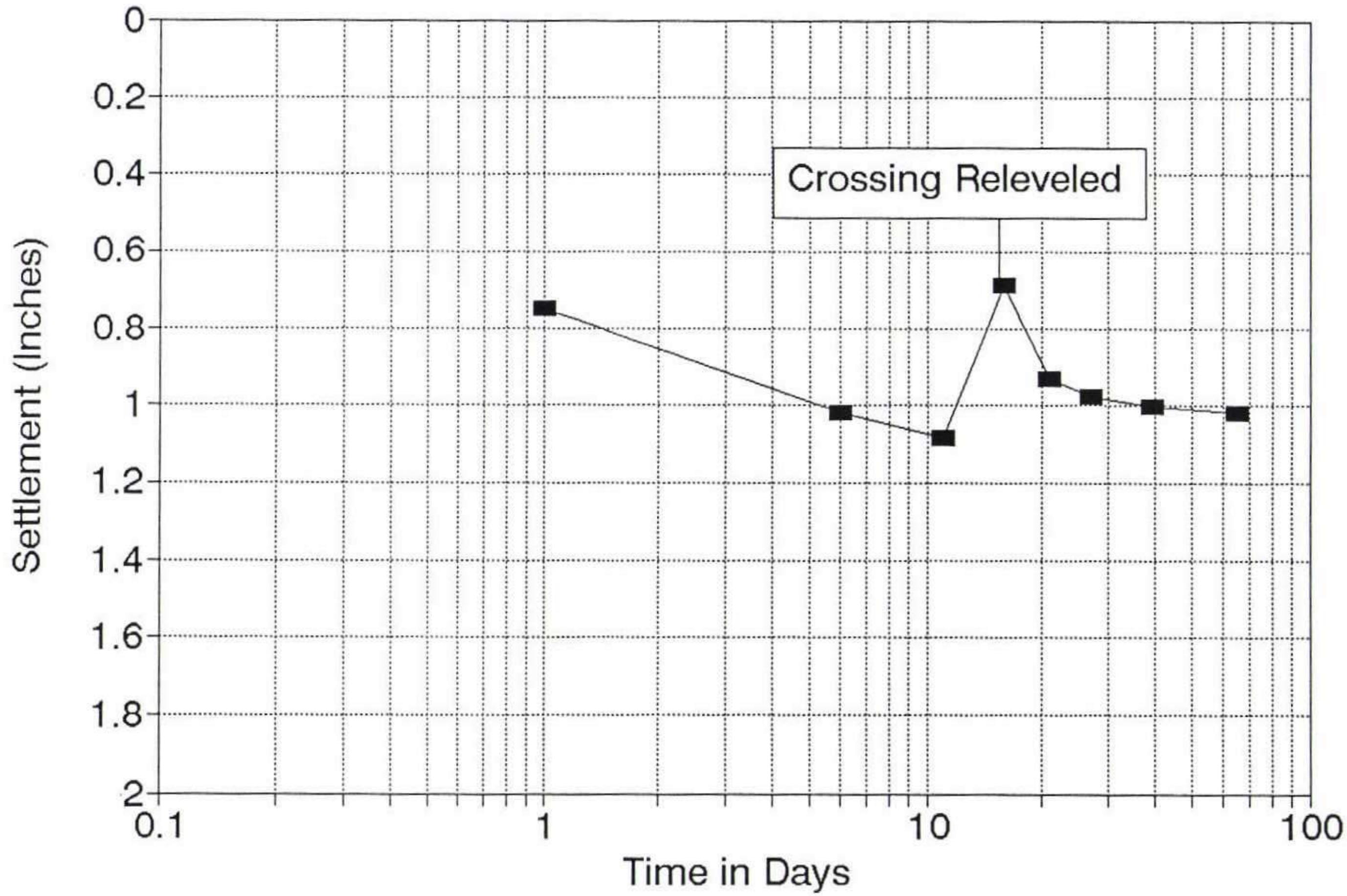
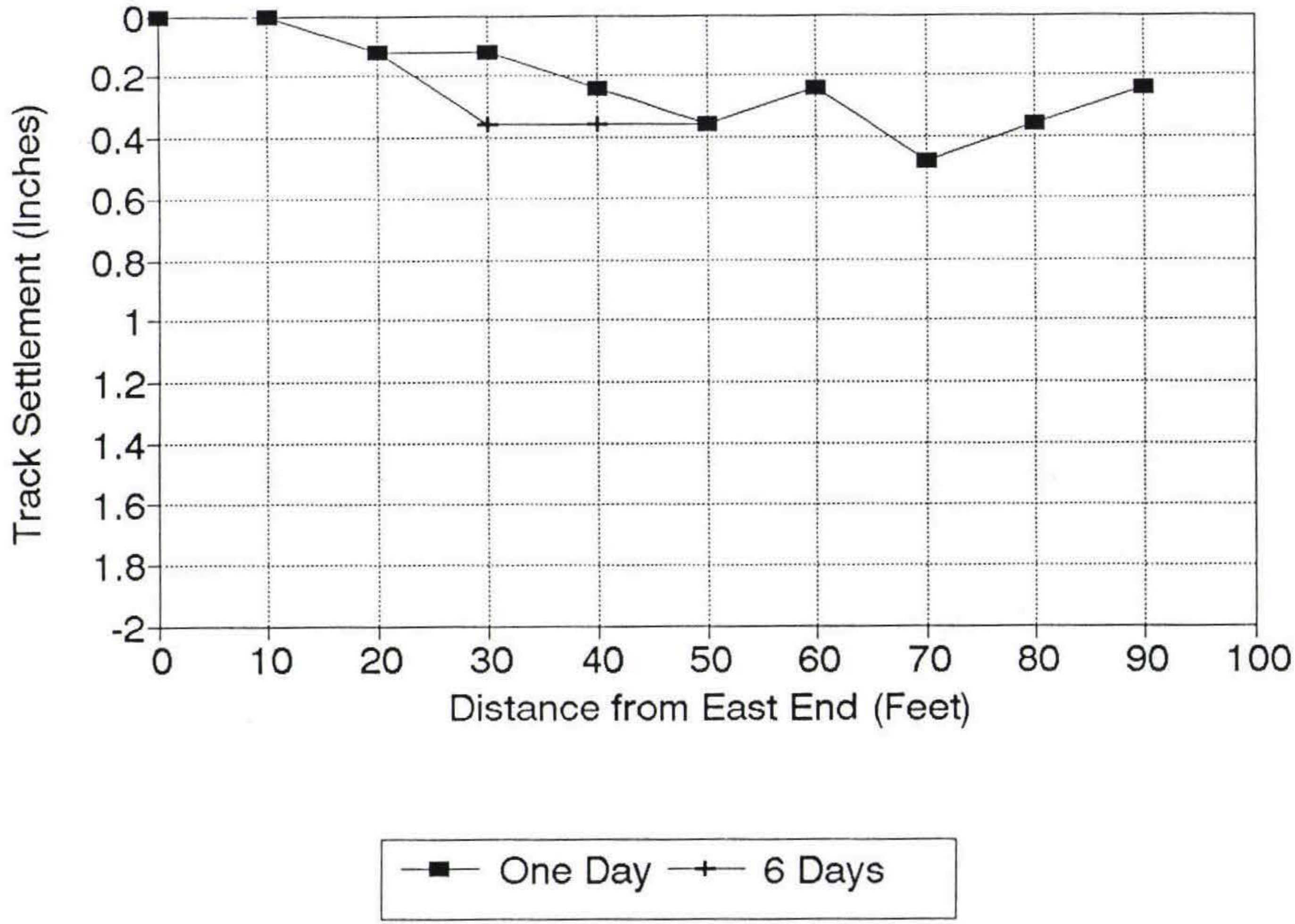


Figure V-7. Second Street
Track Settlement After Releveling



10 years. This behavior is in agreement with previously performed repeated loading on granular material (Stewart, 1986) and was therefore expected. The crossing was surveyed again following relevelling and showed only minor settlement at the location of the trench (Figure V-7). The rate of settlement also seemed to decrease, as the slope of the settlement curve was less following relevelling (Figure V-6).

CHAPTER VI

WINTER ROUGHNESS

VI-1 GENERAL

The effects of seasonal temperature variation, snow, and time were studied by surveying some of the crossings in the winter, resurveying after heavy frost periods, and by reinspection of some of the crossings in the summer. In particular, winter and summer photographs of crossings in Aberdeen and Watertown were compared, and the effects of snow accumulations on and near the crossings investigated in Rapid City. Long term effects of rail and highway traffic on the crossings could not be studied, however, three crossings in Rapid City were resurveyed a year after the initial survey, and the results compared. The effect of frost, snow accumulation and time are discussed under separate headings below.

VI-2 FROST HEAVE

Based on conversations with representatives of Burlington Northern, complaints have been frequently voiced about increased winter roughness of the crossing at Kline Street in Aberdeen. The crossing was originally surveyed in February which is usually the period of maximum frost depth. The crossing was reinspected and photographed during the summer of 1991. Comparison of photographs taken in the winter and summer (Photos 214 and 215) show that the portions of the approach to the north side of the crossing

Photo VI-1 and VI-2. Aberdeen, Kline Avenue - Condition in February, 1991 (Left) and September 1991 (Right).

Photo VI-3. Effect of Freeze-Thaw - Mud Squeezing up between Rails and Panel.

Photo VI-4. Effect of Freeze-Thaw - Mud Squeezing up between Rail and Panel and Outer Panels.

Photo VI-5. Effect of Freeze-Thaw - Frost Heave at Approach to Crossing.

are approximately one inch above the outer rubber panel, while the same portion of the crossing is approximately flush with the panel in the summer.

The effect of freeze-thaw can be illustrated by the photos taken at East Boulevard in Rapid City during a thawing period. At this location mud can be seen squeezing up between the panels and the rails (Photo 216), and between the outer panels (Photo 217). Frost heave and damage may also be seen at the approaches to the crossings in Photos 218 and 219.

VI-3 SNOW ACCUMULATION

Several crossings in Rapid City were inspected after an extended freezing period and a heavy snow fall. The inspection showed that the snow tended to accumulate on the approaches to the crossing, while the snow appeared to jolt loose within the crossing (See Photo 220). Snow also does not seem to stick to and accumulate on the rubber crossings, while it has a tendency to get packed down on the pavement at the approaches to the crossing. In addition, continuous rail traffic keep snow from accumulating at and near the rails, hence the elevation of the crossing is maintained at the rails, while the elevation is raised elsewhere by packing of snow at the approaches to the crossings (See Photo 221 and 222).

Photo VI-6. Effect of Freeze-Thaw - Frost Heave of Asphalt Approach.

Photo VI-7. Snow Accumulation on Approaches.

Photo VI-8. Snow Accumulation on Crossing with Cleared Rails.

Photo VI-9. Snow Accumulation of Crossing Approaches and Center.

VI-4 TIME EFFECTS

Three crossings in Rapid City were resurveyed a year after the initial field study. The crossings resurveyed were a timber crossing (Blackhawk), an asphalt crossing (Steele Avenue), and a rubber crossing (LaCrosse Street). A comparison of the surveys are shown in Figures VI-1 through VI-6.

The crossing at LaCrosse Street showed little or no change at the approaches, but the track appears to have settled between approximately 0.1 and 0.2 inches (Figures VI-1 and VI-2). This is in agreement with the observations at Second Street, where extrapolation of the settlement curve (Figure V-6) would predict a settlement of 0.1 inches caused by the cyclic loading for a period from one to two years after construction.

The resurvey at Steele Avenue showed considerable change within a period of one year (Figures VI-3 and VI-4). The crossing at Steele Avenue is over 10 years old, and the drainage conditions are poor. Overall changes at the wheel paths are small, with most of the changes occurring at the approaches to the crossing. Between the wheel paths, little or no changes have occurred at the approaches, however, immediately outside the mud rails bumps in the asphalt have disappeared.

The timber crossing at Blackhawk (Figures VI-5 and VI-6) also appears to have undergone changes. Since the benchmark

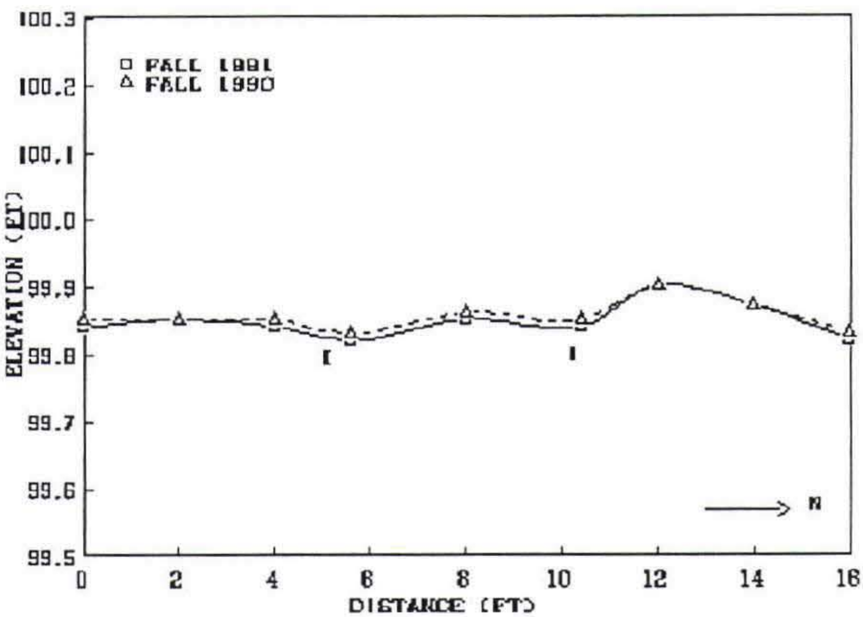


Figure VI-1. LaCrosse Street, Profile at wheel path in the Fall of 1990 and Fall of 1991

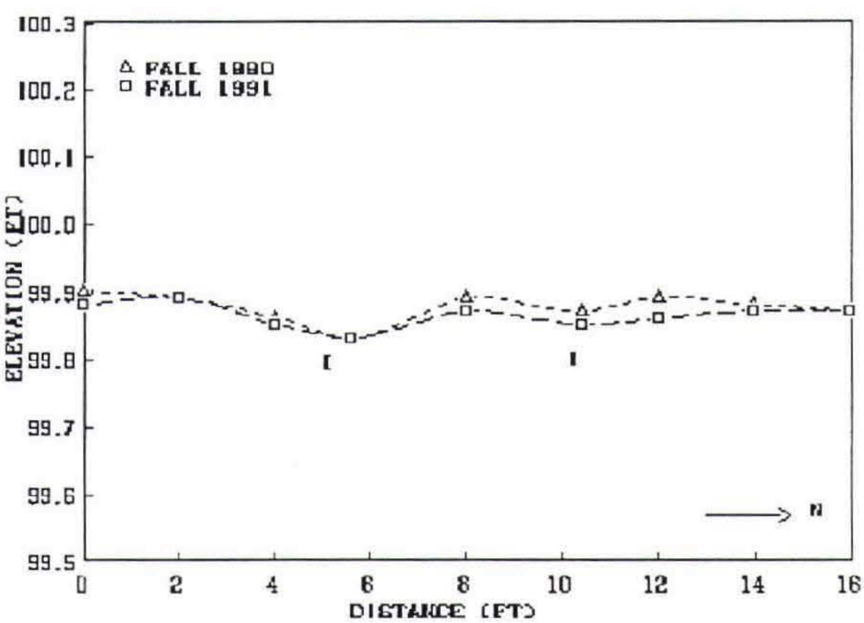


Figure VI-2. LaCrosse Street, Profile between wheel paths in the Fall of 1990 and Fall of 1991

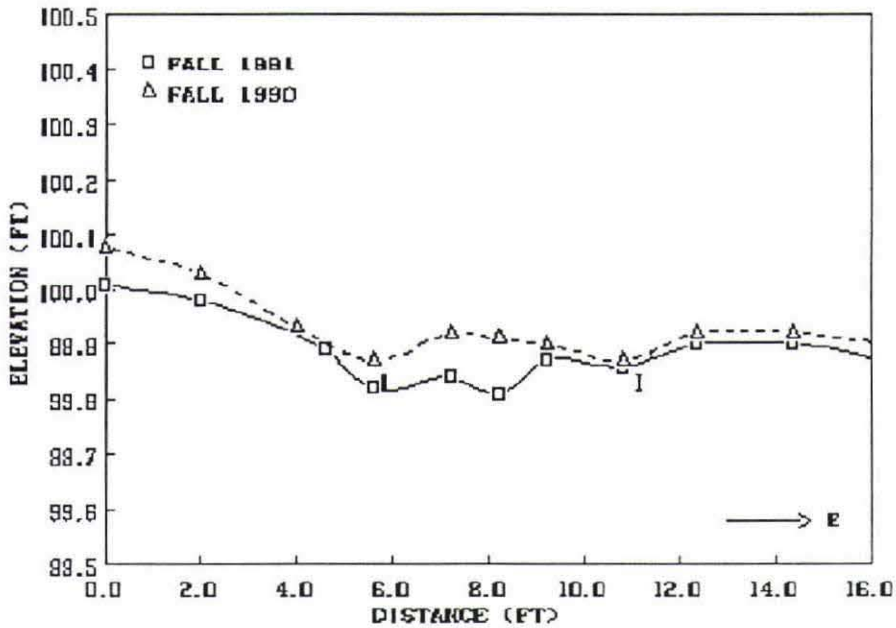


Figure VI-3. Black Hawk, Profile at wheel paths in the Fall of 1990 and Fall of 1991

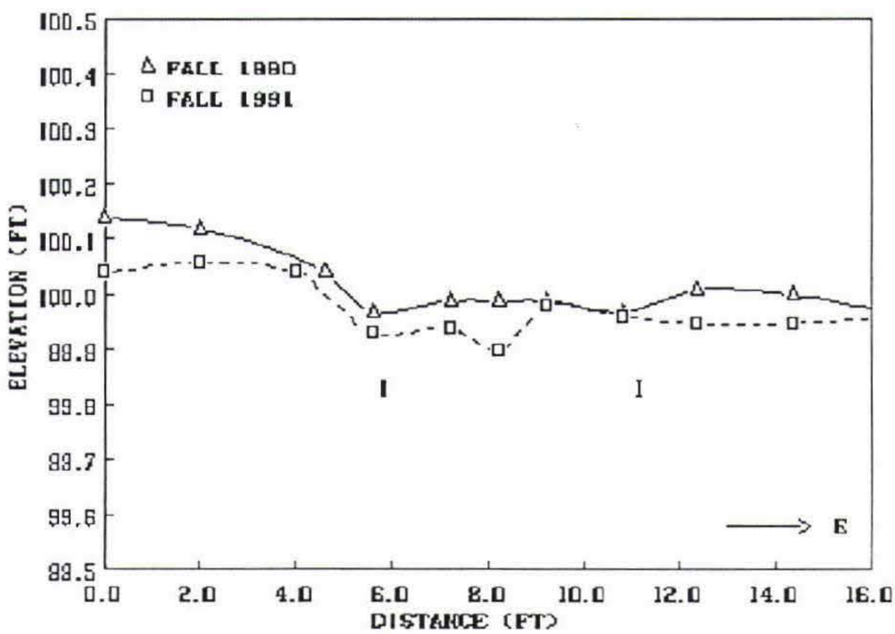


Figure VI-4. Black Hawk, Profile between wheel paths in the Fall of 1990 and Fall of 1991

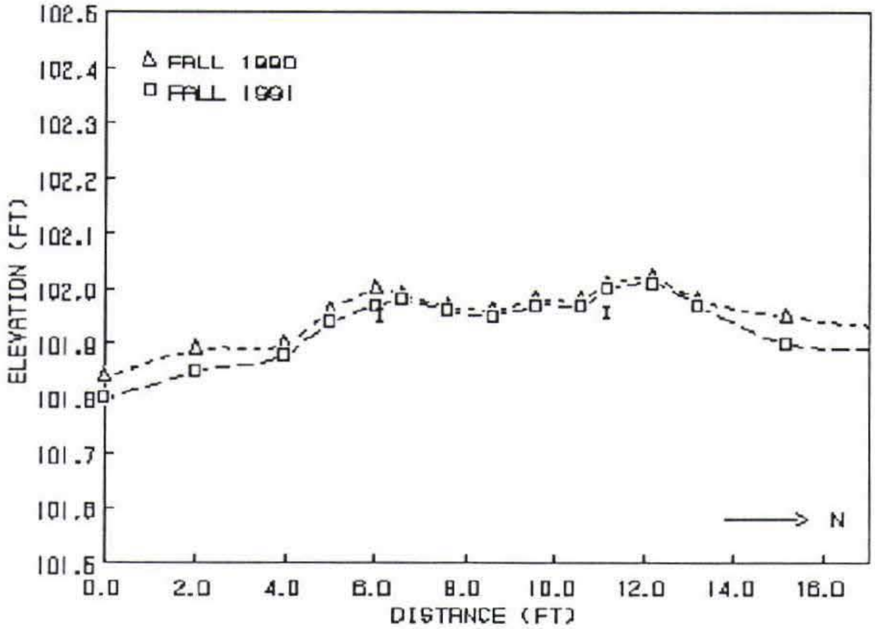


Figure VI-5. Steele Avenue, Profile at wheel path in the Fall of 1990 and Fall of 1991

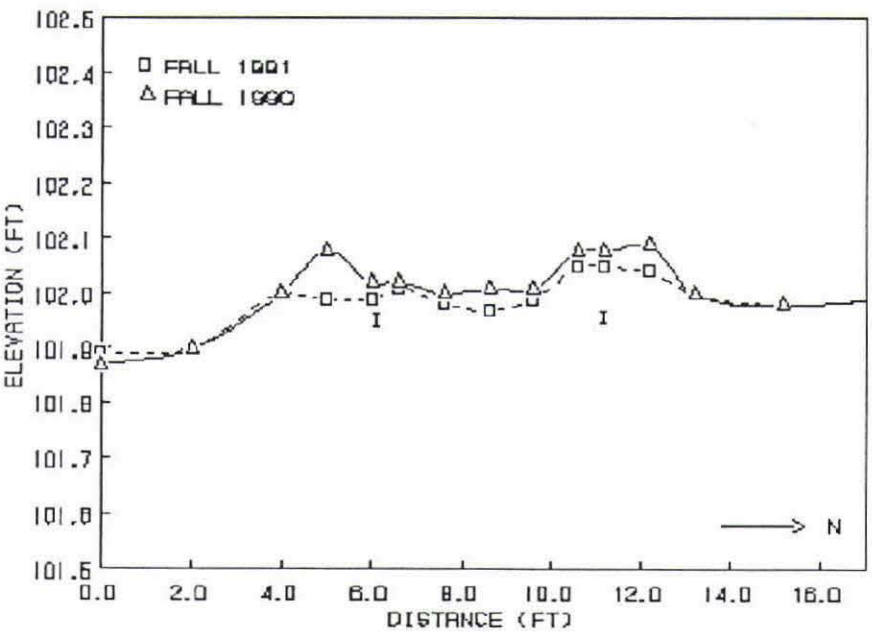


Figure VI-6. Steele Avenue, Profile between wheel paths in the Fall of 1990 and Fall of 1991 used at the Black Hawk crossing was disturbed during the period between the two surveys, absolute differences in elevation cannot be accurately assessed. The overall profile, however, indicates that the track, especially the south rail, has settled up to one inch in relation to the approaches. The approaches also show some changes, with settlement of up to one inch occurring.

CHAPTER VII

SUMMARY AND CONCLUSIONS

VII-1 GENERAL

The conclusions reached herein were mainly drawn from the analyses of measurements and observations at the original 25 crossings which were surveyed, and observations made at the additional 29 crossings during the condition survey. The analyses of the measurements are presented in Section VII-2, and include mostly data from the original 25 crossings. The results of the observations and condition surveys are presented in Section VII-3, and include information obtained at all 54 crossings. The results of the observation of construction procedures (Chapter V) are presented in Section VII-4. Observations regarding maintenance are presented in Section VII-5, and include information obtained at all 54 crossings.

The techniques used were basic observational methods like surveying, direct measurements, and visual inspections, and not sophisticated techniques based on static and dynamic analyses. The results indicate that most of the distress occurring at railroad grade crossings results from progressive deterioration of the crossings. Based on the results of this study, there is little doubt that the initial roughness is caused by the settlement of the track due to rail traffic as well as winter frost heave of the approaches to the crossing, if the subgrade soil is frost susceptible. Evidence of crossing roughness as a result of rail traffic was seen at several crossings described in Appendix A (Merrilat, Seventh Street, South Dakota Cement Plant) with low rail traffic volume side spurs. At all locations, the highway traffic was the same at both the main track and the side spur. The inspection showed that the side spurs had settled negligibly, while the main track was seen to have settled considerably. Frost heave of the approaches will not damage the pavement while the subgrade remains frozen, but loss of bearing capacity during thawing may lead to cracking of the approaches and breakdown of the pavement itself. With regards to the surface material used in the crossing, damage from frost heave at the approaches will occur as a result of increased impact loads. As discussed in Section VII-2, the bulk of the settlement of the track occurs within the first two years. Once the initial roughness is initiated, impact loading from highway traffic is accelerated contributing to the breakdown of the surfacing materials used at the approaches to the crossings and within the crossing. The modes of distress and failure observed vary from crossing to crossing as well as with crossing type. Based on this study, numerous modes emerged as common to the different types of crossing and are discussed below.

Several factors contribute to and accentuate crossing roughness. Such factors include loading conditions and traffic volume, subsurface conditions, material properties, design and construction practices. Basic factors such as loading conditions and traffic are fixed and cannot be changed. However, based on the findings in this study, subsurface conditions can be altered by overexcavation and replacement. Material properties can be improved by using better materials and, based on the observations made in this study, design and construction procedures need considerable attention.

The analysis of the results from the study relative to the variables considered are discussed in the following paragraphs.

VII-2 ANALYSIS OF MEASUREMENTS

VII-2.1 Vibration Measurements

The vibration measurements were performed in accordance with the procedures outlined in Section IV-2.1. Vibration measurements for highway traffic were taken at all 25 crossings that were part of the initial survey. However, following completion and analysis of the vibrations under rail traffic at the crossings in Rapid City, it was decided that the study yielded little useful information. Vibration measurements at other crossing locations were therefore not performed.

The vibration measurements were compared against roughness numbers and soil conditions. The results show that the displacement amplitudes resulting from both the rail traffic and the highway traffic were on the order of .001 inches or less. Such vibration amplitudes are insignificant and, according to most criteria, will not result in any damage. It is therefore felt that the direct impact load from the highway traffic will only cause damage at the location of the impact and not progress from that location. Likewise, vibrations from the train traffic will likely not affect soils outside the track.

VII-2.2 Crossing Settlement

General - The overall relative settlement between the crossing and the highway approaches at each of the original 25 crossings surveyed was calculated and analyzed based on categories including type of crossing, age, soil conditions and drainage. The results are presented in Table VII-1. It should be noted that three crossings were in such condition that no reasonable estimate of settlement could be made.

Crossing Type - The analysis shows that there is no pattern that would indicate that one kind of crossing will settle more than another. This is to be expected, however, since the overall settlement of the crossing is determined based on the loads transferred from the ties to the ballast and subgrade. This load is not dependent on the type of surfacing used but rather on the magnitude and frequency of the loads applied. It should be noted, however, that the sample is small and that any statistical analysis based on type of crossing would be unreliable.

Soil Type - Based on the analysis, it was discovered that the settlement of crossings founded in clay had undergone between two and three times the settlement in comparison to crossings founded in sands and low-plasticity silts. This pattern was noted for rubber crossings, as well as asphalt and timber crossings.

TABLE VII-1

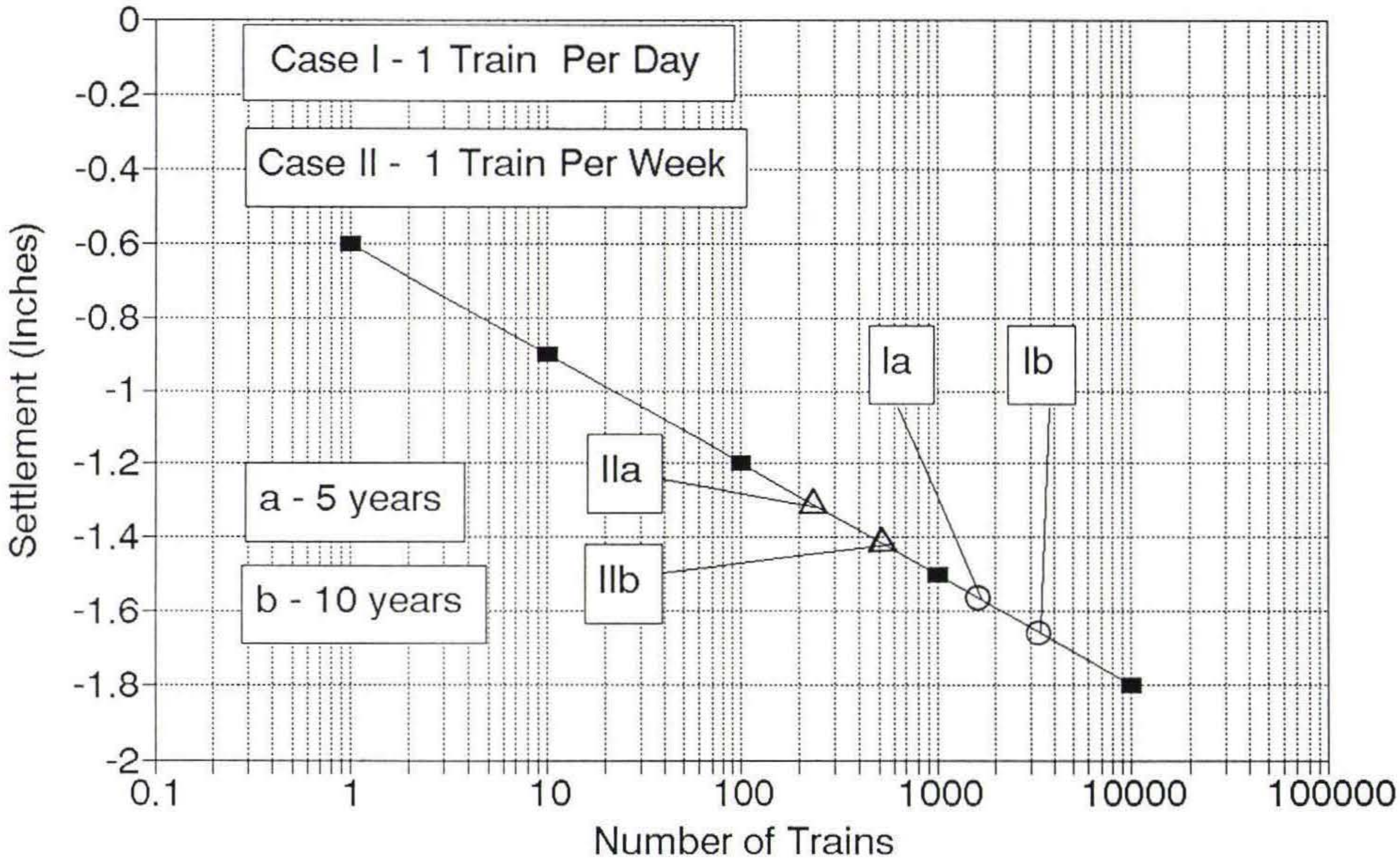
SUMMARY OF CROSSING SETTLEMENT

CROSSING	AGE (YEARS)	DRAINAGE	SOIL	SETTLEMENT (INCHES)
RUBBER:				
LACROSSE STREET	2	GOOD	SM	0.80
MAPLE AVENUE	4	GOOD	SM	0.50
EAST BOULEVARD	9	POOR	CL	0.90
WEST BOULEVARD	8	POOR	CL	2.00
HARRISON AVENUE	5	POOR	CH	1.50
MAIN STREET	7	POOR	CL	1.00
KLINE STREET	5	POOR	CL	1.50
NORTH BROADWAY	11	FAIR	ML	0.75
NORTH MAPLE	12	FAIR	CL	2.00
ELEVENTH STREET NORTH	5	FAIR	CL	1.50
SD38A N. OF SIOUX FALLS	16	GOOD	CH	1.00
MINNESOTA AVENUE	8	POOR	CH	0.00
ASPHALT:				
THIRD STREET	12	POOR	CL	2.00
FIFTH STREET	20	POOR	CH	1.00
KEMP AVENUE	12	GOOD	SL	0.50
SD 20 AND 10TH STREET	4	GOOD	SW	0.60
COTTONWOOD	UNKNOWN	GOOD	ML	0.75
TIMBER:				
BLACK HAWK	4	GOOD	ML	0.50-0.75
SECOND STREET	20+	POOR	CH	2.00+
BROWN COUNTY	10+	POOR	ML-OL	0.50
SOUTH OF US 212	20+	GOOD	SW	0.00
COUNTY 131	2	GOOD	CH	0.75

The average settlement for rubber crossings founded in sand was approximately 0.7 inches as compared to those founded in clay where the settlement was nearly 1.5 inches. Excluding the crossing at Minnesota Avenue in Sioux Falls, where the geometry of the crossing was such that no overall settlement could be detected, the average settlement for rubber crossings on clay was even higher. For asphalt crossings, average settlement for crossings on clay was again 1.5 inches, as compared to 0.6 inches on sand. Likewise, for timber crossings, the average settlement for those on clay was 1.4 inches as compared to 0.4 inches for those in sand. Overall, for all types of crossings, the average settlements were nearly 1.5 and 0.6 inches, respectively, for crossings founded in clay and sand.

Crossing Age - Age could not be correlated to settlement, unless crossings were bracketed into those less than five years old or five years and older. Overall, an average settlement of approximately 0.7 inches was obtained for those less than five years old and 1.1 inches for those over five years old. The average age of the newer crossings was calculated to be 3.2 years and 12 years for the older crossings. This analysis is in accordance with the theories developed for long term settlement of structures subjected to cyclic loading. As an example, the graph presented in Figure VII-1 shows the postulated settlement for a hypothetical crossing. Two cases are presented. Case I represents a crossing with one train per day while Case II represents a crossing with one train per week. Settlements are

Figure VII-1. Relationship Between Number of Trains and Settlement



shown after 5 years of traffic (Case Ia and IIa) and after 10 years of traffic (Case Ib and IIb). As can be seen, more than 90 percent of the settlement that is expected to take place during the first 10 years after construction will have taken place during the first five years for a crossing with one train per week. In excess of 95 percent of the total settlement expected will have taken place after five years if the crossing is subject to one train per day. The graph also shows that over one third of the total settlement to be expected also occurs following the first train, and that nearly half the settlement will have taken place following the first 10 trains. Thus, if paving could be delayed until 10 trains had passed, the lifetime differential settlement between the crossing and the approaches could be reduced by over one half. Vibratory compaction of the ballast with a heavy vibratory roller may have a similar effect, however, this remains to demonstrated in the field. Likewise, if the crossings were relevelled after one year of service, crossing lifetime may be significantly extended. The process of relevelling causes some disturbance of the ballast, however, settlement of the track following the first train after relevelling results in significantly smaller settlement as compared to the passing of the first train after construction (See Figure V-6, page 60). It is realized that relevelling may be impractical and expensive for asphalt crossings, but timber and rubber panel type crossings may be relevelled within short periods of time.

VII-2.3 Approach Settlement

Settlements under the rails at the approaches to the crossings were measured during rail traffic at several locations during both the surveying and condition surveying phases of the field investigation. However, some crossings were missed as no trains ran on the days the surveys or inspections were performed. The results can be seen in Table VII-2, which shows that there is virtually no relationship between soil conditions and rail approach settlement. This may in part be due to the fact that newer crossings have fabric extending past the ends of the shoulders and infiltration of fines into the ballast by pumping is prevented. However, based on the results presented in Table 2 and observations at other crossings inspected, the settlements at the approaches are considerably higher at crossings where there are bolted joints at the ends of the crossings.

VII-2.4 Drainage

Drainage conditions at the crossings were analyzed and an attempt was made to correlate drainage with crossing settlement, crossing age, and deflections at the ends of the crossings. No relationship could be established with any of these variables. It is felt, however, since most of the crossings surveyed are on the order of 10 years or less in age, fabric was in all likelihood installed under a considerable number of the crossings. Based on the performance of the fabric, which was taken out at Second Street in Rapid City (Chapter V), drainage is felt to be of less importance with respect to pumping than in the

TABLE VII-2

DEFLECTION MEASUREMENTS

NO.	HIGHWAY/STREET/LOCATION	CITY	TYPE	DEFLECTION(IN)	SOIL TYPE
1.	LACROSSE STREET	RAPID CITY	RUBBER	0.75	SM
2.	STEELE AVENUE	RAPID CITY	ASPHALT	0.25	CL
3.	MAPLE AVENUE	RAPID CITY	RUBBER	0.50	SM
4.	US 16 EAST BOULEVARD	RAPID CITY	RUBBER	0.625	CL
5.	THIRD STREET	RAPID CITY	ASPHALT	0.75	CL
6.	WEST BOULEVARD	RAPID CITY	RUBBER	0.50	CL
7.	BLACK HAWK	RAPID CITY	TIMBER	0.75	ML
8.	CENTRAL AVENUE	PIERRE	RUBBER	0.75	CH
9.	MAIN STREET	ABERDEEN	RUBBER	0.19	CL
10.	KLINE STREET	ABERDEEN	RUBBER	0.31	CL
11.	NORTH BROADWAY	WATERTOWN	RUBBER	0.00	ML
12.	NORTH MAPLE	WATERTOWN	RUBBER	0.13	CL
13.	ELEVENTH STREET NORTH	WATERTOWN	RUBBER	0.38	CL
14.	KEMP AVENUE	WATERTOWN	ASPHALT	0.25	SC
15.	SD 20 AND 10TH STREET WEST	WATERTOWN	ASPHALT	0.75	SW

past. Permanent settlement and pumping under rail traffic cannot take place unless the subsurface soils can migrate into the ballast and up toward the surface. With fabric installed, such movement is prevented, providing that the mesh openings in the fabric do not let soils through.

VII-2.5 Crossing Roughness

The cross-section information obtained from the surveying of the original 25 crossings was analyzed and rough spots were located. The rough spots were then measured in terms of their height (or depth) in inches and length in feet along the direction of the traffic. Roughness numbers were then calculated by dividing the height (depth) by the length. The results are presented in Table VII-3. Based on the observations and rideability of the crossings, an exemplary crossing should have a roughness index of less than 0.5. The classification of crossings in accordance with the roughness numbers is proposed as follows:

Condition	Roughness Number
Excellent	0 - 0.5
Good	.5 - 1.0
Fair	1.0 - 1.5
Poor	1.5 - 2.0
Repair or Replace	> 2.0

Only LaCrosse Street in Rapid City satisfied the criterion for an excellent crossing. The worst crossings included Fifth Street in Aberdeen (which was replaced in the fall of 1991), the asphalt crossing on North Maple in Watertown, and SD 20 (10th Street) in

TABLE VII-3

COMPUTATION OF ROUGHNESS NUMBER

NO.	HIGHWAY/STREET/LOCATION	CITY	TYPE	ROUGHNESS NUMBER(IN/FT)
1.	LACROSSE STREET	RAPID CITY	RUBBER	0.30
2.	STEELE AVENUE	RAPID CITY	ASPHALT	0.92
3.	MAPLE AVENUE	RAPID CITY	RUBBER	0.60
4.	US 16 EAST BOULEVARD	RAPID CITY	RUBBER	0.78
5.	THIRD STREET	RAPID CITY	ASPHALT	1.18
6.	WEST BOULEVARD	RAPID CITY	RUBBER	0.79
7.	BLACK HAWK	RAPID CITY	TIMBER	1.00
8.	HARRISON AVENUE	PIERRE	RUBBER	0.72
9.	INDIAN LEARNING CENTER	PIERRE	ASPHALT	0.99
10.	CENTRAL AVENUE	PIERRE	RUBBER	0.72
11.	SECOND AVENUE	PIERRE	TIMBER	1.68
12.	MAIN STREET	ABERDEEN	RUBBER	1.05
13.	KLINE STREET	ABERDEEN	RUBBER	1.44
14.	BROWN COUNTY STREET	ABERDEEN	TIMBER	1.06
15.	FIFTH STREET	ABERDEEN	ASPHALT	2.37
16.	NORTH BROADWAY	WATERTOWN	RUBBER	0.92
17.	NORTH MAPLE	WATERTOWN	RUBBER	0.78
			ASPHALT	2.35
18.	ELEVENTH STREET NORTH	WATERTOWN	RUBBER	0.92
19.	KEMP AVENUE	WATERTOWN	ASPHALT	1.18
20.	1/2 MILE EAST OF WATERTOWN	WATERTOWN	TIMBER	1.16
21.	SD 20 AND 10TH STREET	WATERTOWN	ASPHALT	1.97
22.	MINNESOTA AVENUE	SIOUX FALLS	RUBBER	1.05
23.	SD 38A NORTH OF AIRPORT	SIOUX FALLS	RUBBER	0.78
24.	COUNTY 131 N OF SIOUX FALLS	SIOUX FALLS	TIMBER	1.60
25.	COTTONWOOD	COTTONWOOD	ASPHALT	0.80

Watertown. Based on visual observations, these crossings were also determined to be very rough, whereas LaCrosse Street was the smoothest of the crossings surveyed.

VII-3 ANALYSIS OF OBSERVATIONS

VII-3.1 Modes of Distress

The results of the visual observations at the crossings were broken down based on the three basic categories of crossings investigated (rubber, asphalt, and timber). Attempts to break down modes of distress based on type and volume of rail, highway traffic, speed, and rural versus urban location, rail traffic did not seem to produce any trends, with the exception of asphalt crossings. The modes of distress seemed to be almost exclusively related to the type of crossing. At rural asphalt crossings, however, the rutting caused by the wheel impact loads extended over a greater distance from the crossing than at urban locations, and lateral impact loads from the tires seemed to have a tendency to tilt the mud rails toward the main rail (See Appendix A, Cottonwood on US Highway 14). Each mode of distress is listed and discussed.

VII-3.2 Rubber Crossings

The severity of the roughness varied with crossing type, type of headers, and pavement. The most common factors contributing to roughness of rubber crossings include:

1. Overall settlement of track relative to the approaches;

2. Failure of headers;

3. Debris forced under panels from mudfilled space between rails and panels;

4. Shoulder settlement;

5. Pumping of the track bed;

6. Loosening of panels;

7. Warping and buckling of panels;

8. Shifting of panels;

9. Debris between panels and headers;

10. Debris between panels;

11. Loss of fastener protective caps;

12. Loosening of fasteners;

12. Snow plow damage;

13. Panel wear;

14. Failure and loosening of panel shims (Partial depth panels only);

15. Rutting and cracking of the approach pavement;

16 Frost action at the approaches.

Examples of the above factors are shown in Photos VII-1 through VII-11. The first five factors are felt to be directly related to the rail traffic, while the remainder are felt to be highway traffic related. It may be argued, however, that items 6 through 12 would not be serious problems if differential settlements between the approaches could be minimized. Failure of the crossing, however, may be attributed to a combination of several

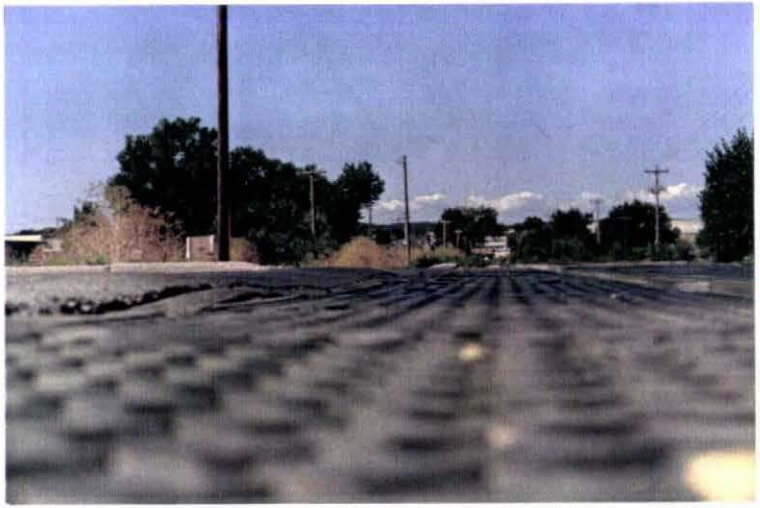


Photo VII-1. Overall Settlement of Track Relative to Approaches.

Photo VII-2 and 3. Failure of Asphalt and Wood Headers.

Photo VII-4. Debris Forced Under Panels.

Photo VII-5. Shoulder Settlement.

Photo VII-6. Pumping of Track Bed.

Photo VII-7. Loosening of Panels, Fastener Failure and Loss of Protective Caps.

Photo VII-8. Warping of Panels.

Photo VII-9. Shifting of Panels.

Photo VII-10. Panel Wear and Snowplow Damage.

Photo VII-11. Rutting and Cracking of Approach Pavement and Frost Action.

Photo VII-15. Pumping and Breakdown of Asphalt along Rail.

Photo VII-12 and 13. Differential Settlement Between Track and Approaches.

Photo VII-14. Differential Settlement between Main Rail and Mud Rail.

factors. Other mechanisms appear to contribute only to minor roughness. It is felt that the most important factors contributing to excessive roughness include track differential settlement between the track and the approaches (Photo VII-1), loosening of panels (Photo VII-7), pumping (Photo VII-6), and failure of headers (Photos VII-2 and VII-3). Snow plow damage and panel wear (Photo VII-10) were not seen as factors contributing to surface roughness to the degree that the crossing would be considered failed. Evidence of direct bearing failure of the crossing by overloaded ties was not observed within the crossings, but could be seen at the approaches to the crossing where pumping had occurred. Pavement rutting at the approaches to the crossing may in fact help to reduce roughness unless the rutting extends below the top of the panels. Such rutting was observed at several locations.

Problems with the panels themselves seemed to be less prevalent for full depth panels, especially when used with concrete pavement, and also in cases where the concrete was poured directly up against the outer panels. Snow plow damage seemed to vary with the type of panels used, as panels with a skewed type of tread pattern appeared especially vulnerable to damage.

VII-3.3 Asphalt Crossings

Several of the asphalt crossings surveyed and inspected were in excess of 10 years old and had been repaved and patched several times, covering some of the long term deterioration. Four of the

Photo VII-16. Rutting of Asphalt.

Photo VII-17. Frost Action.

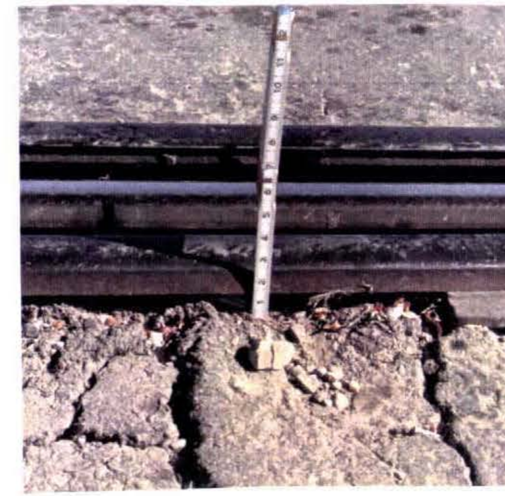


Photo VII-18. Asphalt Weathering and Settlement.

Photo VII-19. Relative Settlement between Crossing and Approach.

Photo VII-20. Wear by Traffic and Protruding Fasteners.

crossings observed during reconstruction were asphalt crossings, which allowed an excellent opportunity to observe the nature and origin of the distress noted during the surveying and condition surveys. As with rubber crossings, the factors leading to distress of asphalt crossings may also be divided into two groups; those resulting from the rail traffic and those related to highway traffic and pavement durability. These factors are outlined below, and typical examples are shown in Photos VII-12 through VII-18. Items 1 through 4 may be related directly to rail traffic, while items 5 through 8 may be attributed to highway traffic and design:

1. Overall differential settlement between the track and the approaches;
2. Differential displacement (vertical) between the mud rails and the main rail;
3. Breakdown of asphalt along the rails (mostly when no mud rails are used);
4. Pumping under the track at the ends of the crossing;
5. Asphalt rutting;
6. Frost action at the pavement approaches;
7. Weathering of asphalt;
8. Settlement of asphalt relative to the rails.

The overall settlement of the track appears to be a major contributing factor leading to the failure of the approaches (See Photos VII-12 and VII-13). There was also evidence, however, that frost action also may play a major role in this regard (See Photo VII-17 at Northville and Chapter VI). Settlement of the asphalt relative to the tracks along the crossing, such as was especially noticeable at several locations in Rapid City (See Photo VII-18), appears to be caused by paving directly on the ballast. Due to the coarse nature of the ballast, the traffic will force the asphalt into the voids of the ballast, and thereby settle. In this regards, it should be mentioned that in the experience by the author, some pavement contractors will refuse to pave over coarse aggregate due to problems that have arisen using such practice in the past.

The cause of the relative displacement between the mud rails and the main rail (Photo VII-14) was clearly seen during the removal of the old track from some of the crossings that were rebuilt. Mud had been forced down between the rails and built up under the mud rails (See Photo V-33, page 56).

VII-3.4 Timber Crossings

As with rubber and asphalt crossings, the sources of roughness and failure may be attributed to both railway and highway traffic. Due to the inherently rough nature of crossings built from individual timbers, damage from highway traffic is felt to be of greater importance. Based on the observations made during the course of this study, the most important factors leading to crossing roughness and failure are as follows:

1. Relative settlement between the track and the approaches;
2. Wear by traffic, especially when studded tires are used;
3. Protruding bolts and fasteners;
4. Damage by snow plows;
5. Pumping and deflection of the track during rail traffic;
6. Timber damage by rail traffic;
7. Uneven and warped;
8. Rutting of approaches;
9. Frost action at approaches;
10. Loosening of timbers timbers.

Examples of the above factors are shown in Photos VII-19 through VII-25). Based on the observation of older timber crossings, roughness caused by wear is just as important as overall differential settlement between the crossing and the approaches (See Photos VII-19 and VII-20). Also, when severely worn, fasteners may protrude as much as an inch above the timbers. With timber panels few problems were noted, however, due to the fact that the crossings inspected were usually less than two years old, problems that could possibly develop may yet need be to be identified. In all likelihood, problems arising may be similar to those experienced with rubber crossings.

VII-4 CONSTRUCTION PROCEDURES

Construction practices were mainly studied from a geotechnical point of view, although all aspects of the construction process

Photo VII-21 and 22. Snow Plow Damage.

Photo VII-23. Pumping and Track Deflection.

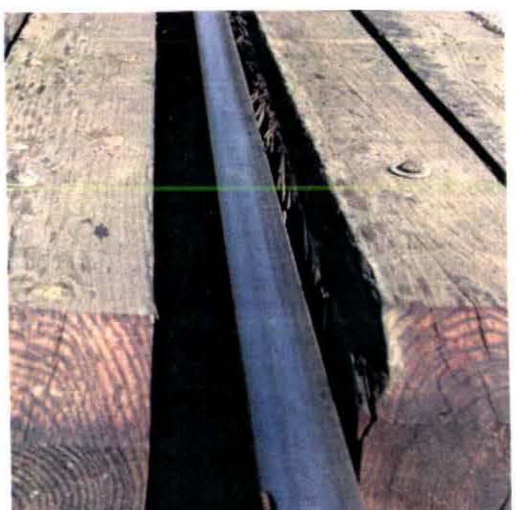


Photo VII-24. Timber Damage from Rail Traffic.

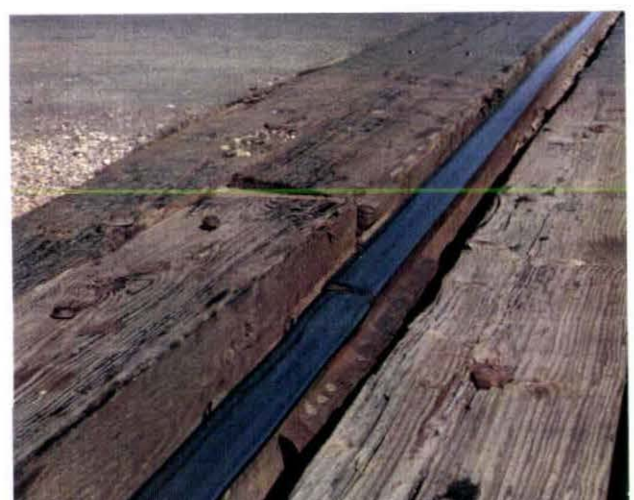


Photo VII-25. Warped Timbers.

were observed. It should be noted that all projects visited involved reconstruction and no new crossings were included. However, it likely that the vast majority of crossings to be installed will involve reconstruction at currently existing tracks. Based on the limited number of observations made, it was felt that the procedures used in South Dakota may be insufficient from a geotechnical point of view, especially in preparation of the subgrade and track bed, and in earthwork at the approaches. The procedures used in track preparation and surfacing installation were considered satisfactory, however. The planning and design, especially in terms of deciding the extent of overexcavation necessary, need for drainage systems, and crossing compatibility with the conditions at the approaches, were also considered insufficient. Specifically, the following factors were noted at the construction site which were visited:

1. The exposed subgrade was not proofrolled or compacted;

2. Loose material was not removed from the excavation prior to placing fabric;

3. Loose material was dumped into the excavation to fill wheel ruts in preparation for the fabric placement;

4. Fabric in some crossings was only installed under the portion of the crossing to be surfaced;

5. Overexcavation in some cases was excessive and unnecessary;

6. Drainage pipe was installed at sites with free-draining subsurface soils;

7. No attempts were made to compact the ballast in areas of deep excavations;
8. Compaction of backfill against the headers was not performed;
9. No quality control was performed by either representatives from the railroads or from the highway departments;
10. At all but one location, no provisions were provided for drainage outlet from the ballast under the crossings;
11. No records of the subsurface conditions encountered were kept;
12 No soil exploration had been performed at the crossings prior to reconstruction.

VII-5 MAINTENANCE

Based on the observations made during this study, maintenance at the crossings, which should be considered essential to prolonging crossing life, seemed to be minimal. Especially noteworthy was the failure to clean mud out next to the rails. Based on the results of the visual inspection performed during the condition survey and construction phase of this project, failure of both panels and mud rails can be attributed to the lack of cleaning. Maintenance and sealing of headers is also considered important, in order to minimize moisture infiltration into the base and subgrade material of the approaches. There was no sign at any of the crossing locations of attempts to repair or replace damaged or disintegrated headers. It also did not appear that any efforts were made to check fasteners, refasten loose panels, or replace severely damaged panels.

CHAPTER VIII

RECOMMENDATIONS

VIII-1 GENERAL

The recommendations and proposed specifications given herein relate to the items for construction and maintenance which were found insufficient. Specifically, items related to earthwork at or near the crossings is included, together with suggestions for maintenance of parts and components that may extend the service life. However, due to insufficient data, recommendations for ballast gradation is not warranted, and is not included. Discussion on items that are felt deficient or need attention is presented below. Proposed paragraphs for specifications are presented in bold characters.

VIII-2 INVESTIGATIONS

It was noticed during the field investigations that excessive overexcavation may have been performed. At old crossings, it is likely the subgrade soils, unless severely disturbed by pumping, have been fully consolidated from years of rail traffic. Removal and replacement of such material is unnecessary and may even be detrimental. Information on the depth of old ballast and the underlying subgrade is therefore necessary to evaluate the extent of excavation necessary, and to ensure that old competent material is not removed. Information on the groundwater level and soil permeability is also essential to assess that a drainage system is necessary. Based on the above information, specifications are proposed as follows:

A baseline geotechnical investigation should be performed at both the locations of the old and the new crossings, such that information about the soil, subsurface drainage, and groundwater conditions can be identified. In addition to information necessary to classify the soils, frost susceptibility and strength under saturated conditions need to be determined. The investigation should consist of at least one boring extending to a depth of 10 feet. The boring should be performed within the confines of the crossings, such that the depth of ballast, the extent of weak soils, and the depth to the ground water level, if encountered, can be determined.

A baseline investigation is estimated to require a drilling rig and a crew for up to a period of one day. Based on current rates for subsurface investigations, the cost of one rig day is on the order of $500 to $700.

VIII-3 CONSTRUCTION

VIII-3.1 Ballast Thickness

The American Railway Engineering Association (AREA Manual, Chapter 9, Highway-Railway Crossings) states that a minimum of 10 inches of ballast should be placed below the bottoms of the ties. At this depth, and for tie spacing up to 24 inches, it can be shown that the stress distribution at the bottom of the ballast is nearly uniform. Greater ballast thickness is therefore not necessary, unless it can be shown that the subgrade is of such a nature that settlements can be reduced by further replacement of subgrade material with ballast. Decisions on overexcavation and placement of greater thickness of ballast should therefore be made based on the results of the baseline exploration and inspection of the exposed subgrade. Specifications for ballast thickness are proposed as follows:

A minimum of 10 inches of ballast should be placed beneath the bottom of the ties. Greater thickness may be used if deemed necessary to replace old contaminated ballast and weak subgrade material, provided that such replacement will lead to reduced crossing settlement.

Based on the observations made during this study, ballast thickness from 6 to over 30 inches was used below the ties. It is felt that the ballast thickness at some locations could have been reduced, since some of the material removed was well compacted from years of rail and highway traffic. It is therefore likely that careful planning and inspection may result in reduced ballast thickness, and therefore cost savings.

VIII-3.2 Removal of Unsuitable Material

At old crossings it is likely that most of the settlements due to compression of the subgrade soils may have taken place. Based on information obtained from the field study, the subgrade, if pumping has not occurred, is firm and in all likelihood, not subject to much additional settlement. If disturbed, however, the soil compressibility is increased. Based on the above information, specifications are proposed as follows:

Excessive disturbance of the subgrade during removal of old ballast should be avoided. At new crossings, if poor soil conditions are encountered, the amount of overexcavation of the subgrade should be determined based on the information obtained from the soil investigation. If possible, the ballast should be removed with as little disturbance to the subgrade as possible. Track mounted equipment is preferred for removal of old ballast as it causes less rutting than rubber tire mounted equipment. Disturbed areas should be proofrolled and inspected for soft spots during the proofrolling.

The depth of the ballast should be tapered from the ends of the excavation to where it joins with the bottom of the ballast under the track section outside the crossing. The taper angle should not be steeper than 1 vertical to 15 horizontal. The tapered sections should begin 15 feet beyond the crossing. The highway approach should also be overexcavated to the same depth as the ballast in the crossing. Tapering should then be done on the road base at the same angle. Proposed sections beyond the ends of the crossing and under the approaches are shown in Figures VIII-1 and VIII-2. The base material should consist of frost-free material and a fabric should be used under the base if the subgrade is soft. Fabric should also be carried up along the sides of the ballast adjoining the road base material to prevent loss of base material into the ballast.

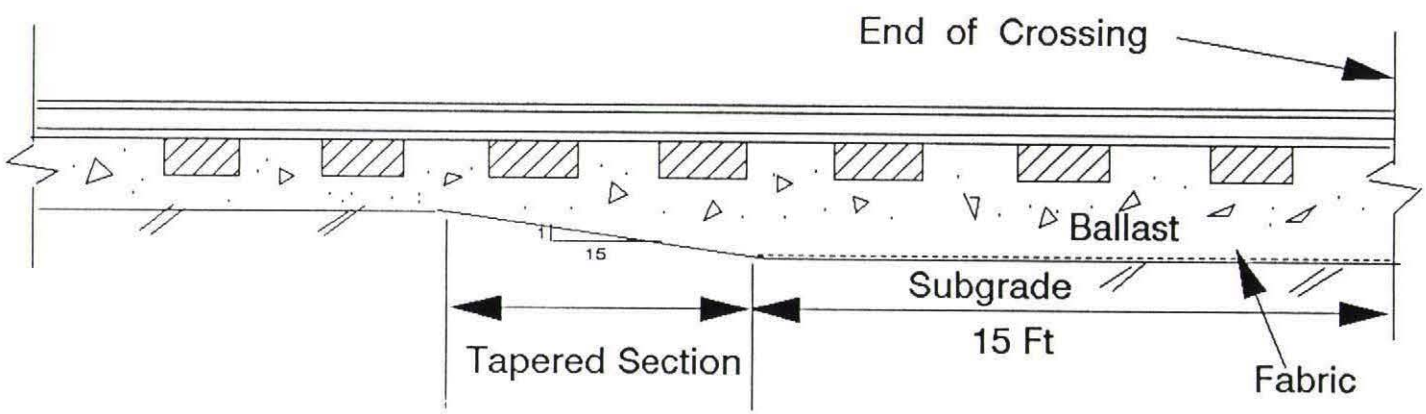


Figure VIII-1 Proposed Excavation Profile Along the track

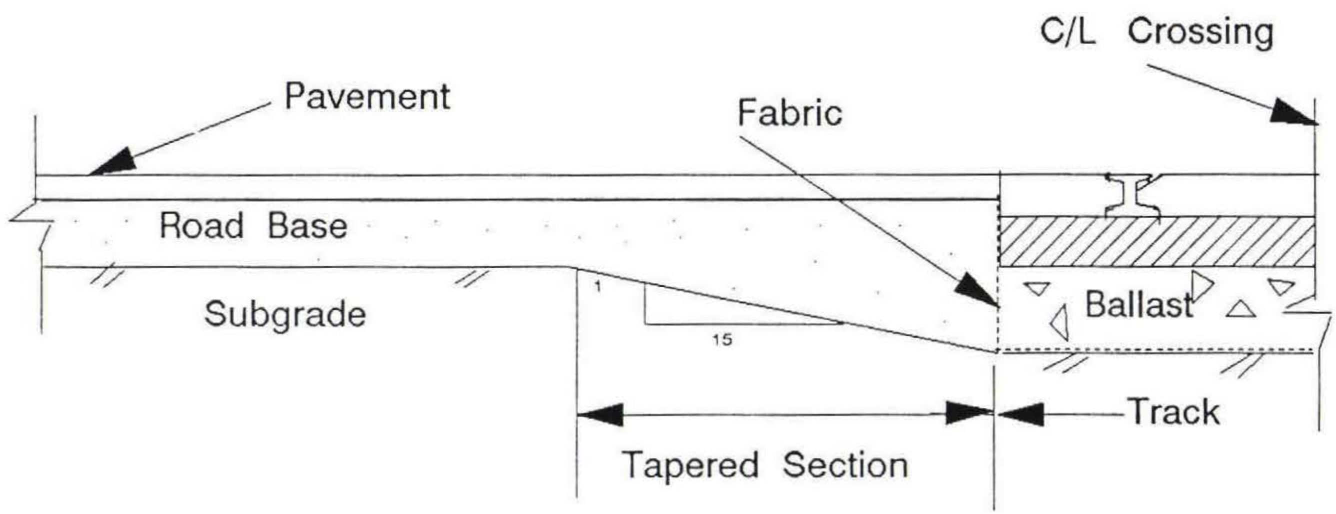


Figure VIII-2 Proposed Excavation Profile At Perpendicular to the track

The tapering of sections beyond the crossings and under the highway approaches will result in higher installation cost. Especially, the approach work may be significant unless the crossing is installed in conjunction with repaving or other highway work. It is felt that such practices will lead to less differential settlement between the crossing and the approaches, thus minimizing damage from frost heave. The implementation of tapered section may therefore lessen crossing roughness, reduce maintenance cost and lead to longer crossing service life.

VIII-3.3 Drainage

Caution should be taken against indiscriminate use of drainage systems that may lead to settlements. If the drain pipe is installed below the water table, the drain system will lower the table, leading to increased settlements. The information obtained from the exploratory boring should therefore be studied carefully. The drain pipe should have an outlet, otherwise a bathtub effect is created. The excavation under the crossing will then serve a sump, drawing water not only from the ballast under the adjoining track, but also from the road and the area surrounding the crossing. If the terrain is such that there is no possibility of an outlet, there is no purpose in installing a drain pipe. Furthermore, if the information from the exploratory boring indicates that the crossing is founded in free-draining material, no drain system is necessary. Based on the above information, specifications are proposed as follows:

If a drain system is used, the drain pipe should be wrapped in fabric and placed in the subgrade below the ballast. An outlet for the drain system must be provided and the drain pipe should be placed such that it will drain toward the outlet. In flat areas where there is no outlet, sumps should be installed.

VIII-3.4 Ballast Placement

Based on the results of this study, severe degradation of the limestone ballast was seen at two locations. However, the number of crossing installations observed were not sufficient to draw any conclusions on the use of limestone ballast, and further studies are felt necessary in order to compare the performance of different ballast material before recommendations regarding the use of limestone ballast.

It is strongly felt that in order to minimize track settlement, the ballast should be compacted using a heavy vibratory roller. If the ballast is thick, it may also be placed in layers and each layer must be compacted. Information shows that the passage of trains on the crossing will greatly reduce long term settlements. It is therefore desirable to have as much train traffic on the crossing before paving, such that future settlements can be minimized. Based on the information above, specifications are proposed as follows:

The ballast should be placed in lifts not exceeding one foot and compacted using a heavy vibratory roller. Once the ballast has reached the proposed level of the bottom of the ties, the ties or

prefabricated track should be laid and the ballast then placed between the ties and tamped. It is necessary to run as many trains on the crossing as possible before paving.

Based on conversations with representatives for the railroads and railroad construction contractors, proofrolling and compaction will require the purchase or rental of compaction equipment. For some contractors, the purchase of compaction equipment will require a major investment. Rental and mobilization of such equipment will result in cost increases in the range of $500 to $1000 per day. Nevertheless, the potential benefits in terms of reduced crossing settlement are considerable, and it is therefore strongly recommended that the procedure be implemented.

VIII-3.5 Headers

Based on the observations during this study, the failure of wood headers does not necessarily contribute significantly to crossing roughness. The wood headers are the weakest component of the crossing and will disintegrate. Asphalt headers and asphalt used as pavement filler (between crossings and concrete pavement) become significant sources of roughness when they disintegrate. It is therefore recommended that headers be avoided if possible. Based on the above information, specifications are proposed as follows:

Headers should not be used if at all possible. For full depth panels, the construction should involve coordination between

highway and railroad representatives such that scheduling of construction or reconstruction of the crossing is done prior to paving. Where this is not possible, gaps between concrete approaches and the crossings should be filled with an early high strength or steel fiber reinforced type concrete to assure strength.

The cost associated with using early high strength concrete is minimal. The cost of steel fiber reinforced concrete is about one and one half to two times the cost of regular concrete. However, relatively small quantities would be required, hence additional cost is not likely to exceed $100 to $200.

VIII-4 TYPE OF CROSSINGS

Based on the observations made during this study, it is recommended that asphalt crossings be avoided at locations of high traffic volume and loads. At such locations, it is recommended that full depth rubber panel type crossings be used. Partial depth rubber panel type crossings may also be used, but due to problems associated with loosening of the panels and panel damage, higher maintenance cost and lower service life should be anticipated with this type of crossing. Full depth rubber crossings should also be used at crossings with heavy truck traffic. Timber crossings may be used at low volume rural locations, but it is recommended that timber panel type crossings be used on highways with higher speed limits. Where asphalt crossings are installed, it is recommended that impact and rutting resistant asphalt be used within the crossing and at the approaches to the crossing.

At sites with poor subsurface conditions and at locations where significant settlement problems are anticipated, it recommended that asphalt crossings be avoided. At such locations, crossings with easily removable panels should be used, such that the effort associated with removal of panels and releveling of the track can be kept to a minimum.

VIII-5 INSPECTION

During the course of this investigation, an inspector was only present at one of the five sites where construction was observed. In addition, the inspector expressed concerns with respect to what to inspect, and general lack of knowledge of railroad grade crossing construction. It is therefore recommended that personnel be specially trained in the field of railroad crossing construction, and that an inspector be present at the site during the earthwork and ballast placement of the project. In particular, the excavation, subgrade preparation, filter fabric and drainage system installation, and fill and ballast placement should be observed and checked. It is not anticipated that the effort associated with inspection and quality control will exceed one day.

VIII-6 MAINTENANCE

During the field and the condition survey phases of the investigation, several items (Chapter VII) regarding maintenance that may contribute to the extension of the service life of crossings were noted. The items which were felt to be essential to crossing maintenance are those that are progressive in nature and, unless checked, may contribute towards the eventual failure of the crossing. The items, in order of importance, are discussed in the sections below:

1. **Cleaning next to rails;**
2. **Tightening of fasteners for panels and timbers;**
3. **Sealing at and next to headers;**
4. **Replacing damaged panels and timbers;**
5. **Replacing damaged headers;**
6. **Repairing and maintaining approach sections.**

Representatives of the railroad companies operating in South Dakota revealed that crossing maintenance was scheduled for twice a year, however, a shortage of personnel prevented this maintenance item from being performed. It is the recommendation of this report that the maintenance schedule be enforced. Items 2 through 6 above may be performed on an as-needed basis. However, it is recommended that these items also be accounted for during the semi-annual cleaning of the crossings.

VIII-7 SNOW PLOW DAMAGE

Snow plow damage is one of the major contributors to premature panel failure. It is recommended that the respective highway departments and representatives for the railroads meet and discuss to find solutions to this problem. It is the recommendation of this report that the snow plow operators raise their plows slightly when passing a crossing and that a non-corrosive deicer be tried within the crossing.

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