Beck

BRIDGE ENGINEERING
SYNTHESIS OF PLANNING, DESIGN, CONSTRUCTION, MAINTENANCE, MATERIALS AND RESEARCH

MDOT
Michigan Department of Transportation

Technical Report Documentation Page

1. Report No. RC-1369	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Bridge Engineering, Synthesis of Planning, Design, Construction, Maintenance, Materials and Research		5. Report Date December 1998
7. Author(s) Andrzej S. Nowak, Chris Eamon and Maria M. Szerszen		6. Performing Organization Code
9. Performing Organization Name and Address University of Michigan Civil & Environmental Engrg. 2340 G. G. Brown Bldg. Ann Arbor, MI 48109-2125		8. Performing Org Report No. UMCEE 98-30
12. Sponsoring Agency Name and Address Michigan Department of Transportation		10. Work Unit No. (TRAIS) 11. Contract/Grant No. 96-0195
15. Supplementary Notes		13. Type of Report & Period Covered Final Report, June 96 - December 98 14. Sponsoring Agency Code

16. Abstract

The report objective is to synthesize the information related to various phases of bridge engineering as practiced by the Michigan DOT. It covers the areas of planning, design, construction, maintenance, materials, and research. In particular, the synthesis is intended to serve as a reference document, and to provide support for the introduction of PONTIS and future development of a new generation of comprehensive Bridge Management Systems (BMS). The documented information is based on MDOT and AASHTO publications, interviews with MDOT staff, and research results. The statistical data is presented in graphs and tables, based on the Michigan Bridge Management Database.

17. Key Words bridges, design, maintenance, construction, materials, research		18. Distribution Statement No restriction. This document is available to the public through the Michigan Department of Transportation	
19. Security Classification (report)	20. Security Classification (Page)	21. No of Pages 250	22. Price None

Form DOT F 1700.7 (8-72)

DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the information presented herein. This document is disseminated under the sponsorship of the Michigan Department of Transportation in the interest of information exchange. The Michigan Department of Transportation assumes no liability for the contents or use thereof.

TABLE OF CONTENTS

1.	Introduction		3
	1.1	Purpose/Objectives	3
	1.2	Scope	3
	1.3	Users	3
2.	Legislative Administration		7
	2.1	Federal, State and Local	7
	2.2	Tax Collection and Distribution	12
	2.3	Permissible Loads in Michigan	14
	2.4	Transportation Subcommittee and Commission	19
3.	Bridge Program Administration		23
	3.1	General Information	23
	3.2	AASHTO, FHWA, State and Local Roles	65
4.	Planning and Programming		69
	4.1	Needs	69
	4.2	Public Input	69
	4.3	Project Development - Improve/Expand	69
	4.4	Surveys - Topological, Hydraulics, Traffic	71
	4.5	Geotechnical Investigation	71
	4.6	Environmental Impact Statement	73
	4.7	Concepts, Design Alternates, Cost Estimates, and Value Engineering	73
	4.8	Project Report	75
	4.9	Bridge Programs: Preserve	78
5.	Design		81
	5.1	Structures - Types	81
	5.2	Analysis	83
	5.3	Design Criteria	88
	5.4	Construction Requirements	96
	5.5	Computer Aided Design - Bridge Design System	109
	5.6	Computer Aided Drafting	110
	5.7	Contract Plans	110
	5.8	Specifications and Cost Estimates	113
	5.9	Reviews, Advertisement and Letting	114
	5.10	Bridge Design for Better Maintenance	117
	5.11	Other Design Issues	17

6. Construction 123

6.1 Construction Contract - Project Management 123
6.2 Bridge Construction 124
6.3 Post Construction Review 127

7. Materials 131

7.1 Concrete 131
7.2 Structural Steel 131
7.3 Reinforcing and Prestressing Steel 133
7.4 Wood 134
7.5 Bearings and Expansion Joints 134
7.6 Sealants and Epoxy 135

8. Quality Control 139

8.1 QA/QC Stages of the Project 139
8.2 Pre Grade Inspection 141
8.3 Grade Inspection, Plans-in-Hand Inspection 142
8.4 Standards 142
8.5 Coordination 142
8.6 Reviews 143

9. Maintenance 147

9.1 Bridge Inspections 148
9.2 Condition Ratings 149
9.3 Evaluation of Existing Bridges 150
9.4 Maintenance Strategies 152
9.5 Emergency Bridge Repairs 156
9.6 Field Testing 157

10. Management 163

10.1 Concepts, Needs, Costs 163
10.2 Bridge Management System (BMS) 164
10.3 Bridge Rehabilitation 166
10.4 Network Level 169
10.5 Big Bridges 172

11. Research 177

11.1 Major Research at MDOT 1960-97 177
11.2 Current and Future Research 177
11.3 National Research Programs - NCF, NCHRP, SP&R 178
11.4 Implementation of Research Findings - AASHTO, FHWA, MDOT 182
11.5 Research Pay-offs 183

12. Automation 187

12.1 Development of automation at MDOT 187
12.2 Future Automation 188
12.3 National Trends 188

13. Historical Bridges in Michigan 193

14. Future Bridges in Michigan 197

15. Human Resources 201

16. References 205

17. Glossary 209

Appendices 223

Appendix A: Example GDF Calculation 223
Appendix B: Example Proof Load Calculations 227
Appendix C: Typical Bridge Configuration 231
Appendix D: English/Metric Unit Conversions 233

Index 237

Acknowledgments

The information presented in this report was obtained from MDOT publications and MDOT current and former engineers and other staff members.

We would like to thank many individuals for sharing with us their experience, and in particular:

Sam Awwa (Design),
Dave Barrett (Maintenance),
Steve Beck (Design),
Andrea Bergemann (Planning),
Patricia Blackledge (Hydraulics),
Glen Bukoski (Construction),
Dave Calabrese (FHWA),
Mark Chaput (Planning),
Steve Cook (Construction and Technology),
Dick Endres (Geotechnical),
Larry Felsing (Quality Control),
Denise Jackson (Planning),
Sonny Jadun (Maintenance),
Raja Jildeh (Design),
Dave Juntunen (Construction & Technology),
Robert Kelley (Bridge Management),
Dr. Sudhakar Kulkarni (Project Management, Design),
Marge Lauer (Construction).
Lynn Lynwood (Design),
Ali Mahdavi (Design),
Dale McBurrows (Planning),
R. McCrum (Construction & Technology),
Steve O'Connor (Design),
John Olszewski (Construction),
Rick Smith (Maintenance),
John Staton (Research)
Winston Stebbins (Planning),
Mike Terazi (Design),
John Tiedt (Automation),
Roger Till (Research, Construction & Technology),
Maury Van Auken (Design),
Mark Vanportfleet (Design),
Ken Whelton (Maintenance),
Vladimir Zokvic (Design).

1. INTRODUCTION

1.1 Purpose/Objectives

1.2 Scope

1.3 Users

1. INTRODUCTION

1.1 Purpose/Objectives

There is a great need to synthesize the information related to various phases of bridge engineering as practiced by the Michigan Department of Transportation (MDOT). With a significant number of experienced engineers retiring, the new generation of engineers must rely on the documented engineering experience of MDOT. Therefore, the objective of this Report is to document the Michigan DOT's past and present engineering practices in the areas of Planning, Design, Construction, Maintenance, Materials, and Research. In particular, the synthesis is intended to serve the following purposes:

- Provide a reference document for bridge engineering practices at MDOT.
- Educate the new generation of MDOT engineers.

1.2 Scope

The Report covers past and present engineering practices of MDOT in the areas of Planning, Design, Construction, Maintenance, Materials, and Research. Emphasis is placed on procedures and supporting documentation. Reference is made to AASHTO Specifications and MDOT guides.

1.3 Users

The Report is intended for MDOT engineers, in particular junior bridge engineering staff. It can serve as a reference documentation for Planning, Design, Construction, Maintenance, Materials, and Research.

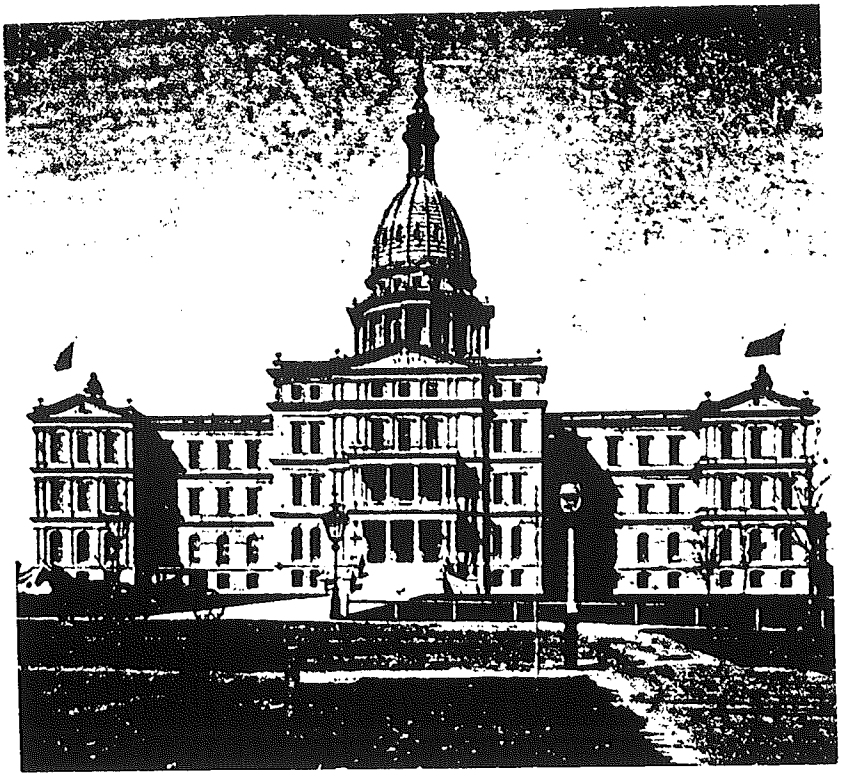
2. LEGISLATIVE ADMINISTRATION

2.1 Federal, State and Local

2.2 Tax Collection and Distribution

2.3 Permissible Loads in Michigan

2.4 Transportation Subcommittee and Commission



2. LEGISLATIVE ADMINISTRATION

2.1 Federal, State and Local

At the federal level, bridges are administered by the Federal Highway Administration (FHWA), which is a part of the US Department of Transportation (US DOT). Organizational charts of US DOT and FHWA are shown in Fig. 2-1 and 2-2, respectively. The FHWA flowchart is currently being revised.

The mission of the Michigan Division of the Federal Highway Administration is to "assure quality transportation programs by surpassing the needs and expectations of MDOT and our other customers and by focusing on product quality, process improvement and teamwork." To carry out this mission, the Michigan Division attempts to act strategically and in an innovative way, utilize quality principles, promote and focus on value added activities, ensure accountability, and enhance intra-office relationships.

The FHWA provides leadership, expertise, resources and information in cooperation with other organizations to enhance the country's economic vitality, the quality of life, and the environment. The FHWA directly administers a number of highway transportation activities including standards development, research and technology, training, technical assistance, highway access to federally owned lands and Indian lands, and commercial vehicle safety enforcement. Further, FHWA has a significant role, working through partnerships, programs, policies, and allocating resources, to facilitate the strategic development and maintenance of State and Local transportation systems as effective and efficient elements of the national intermodal transportation system.

The FHWA administers the Federal-aid Highway Program, which provides federal financial and technical assistance to the states to plan, construct, and improve the National Highway System, urban and rural roads, and bridges. The program fosters the development of a safe, efficient, and effective highway and intermodal system nationwide (FHWA National Strategic Plan, January 1998).

The FHWA is directly involved in only some MDOT projects, which are referred to as "non-exempt' projects. The determination of exempt (no FHWA involvement) or non-exempt (FHWA involvement) status for bridge projects primarily depends on the system that the bridge belongs to, the type of work to be done, and the project budget.

It is sometimes difficult to determine what system the bridge belongs to if the structure carries one roadway over another, as these bridges can be classified as part of two different systems. This is because a bridge over a highway is also an integral part of the roadway system carried under the bridge, as in many situations the system under the bridge could not

function as designed if the bridge were not provided. In any case, all bridges which are not on the National Highway System (NHS) are exempt. For bridge projects on the NHS, non-exempt status is given to projects that have a budget greater than $1 million and are to be completely new structures or are reconstruction work. Reconstruction is defined as the replacement of the deck or superstructure, or widening by at least one traffic lane.

The FHWA has recently attempted to increase efforts to be involved early in the project development on non-exempt projects. In order to provide a coordinated response on project development, a tentative determination of project exemption should be made during the program processing. This is done in consultation with FHWA at the time the annual program is finalized.

Once this determination is made, the exempt/non-exempt status is not normally changed. This is to minimize the delays and confusion that may result if status is changed during project development. The status is subject to revision if there is a major change in project scope of work, however.

The FHWA is committed to provide technical assistance and support upon the request of MDOT in any matter relating to the Federal-Aid Highway and Transportation Program including those projects that may be exempted.

Administration of State owned bridges is under the jurisdiction of the Michigan Department of Transportation (MDOT). The State policy in the area of transportation is formulated by the State Transportation Commission, reporting to the Governor. The organizational chart of MDOT is shown in Fig. 2-3 (as of 12-97).

At the county and city level, bridges are under the jurisdiction of County Road Commissions and City Engineering Departments, respectively.

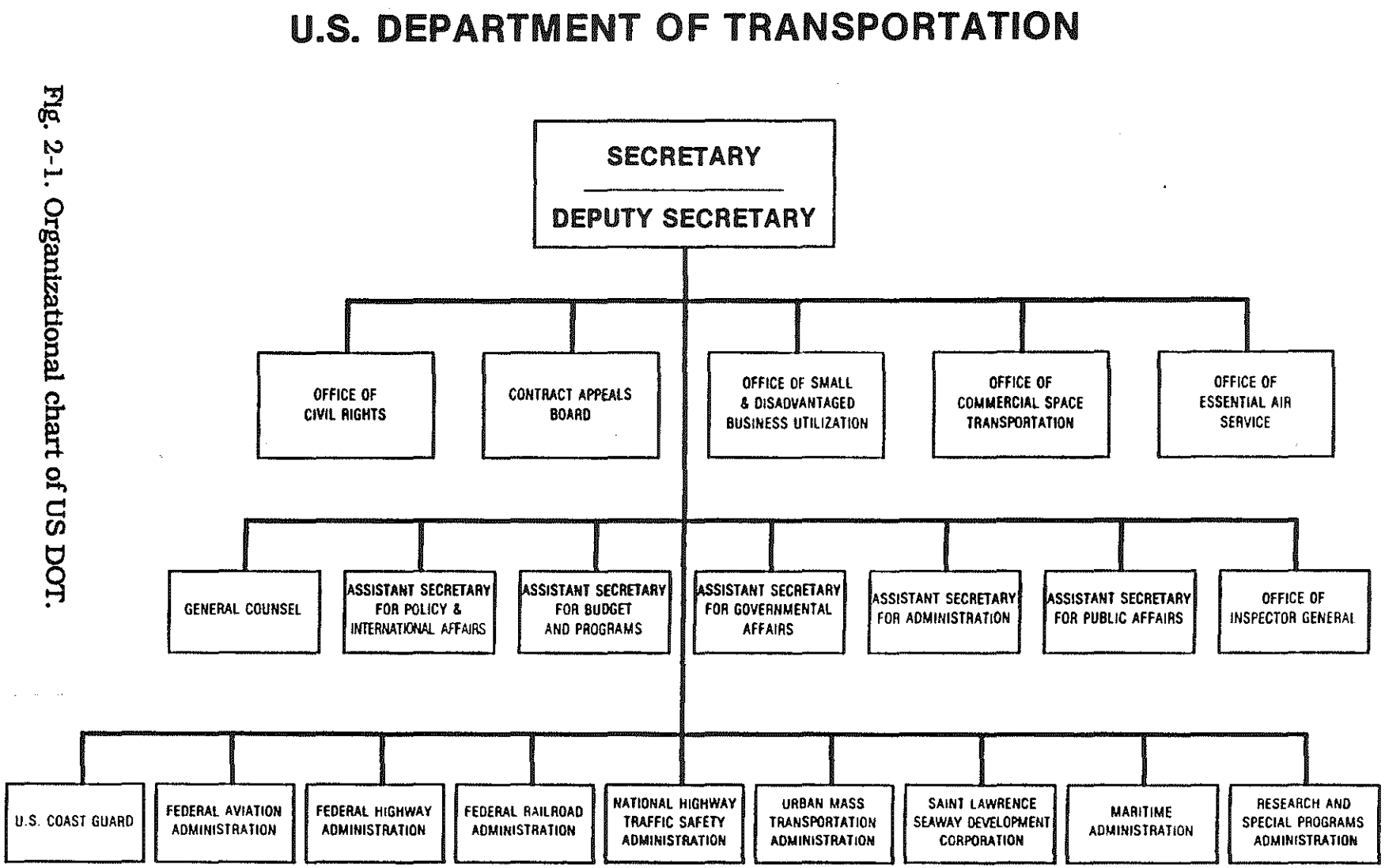
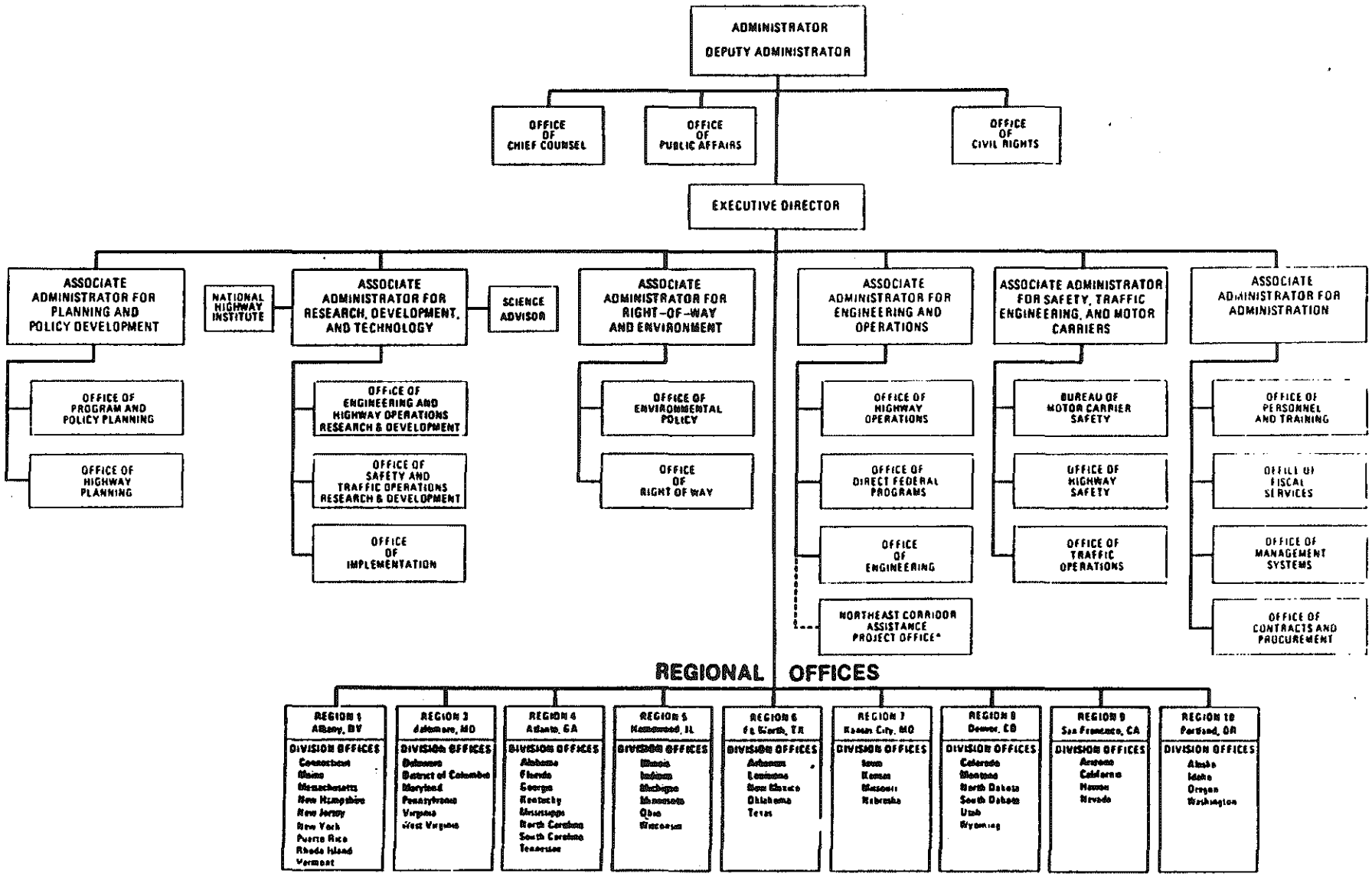


Fig. 2-1. Organizational chart of US DOT.

FEDERAL HIGHWAY ADMINISTRATION



*Provides institutional, technical and professional support to FRA.

Fig. 2-2. Organizational chart of FHWA.

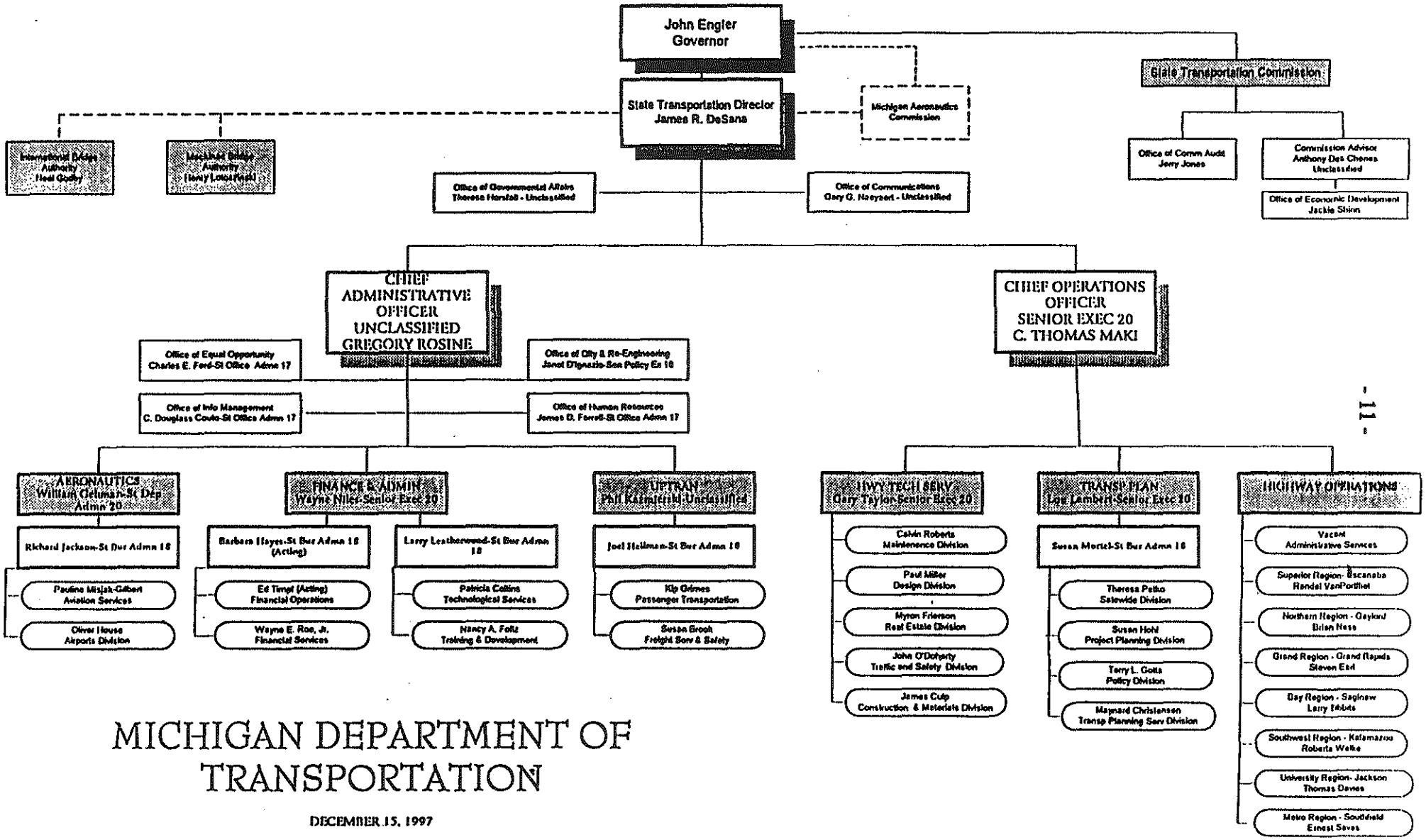


Fig. 2-3 Organizational chart of MDOT.

MDOT is currently being reorganized (1998), as the department's nine district offices are being restructured to seven Regional offices. The duties of these new offices will follow those of the former district offices, with additional planning and programming responsibilities. Additionally, the approximately 50 project offices are being converted into approximately 25 Transportation Service Centers (TSC) to better serve customers in the state (MDOT, Build Michigan II Projects: Fixing Our Roads, Jan. 16, 1998).

Following this restructuring, goals and strategies will be established on a statewide level at the central office in Lansing. Based on these goals and a Regional analysis of needs, the central office then allocates funds to the Regions. Each Region will develop its own strategy to invest its funding. These strategies are subject to approval by the central office, to insure that the Regional strategies satisfy the statewide strategy. The Regions have the responsibilities of inspection and data maintenance of the structure inventory. Each Region will also establish the specific responsibilities of the TSC's within their jurisdiction.

2.2 Tax Collection and Distribution

In 1998, $731 million was appropriated to road and bridge repair and reconstruction. 2560 km (1,600 mi) of road were to be improved, and 230 bridges were to be rehabilitated. This funding is from the gas tax and $300 million of new revenue from the state. The majority of this money was to be spent on rehabilitation and repair, as less than 5% was marked for new construction (MDOT, Build Michigan II Projects: Fixing Our Roads, Jan. 16, 1998). Of this $731 million, $265 million (36%) will be used for roads and $160 million (22%) will be used for bridges. The remaining funds will be distributed among: Improve and Expand projects ($140 million), Traffic and Safety Projects ($41 million), Roadside development and Weigh stations ($3 million), Federally mandated projects ($34 million), and other federal and state special uses ($85 million). This distribution is shown in Figure 2-4.

Although not the only source of bridge funding, all funds from the gas tax are dedicated to surface transportation. A part of this funding is allocated to repair, rehabilitate or replace bridges on the existing highway network. The Federal government collects these funds and redistributes the money to the states based upon the deck areas of deficient bridges. This concept is used by MDOT to distribute these funds to the MDOT Regions within its jurisdiction.

Currently, $160 million is allocated to bridge rehabilitation/ reconstruction, and $5 million for the preventative maintenance of bridges. In 1998, a total of $200 million was allocated to all highway maintenance, with $10 million marked specifically for bridge maintenance, money which is most often used for immediate repairs. In

the future, it is expected that $106 million will be dedicated to bridge replacement and $35 million to bridge rehabilitation. These funds, however, are not directly comparable to past values, as what specific tasks fall into the categories of maintenance, replacement and rehabilitation have recently changed.

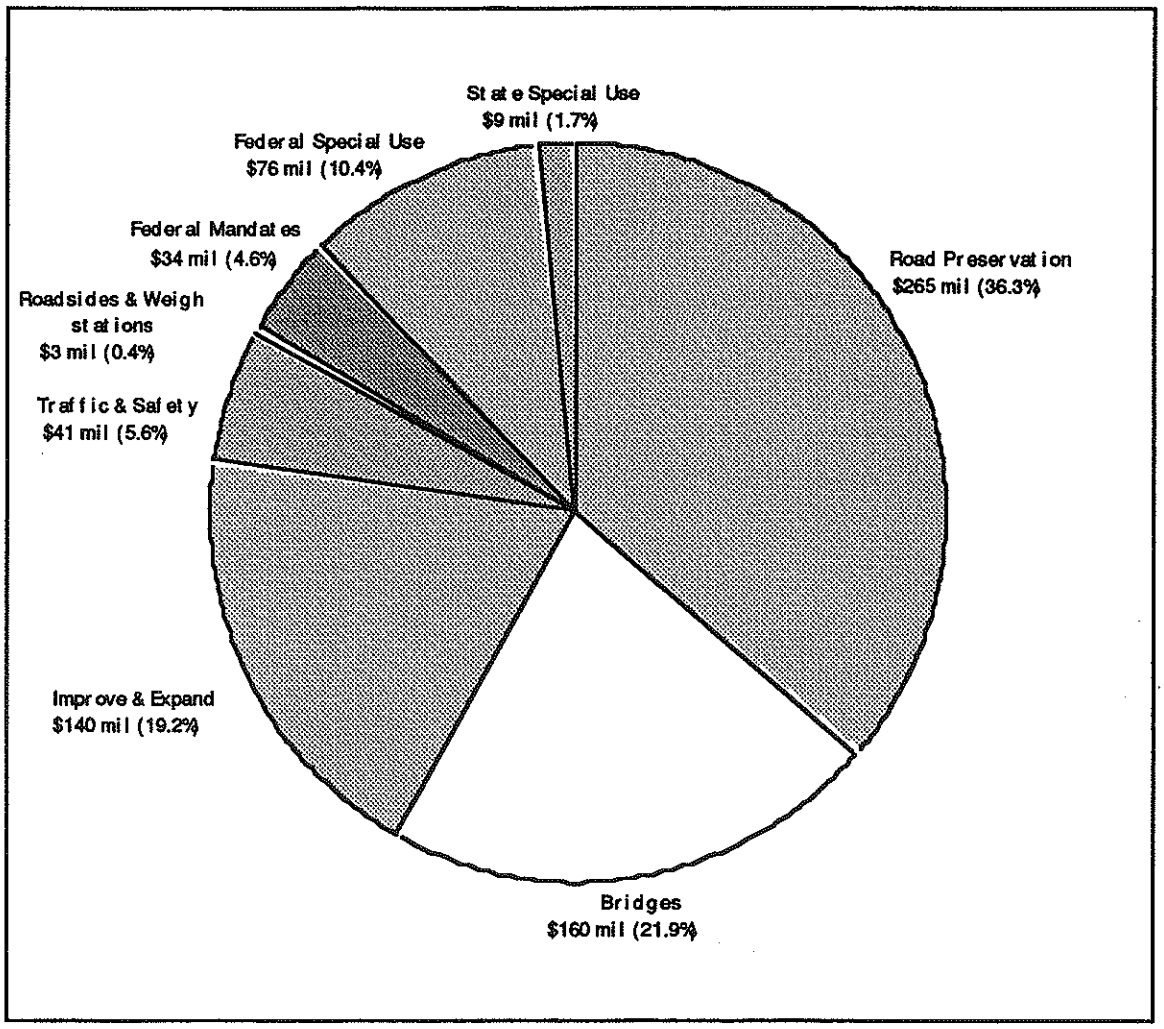


Fig. 2-4. MDOT Road and Bridge Budget Distribution.

Road Preservation includes the categories of Repair surface/base ($225 million), Passing Relief Lanes ($10 million), and Highway Preventative Maintenance ($30 million).

Improve and Expand includes Critical conversions ($66 million), Demo projects ($14 million), Other improve projects ($20 million), and Other expand projects ($39.6 million).

2.3 Permissible Loads in Michigan

Legal loads in Michigan are shown in Fig. 2-5 and Fig. 2-6. The moments generated by some of these loads, as a function of bridge span, are given in Table 2-1.

The legal axle load limits are:

- 80 kN (18 kips) for a single axle.
- 70 kN (16 kips) for each axle in a group of two axles spaced at 1.2m (4').
- 60 kN (13 kips) for each axle in a group of axles spaced at 1.0m (3.5').

Permissible vehicle loads are shown in Fig. 2-7. This sheet was designed to eliminate the need for the engineer to check whether a truck type given in the chart is allowed on a bridge. For a given bridge class (A, B, or C)[1] and truck type, a maximum permissible axle weight is given in the chart. Note that for truck types 7-17, this allowed axle weight value is reduced for the front truck axle(s), as indicated as a fraction of "P" in the corresponding truck diagram. As indicated on the sheet, these values are valid only for trucks with axle widths of 2.4 m (8'). For axle widths other than 2.4 m (8'), the axle load must be adjusted by: (W + 2.7)/5.3, where W is the axle width in meters.

In most states, the maximum gross vehicle weight is 360 kN (80,000 lbs) for commercial trucks. In contrast, the Michigan maximum gross vehicle weight is 720 kN (164,000 lbs). There are 108,000 registered commercial trucks in Michigan, and approximately 15,000 of these carry over 360 kN (80,000 lbs). At least 300,000 trucks operate in Michigan, most from other states. Based on these statistics, less than 5% of all trucks in Michigan are over 360 kN (80,000 lbs), and there are about 850 trucks registered at the maximum allowable 720 kN (164,000 lbs) (MDOT Position Paper on Trucks and Transportation, 1998).

---

[1]Bridge class indicates the ability of a bridge to carry loads. Class A bridges carry highest loads, while Class C bridges carry the lowest loads. These charts are used by the Traffic Permit Unit.

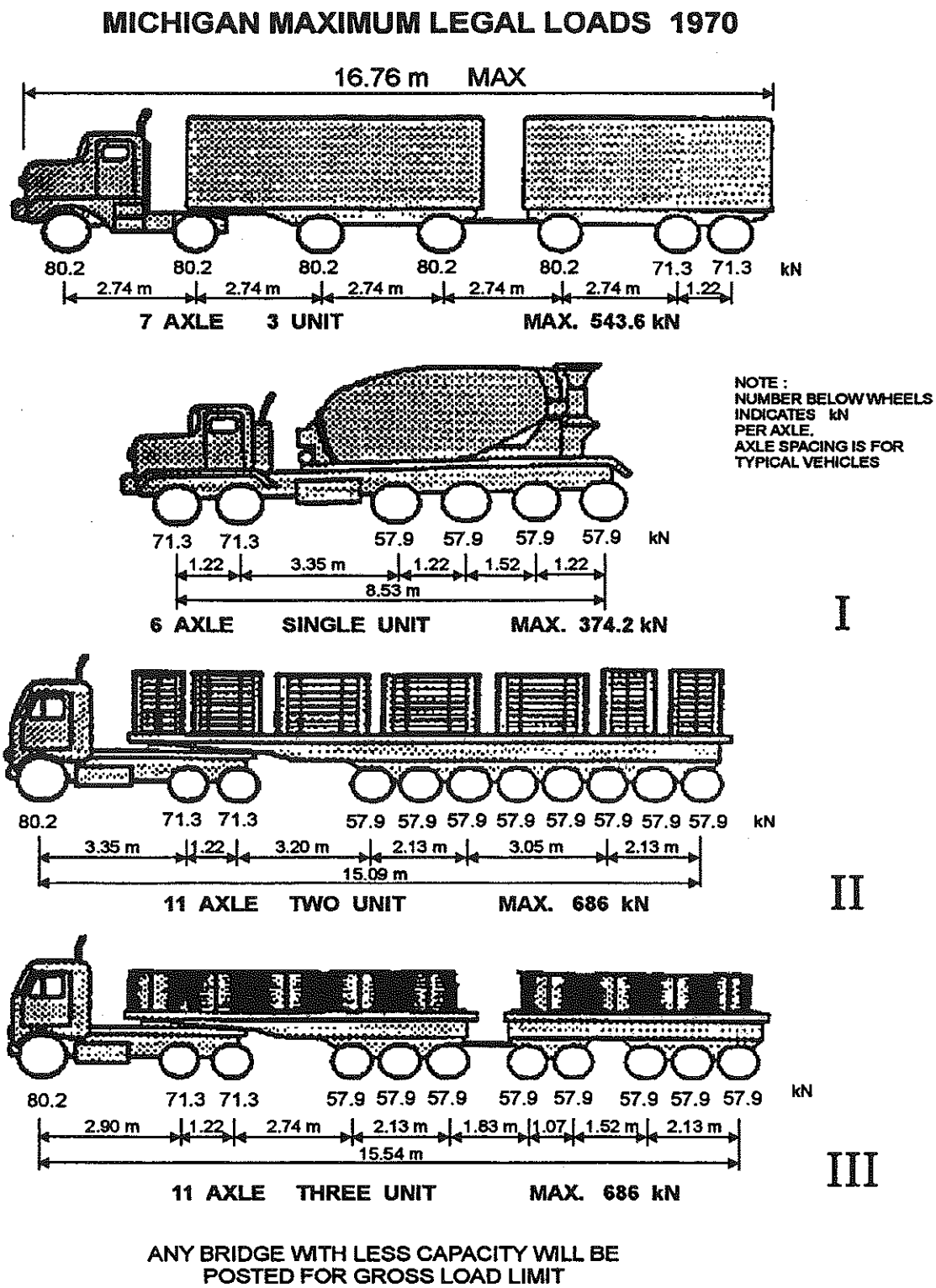
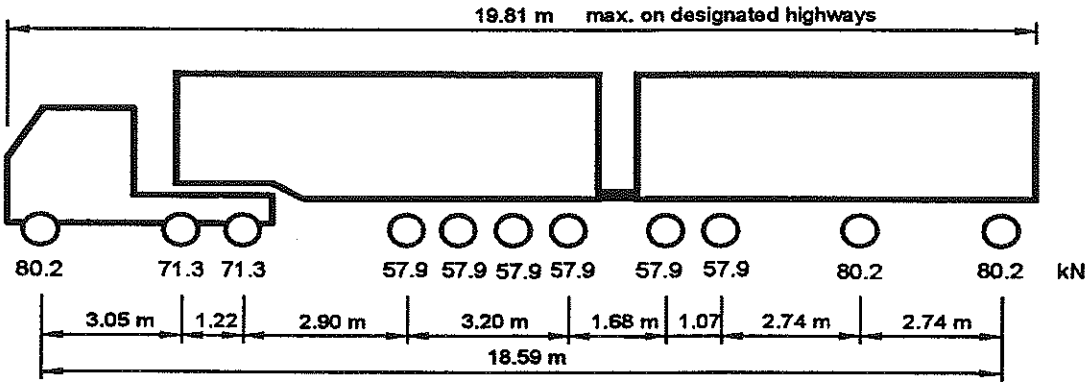


Fig. 2-5. Michigan Legal Loads, Part I.

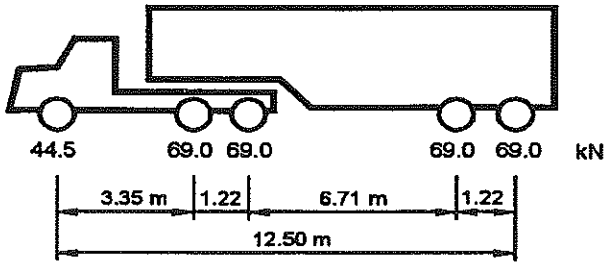
OTHER MAXIMUM LEGAL LOADS



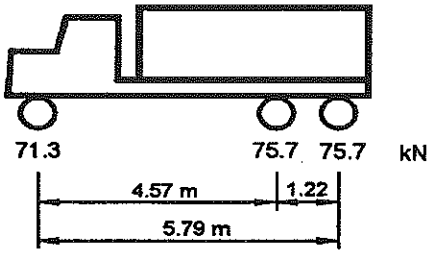
MICHIGAN 11 AXLE THREE UNIT MAX. 730.6 kN

(Moments are less than two unit 686 kN for spans less then 33.22 meters)

NOTE :
NUMBER BELOW WHEE
INDICATES kN
PER AXLE.
AXLE SPACING IS FOR
TYPICAL VEHICLES



AASHTO TYPE 3S2 **5 axle** **Max. 320.5 kN** **II A**



AASHTO TYPE 3 **3 axle** **222.7 kN** **I A**

MOMENTS FOR TYPE 3 & 3S2 on page 48 of AASHTO Manual.
If any bridge dates before about 1920 or has a known weakness (say less than 490 kN) the AASHTO type 3 and 3-S2 should be used for initial analysis.
If the resulting axle loads exceed legal loads then use veh. I & II.

Fig. 2-6. Michigan Legal Loads, Part II.

Table 2-1. Moments for Michigan Maximum Legal Truck Loads

Span	Moment (11-axle, 2-unit, 77 ton)	Moment (11-axle, 3-unit, 77 ton)	Moment (11-axle, 3-unit, 82 ton)	Moment (AASHTO Type 3S2)	Moment (AASHTO Type 3)
m (ft)	kN-m (k-ft)	kN-m (k-ft)	kN-m (k-ft)	kN-m (k-ft)	kN-m (k-ft)
6 (20')	257 (189)	230 (169)	239 (175)	171 (125)	141 (104)
9 (30')	569 (418)	473 (348)	488 (359)	302 (222)	307 (226)
12 (40')	922 (678)	817 (601)	794 (584)	442 (325)	476 (350)
15 (50')	1342 (987)	1214 (893)	1196 (880)	601 (442)	645 (474)
18 (60')	1805 (1327)	1686 (1240)	1640 (1206)	842 (619)	814 (599)
21 (70')	2315 (1702)	2209 (1624)	2177 (1601)	1082 (796)	983 (723)
24 (80')	2837 (2086)	2731 (2008)	2734 (2011)	1325 (974)	1153 (848)
27 (90')	3361 (2471)	3255 (2393)	3293 (2421)	1568 (1153)	1323 (973)
30 (100')	3883 (2855)	3777 (2777)	3850 (2831)	1812 (1332)	1493 (1098)
33 (110')	4405 (3239)	4300 (3162)	4407 (3241)	2054 (1511)	1662 (1222)
36 (120')	4929 (3624)	4824 (3547)	4965 (3651)	2299 (1690)	1832 (1347)
39 (130')	5451 (4008)	5348 (3932)	5523 (4061)	2542 (1869)	2002 (1472)
42 (140')	5975 (4393)	5871 (4317)	6080 (4471)	2787 (2049)	2172 (1597)
45 (150')	6497 (4777)	6395 (4702)	6638 (4881)	3031 (2229)	2342 (1722)
48 (160')	7019 (5161)	6918 (5087)	7196 (5291)	3276 (2409)	2512 (1847)
52 (170')	7541 (5545)	7442 (5472)	7753 (5700)	3010 (2213)	2682 (1972)
55 (180')	8063 (5929)	7966 (5857)	8310 (6110)	3234 (2378)	2852 (2097)
58 (190')	8587 (6314)	8489 (6242)	8868 (6520)	3460 (2544)	3022 (2222)
61 (200')	9109 (6698)	9013 (6627)	9425 (6930)	3686 (2710)	3192 (2347)

MICHIGAN DEPARTMENT OF TRANSPORTATION
OVERLOADS PERMISSIBLE ON BRIDGES

2.4 M

TYPICAL VEHICLES

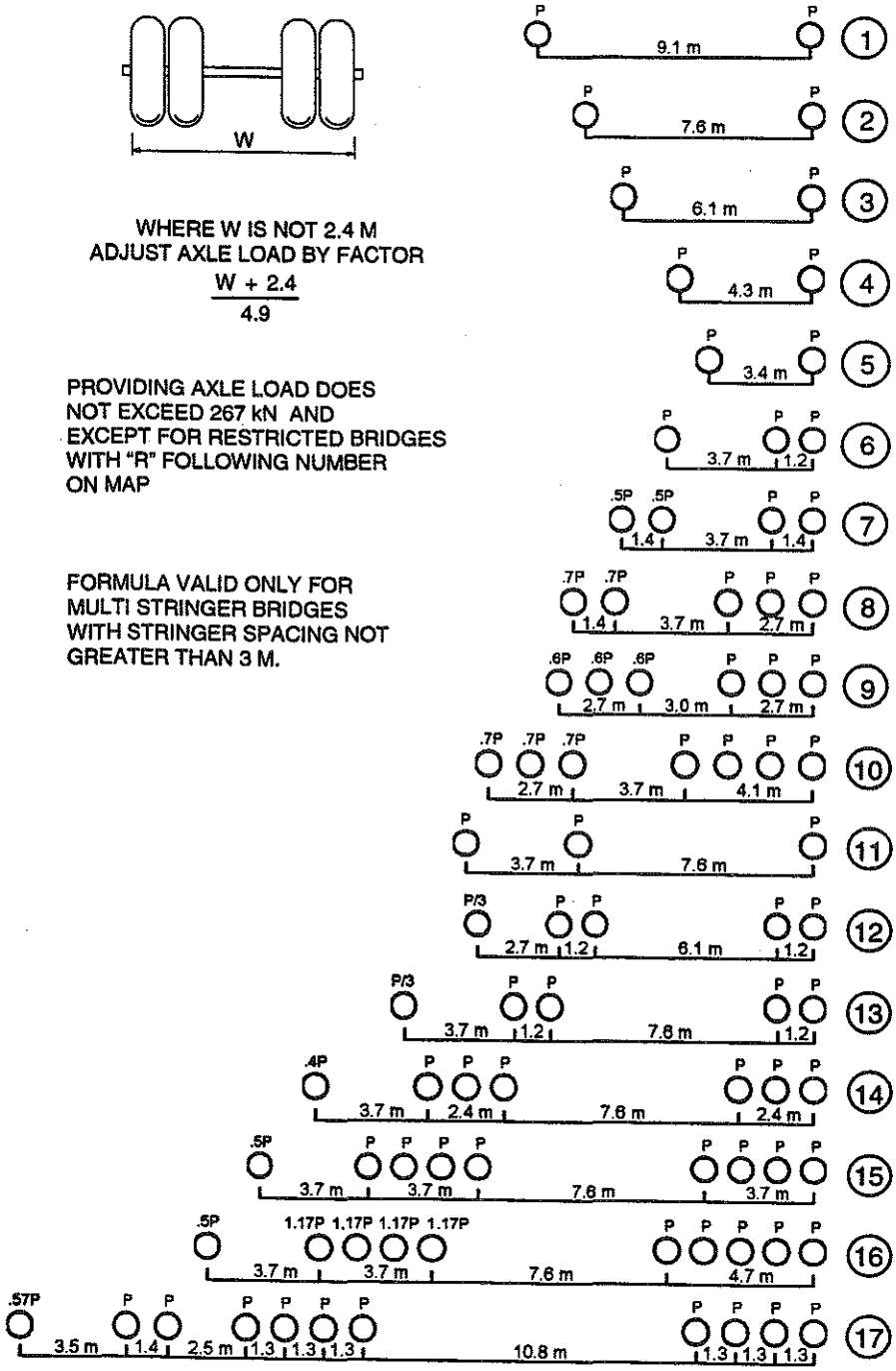
WHERE W IS NOT 2.4 M
ADJUST AXLE LOAD BY FACTOR

$$\frac{W + 2.4}{4.9}$$

PROVIDING AXLE LOAD DOES NOT EXCEED 267 kN AND EXCEPT FOR RESTRICTED BRIDGES WITH "R" FOLLOWING NUMBER ON MAP

FORMULA VALID ONLY FOR MULTI STRINGER BRIDGES WITH STRINGER SPACING NOT GREATER THAN 3 M.

2.4 M WIDE



** BRIDGE CLASS	PERMISSIBLE AXLE LOADS						
	A		B		C		
	AXLE [kN]	GROSS [kN]	AXLE [kN]	GROSS [kN]	AXLE [kN]	GROSS [kN]	
1	267.0	534.0	267.0 169.0	534.0 338.0	267.0 169.0	534.0 338.0	*
2	267.0	534.0	267.0 169.0	534.0 338.0	267.0 169.0	534.0 338.0	*
3	267.0	534.0	263.0 169.0	526.0 338.0	254.0 169.0	508.0 338.0	*
4	267.0	534.0	140.5 169.0	281.0 338.0	218.0 169.0	436.0 338.0	*
5	267.0	534.0	231.5 169.0	463.0 338.0	196.0 169.0	392.0 338.0	*
6	187.0	561.0	160.5	481.5	133.5	400.5	
7	205.0	615.0	169.0	507.0	138.0	414.0	
8	151.5	666.5	129.0	567.5	107.0	471.0	
9	147.0	970.0	120.5	795.5	98.0	647.0	
10	129.0	787.0	107.0	652.5	89.0	543.0	
11	267.0	801.0	236.0 169.0	708.0 507.0	205.0 169.0	615.0 507.0	*
12	196.0	848.5	165.0	714.5	138.0	597.5	
13	200.5	868.0	173.5 169.0	751.5 732.0	151.5	656.0	*
14	147.0	941.0	124.5	797.0	107.0	685.0	
15	124.5	1058.5	107.0	909.5	89.0	756.5	
16	107.0	1089.5	89.0	906.0	75.5	768.5	
17	115.0	1215.5	98.0	1036.0	77.0	814.0	

Note: Loads exceeding these values must be checked out for individual bridges

* FOR BRIDGES DESIGNED FOR H15 BETWEEN 1965 AND 1972 SLAB CONTROLS

** FOR BRIDGE CLASS REFER TO MAP WITH "TABLE OF BRIDGES WITH RESTRICTED LOAD LIMITS".

Fig. 2-7. Michigan Permissible Loads.

2.4 Transportation Subcommittee and Commission

The State Transportation Commission awards contracts for construction and maintenance of the state transportation system. It was initially established in 1964 by MCL Act 286. It advises the governor on transportation issues, and its members are appointed by the governor for 3 year periods. Some of the items brought before the Commission for review and approval are the following:

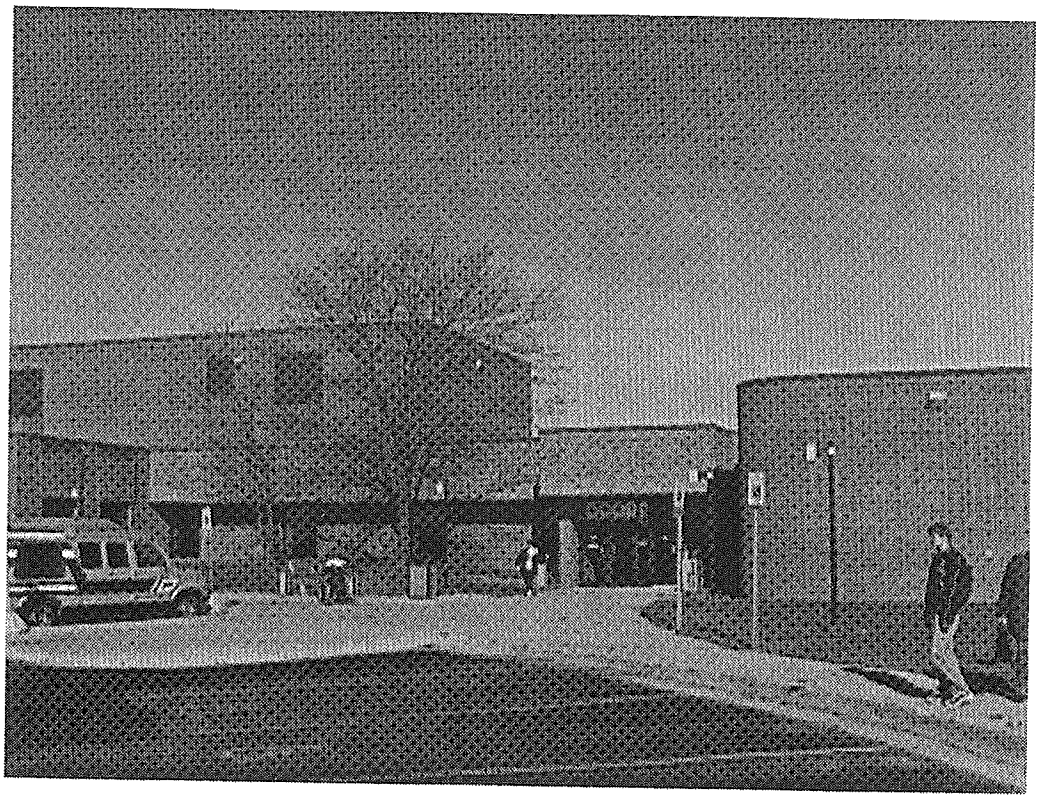
- Construction contracts and Department grants over $500,000, and contracts under $500,000 with fewer than 3 bidders.
- Payments for extra work and contract overruns, when approval by the State Administrative Board is also required.
- When local agencies take bids for construction or perform the construction, or when state dollars are expended on non-trunkline routes.
- State lease contracts and public transportation contracts, water and port facilities contracts, and railroad structure contracts over $50,000.
- Bond issuances.
- The establishment and abandonment of state highways, and additions to the interstate system.
- The use of state rights-of-way for nontraditional transportation purposes.

Other items that the Commission reviews and must approve are detailed in MCL Act 286 (1964) and the Executive Bureau's Division of Authority document CP 000.01 (1994).

3. BRIDGE PROGRAM ADMINISTRATION

3.1 General Information

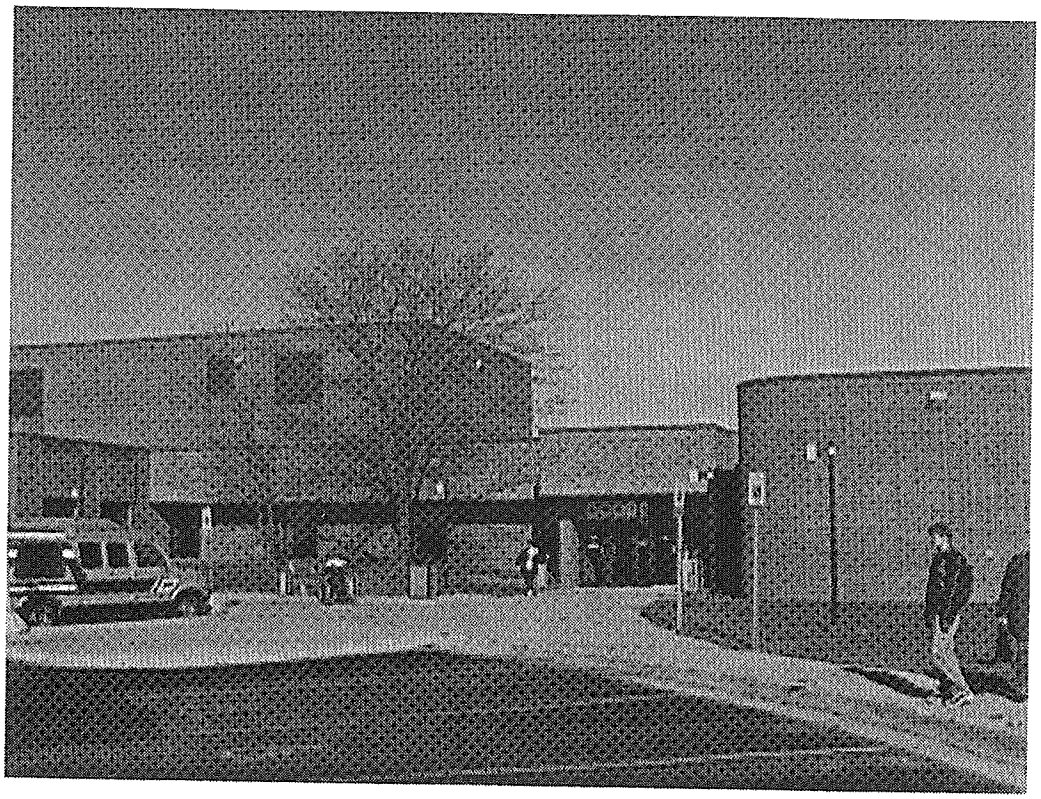
3.2 AASHTO, FHWA, State and Local Roles



3. BRIDGE PROGRAM ADMINISTRATION

3.1 General Information

3.2 AASHTO, FHWA, State and Local Roles



3. BRIDGE PROGRAM ADMINISTRATION

3.1 General Information

Bridges are administered by their owners. State governments own 270,546 bridges in the United States. The remaining 304,379 are owned by counties, cities and private owners.

Since 1956 and the onset of the Interstate Highway Program, the number of new bridges built in the United States of America has increased significantly. The Interstate Highway System consists of 73,200 km (42,000 miles) of highways and 54,800 bridges. Several years ago, FHWA created the National Highway System (NHS) and eliminated the distinction between interstate and non-interstate routes which pertained to Federal Aid requirements. All former interstate routes are on the NHS.

The following tables and graphs are based on the Michigan Bridge Management Database using the Structure Inventory and Appraisal Coding Guide (as of Jan. 1, 1997).

There are 12,428 spanning structures in Michigan. These structures are divided into two categories: bridges (10,350), and culverts (2,078). The dividing line between a culvert and a bridge is sometimes vague. Span is sometimes used as a criterion (a bridge usually being 20', or 6.1 m in span or greater), but a more accurate distinction can be made based on structural type. Culverts are often monolithic structures without distinct structural members, while bridges most often have a girder and deck arrangement. It is also possible for multiple culverts to be classified as a bridge, if the distance between the extreme ends of the group of culverts is greater than 6.1m (20') and the clear distance between openings is less than half of the smaller contiguous opening of the culvert.

MDOT owns 4,584 bridges and 1,068 culverts. Bridges are on the interstate, "US" and "M" routes, which carry approximately 70 percent of commercial traffic. There are 5,766 bridges and 1,010 culverts under the jurisdiction of local authorities (counties, cities and private owners).

The most common types of bridges in the State of Michigan are reinforced concrete, steel and prestressed concrete bridges. For steel and prestressed concrete bridges, the typical superstructure is a reinforced concrete deck on multiple beams. Most of the substructure units are reinforced concrete members. In addition to these typical structures, there are 52 big bridges, 13 of which are movable. Big bridges are discussed in section 10.5

Bridges are put into categories with regard to the following parameters:

- Structural type
- Material
- Span length
- Year of construction
- Number of spans

The original year of construction is used in the tables and graphs. Since their construction, some bridges underwent extensive repair or rehabilitation, resulting in a major change in their structural category (for example, an older reinforced concrete bridge rehabilitated with prestressed concrete girders). For this reason, some prestressed concrete bridges are listed as built prior to introduction of that technology. It should also be noted that, due to slight inaccuracies in the database, the total number of structures, when sorted into different categories, does not always exactly match. The following graphs use 1998 database information, and one should be aware that the numbers change yearly.

The following structural types are considered:

- Slab bridges
- Multi stringer, W or I- beam
- Girder, floor beam - deck
- Tee beam
- Box beam
- Frame
- Orthotropic
- Truss
- Arch
- Suspension and Cable Stay
- Movable bridge
- Tunnel
- Culvert
- Mixed Type
- Channel beam
- Others

The following material categories are considered:

- Reinforced concrete
- Steel
- Prestressed concrete
- Timber
- Masonry

- Aluminum, Wrought Iron (W.I.) and Cast Iron (C.I.)
- Others

The following structure conditions are considered:

- Not deficient
- Structurally deficient
- Functionally obsolete

The precise definitions of these conditions are discussed in section 9.

Table 3-1. Bridges in Michigan (Structural Types)

Structure type	MDOT	Local	All
Slab	146	511	657
Multi Stringer	3542	2280	5822
Girder Floor Beam	151	284	435
Tee Beam	412	494	906
Box Beam	238	1714	1952
Frame	6	39	45
Orthotropic	1	1	2
Truss	35	256	291
Arch	31	105	136
Suspension & Cable Stay	1	0	1
Movable	13	14	27
Tunnel	0	0	0
Culvert	1068	1010	2078
Mixed Types	0	0	0
Channel Beam	0	0	0
Other	1	68	69
Total	5644	6708	12352

Table 3-2a. Bridges in Michigan (Materials)

Materials	MDOT	Local	All
Concrete	402	672	1074
Concrete continuous	204	80	284
Steel, simple or cantilever	2777	2336	5113
Steel continuous	372	142	514
Prestressed concrete	763	2008	2771
Prestressed concrete continuous	36	33	69
Timber	25	469	494
Masonry	1	4	5
Aluminum, W.I. or C.I.	2	16	18
Other	0	6	6
Total	4582	5766	10348

* Culverts not included

Table 3-2b. Culverts in Michigan (Materials)

Materials	MDOT	Local	All
Concrete	909	238	1147
Concrete continuous	38	22	60
Steel, simple or cantilever	119	670	789
Steel continuous	0	1	1
Prestressed concrete	1	8	9
Prestressed concrete continuous	0	0	0
Timber	0	51	51
Masonry	0	1	1
Aluminum, W.I. or C.I.	0	12	12
Other	0	7	7
Total	1067	1010	2077

Table 3-3a. Bridges in Michigan (Span length)

Maximum Span (m)<	Local	MDOT	Total
5	101	90	191
10	311	2326	2637
15	681	1598	2279
20	1025	990	2015
25	971	449	1420
30	592	154	746
35	399	60	459
40	222	36	258
45	136	11	147
50	64	10	74
55	19	4	23
60	16	2	18
65	2	4	6
70	2	4	6
75	4	1	5
80	1	1	2
85	4	4	8
90	0	0	0
95	3	0	3
100	0	0	0
>100	7	1	8
Total	4560	5745	10305

Culverts not included

Table 3-3b. Bridges in Michigan (MDOT – Span length)

Maximum Span (m) <	Conc.	Steel	PC	Timber	Other
5	91	3	2	5	0
10	188	49	56	17	1
15	115	348	218	0	0
20	63	736	226	0	0
25	99	701	169	1	1
30	21	527	44	0	0
35	12	334	52	1	0
40	6	198	16	0	1
45	0	132	4	0	0
50	0	63	0	1	0
55	0	19	0	0	0
60	0	15	1	0	0
65	0	2	0	0	0
70	0	2	0	0	0
75	0	3	1	0	0
80	0	1	0	0	0
85	0	2	2	0	0
90	0	0	0	0	0
95	0	3	0	0	0
100	0	0	0	0	0
>100	0	4	3	0	0
Total	595	3142	794	25	3

Table 3-3c. Bridges in Michigan (Local – Span length)

Maximum Span (m) <	Conc.	Steel	PC	Timber	Other
5	18	47	6	17	2
10	419	1085	409	409	4
15	164	680	724	27	3
20	86	353	546	5	0
25	39	157	238	8	7
30	20	66	65	2	1
35	3	32	18	0	7
40	1	21	13	1	0
45	1	9	1	0	0
50	0	10	0	0	0
55	0	4	0	0	0
60	0	2	0	0	0
65	0	3	1	0	0
70	0	4	0	0	0
75	0	1	0	0	0
80	0	0	0	0	1
85	0	4	0	0	0
90	0	0	0	0	0
95	0	0	0	0	0
100	0	0	0	0	0
>100	0	0	1	0	0
Total	751	2478	2022	469	25

Table 3-4a. Bridges in Michigan (Year of Construction)

Year of Construction	MDOT	Local	All
Before 1900	2	55	57
1900	11	308	319
1910	21	277	298
1920	189	768	957
1930	328	715	1043
1940	229	309	538
1950	729	400	1129
1960	1697	655	2352
1970	926	822	1748
1980	330	840	1170
After 1990	121	616	737
Total	4583	5765	10348

Culverts not included

Table 3-4b. Bridges in Michigan (MDOT – Year of Construction)

Year of Construction	Conc.	Steel	PC	Timber	Other
Before 1900	1	1	0	0	0
1900	6	3	1	0	1
1910	18	2	1	0	0
1920	87	81	21	0	0
1930	111	188	29	0	0
1940	70	149	9	0	0
1950	200	472	57	0	0
1960	104	1249	344	0	0
1970	4	823	75	22	2
1980	4	162	162	2	0
After 1990	1	19	100	1	0
Total	606	3149	799	25	3

Table 3-4c. Bridges in Michigan (Local – Year of Construction)

Year of Construction	Conc.	Steel	PC	Timber	Other
Before 1900	2	43	2	5	3
1900	37	245	13	12	1
1910	53	207	12	4	1
1920	227	473	61	5	2
1930	162	513	27	10	3
1940	44	247	8	9	1
1950	99	191	78	32	0
1960	29	303	231	90	2
1970	39	164	469	137	13
1980	26	64	649	101	0
After 1990	34	27	491	64	0
Total	752	2477	2041	469	26

Table 3-5a. Bridges in Michigan (Number of Spans)

	MDOT	Local	All
Single Span	1119	3909	5028
Multi - Span			
Simple	2852	1599	4451
Continuous	607	245	852
Total	4578	5753	10331

Culverts not included

Table 3-5b. Bridges in Michigan (MDOT – Number of Spans)

	Conc.	Steel	PC	Timber
Single Span	358	547	205	6
Multi - Span				
Simple	44	2230	558	19
Continuous	204	367	36	0
Total	606	3144	799	25

Table 3-5c. Bridges in Michigan (Local – Number of Spans)

	Conc.	Steel	PC	Timber
Single Span	554	1778	1347	209
Multi - Span				
Simple	118	558	661	260
Continuous	78	135	30	0
Total	750	2471	2038	469

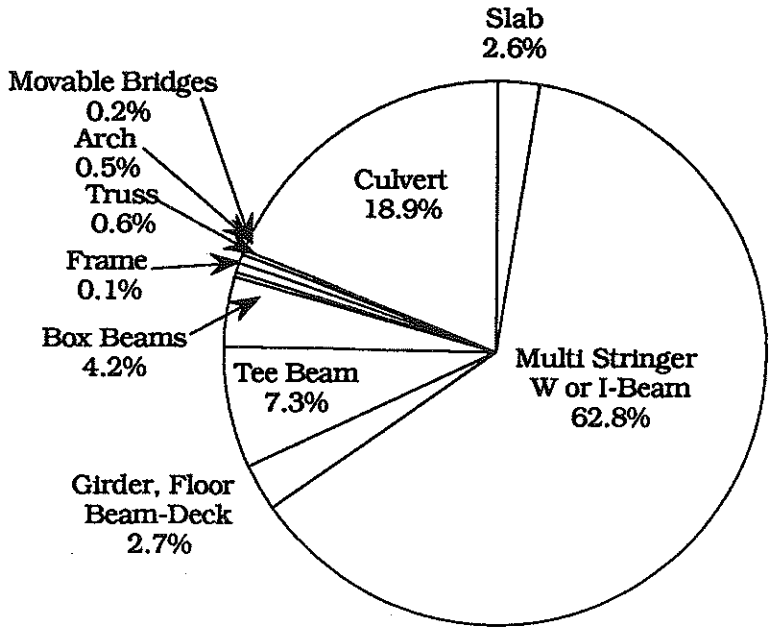
Table 3-6a. Bridges in Greater Detroit Area (MDOT)

Type	Wayne County	Oakland County	Macomb County	Detroit City
Concrete	19	8	5	3
Steel	744	189	121	459
PC	69	101	33	15
Others	18	4	0	0
Total	851	302	159	477

Table 3-6b. Bridges in Greater Detroit Area (Local)

Type	Wayne County	Oakland County	Macomb County	Detroit City
Concrete	144	32	14	16
Steel	299	38	82	144
PC	55	57	78	6
Others	8	12	4	0
Total	506	139	178	166

MDOT Structural Types (5644 Structures)



Local Structural Types (6708 Structures)

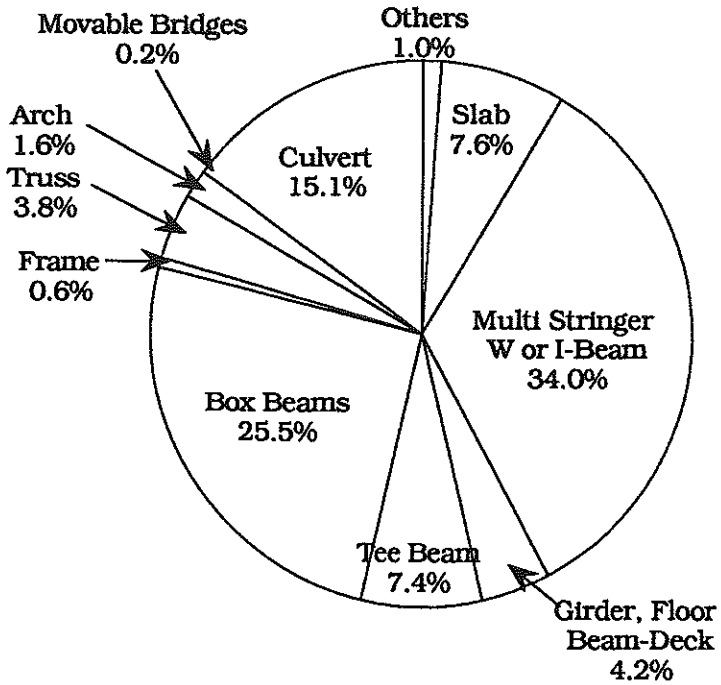
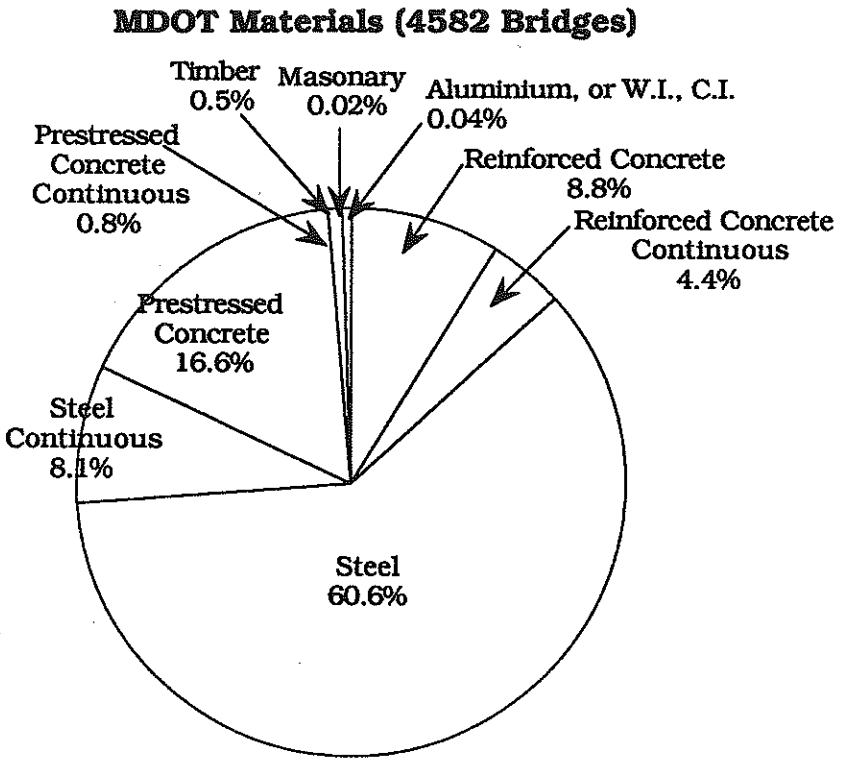


Fig. 3-1. Structural Types



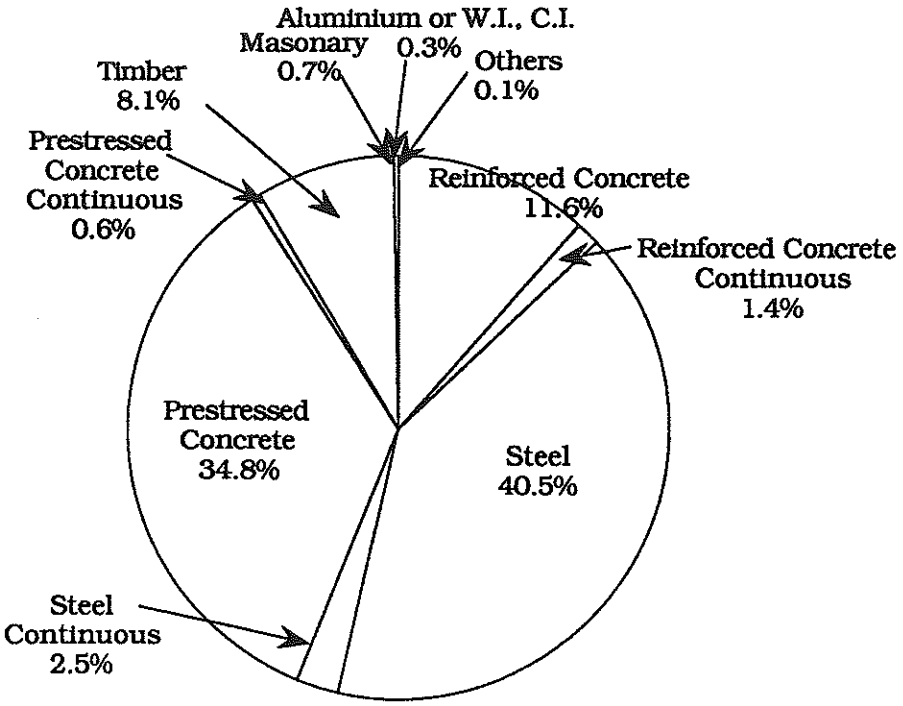
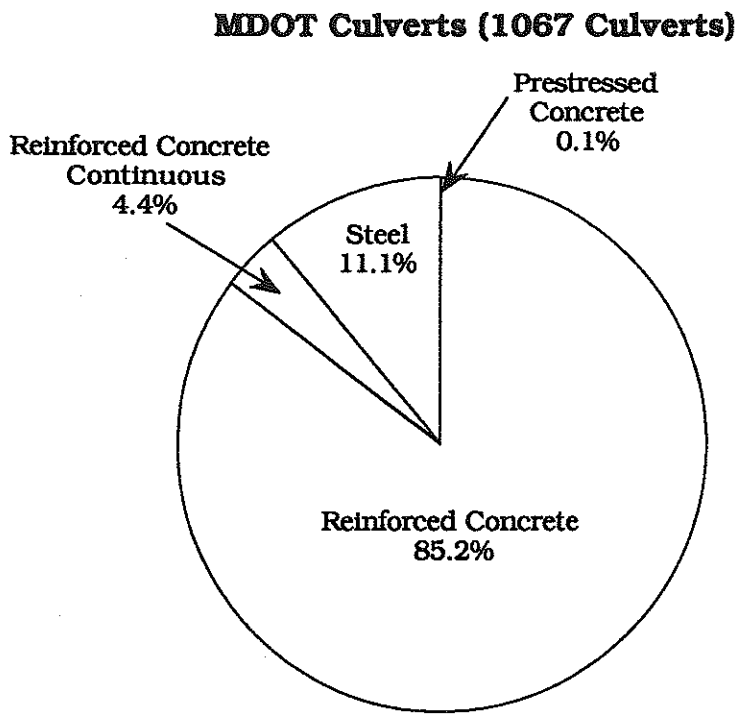


Fig. 3-2. Materials



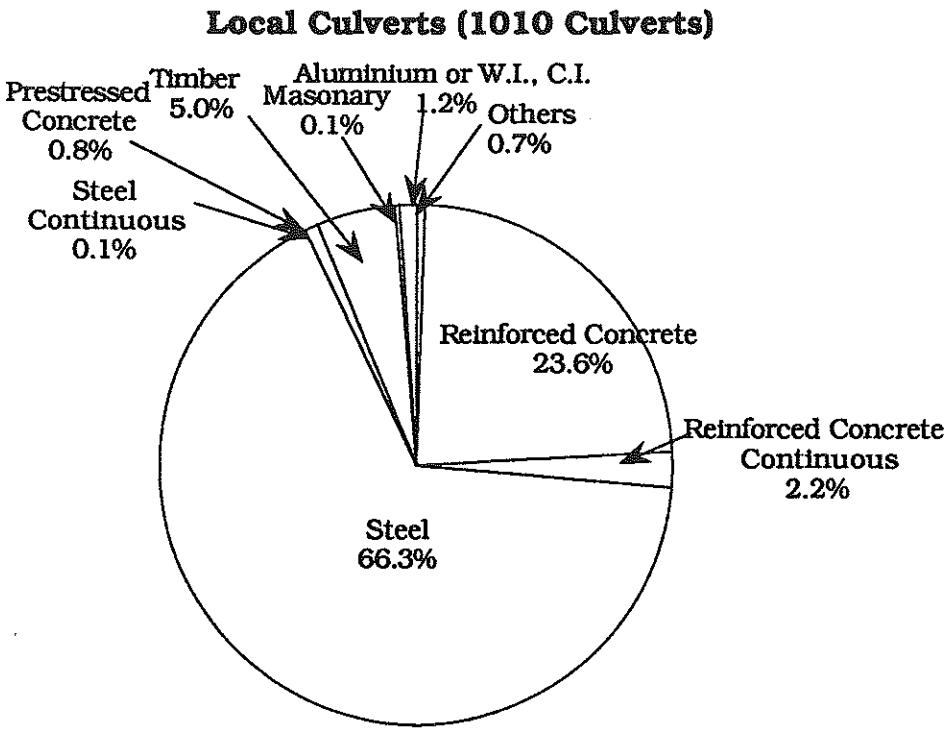
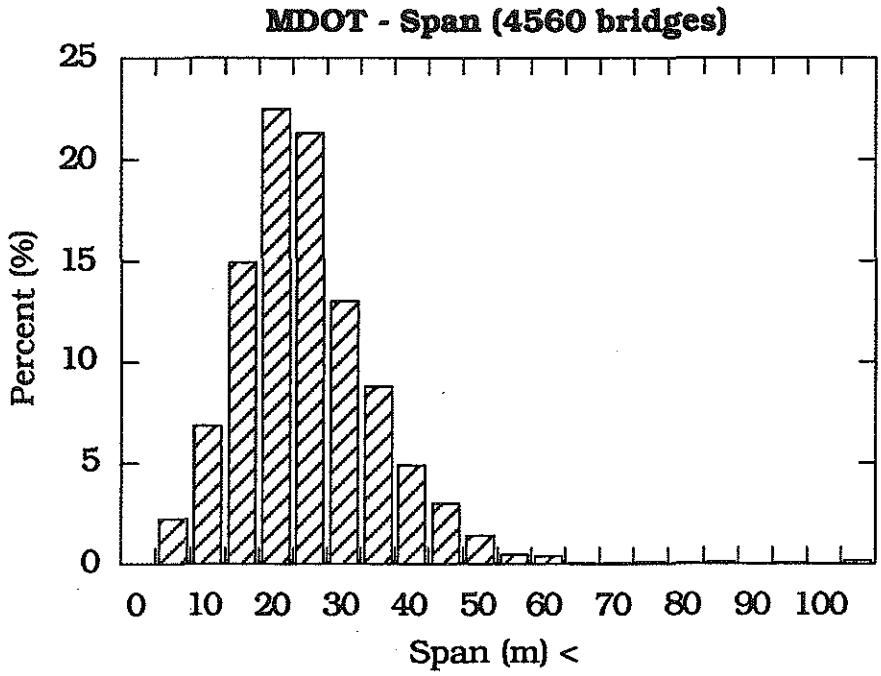


Fig. 3-2a. Materials for Culverts



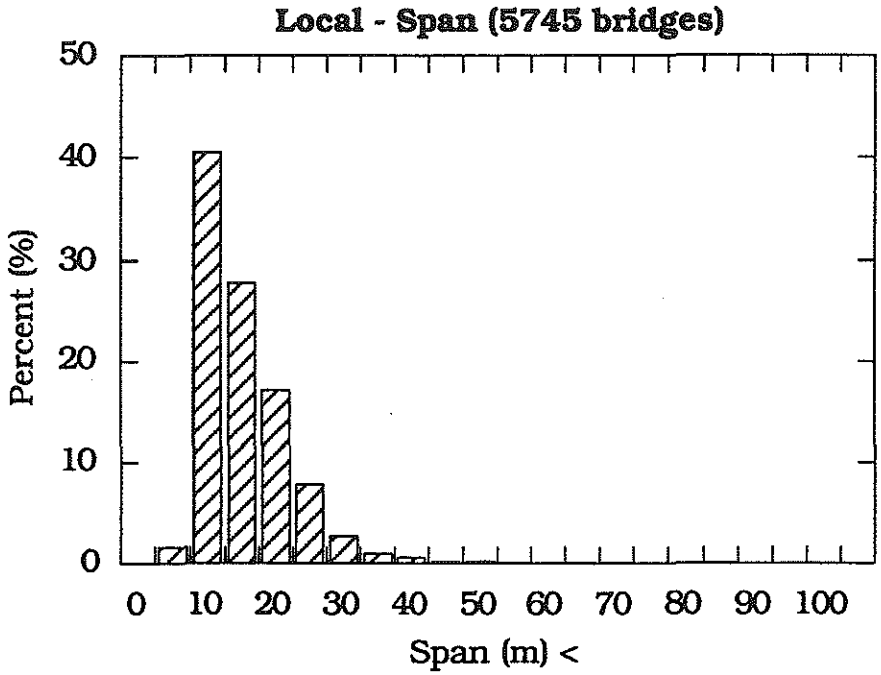
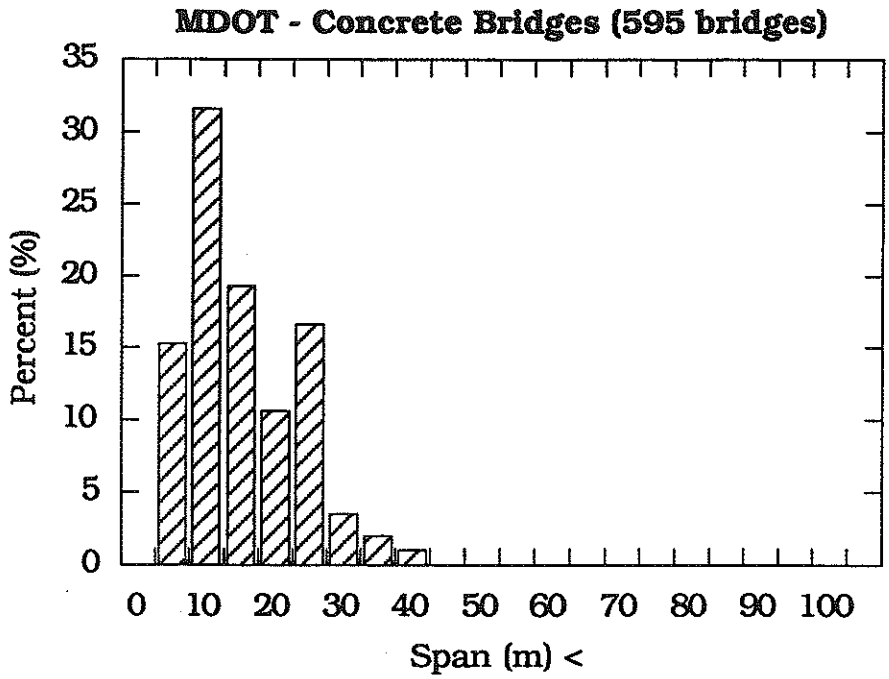


Fig. 3-3a. Span Length



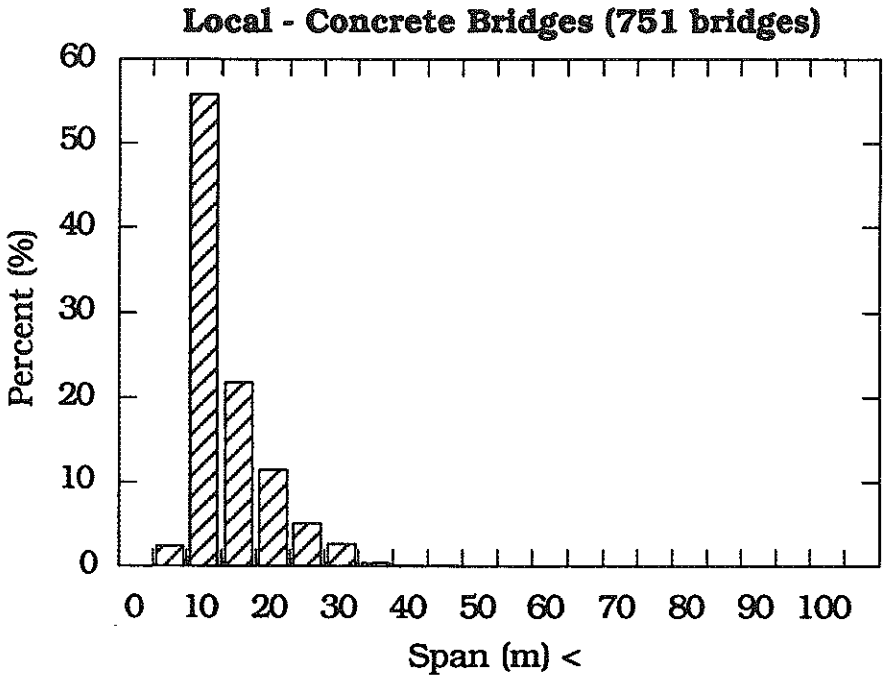
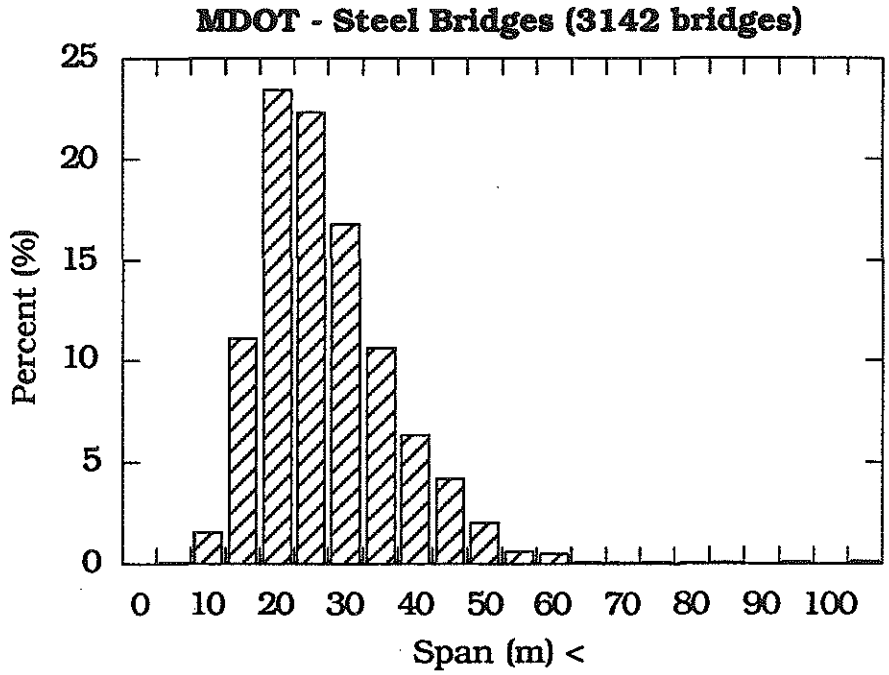


Fig. 3-3b. Span Length for Concrete Bridges.



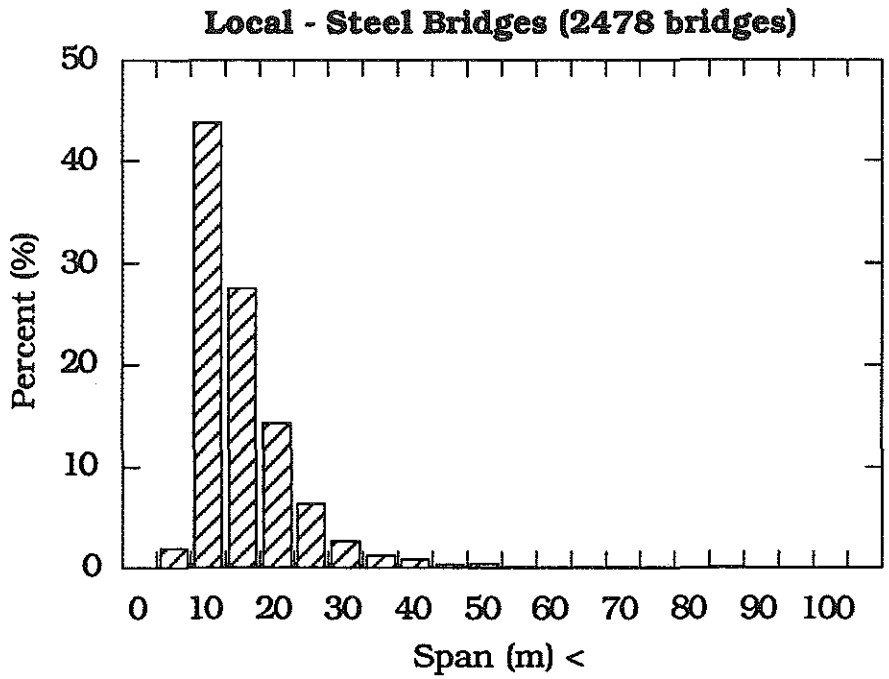
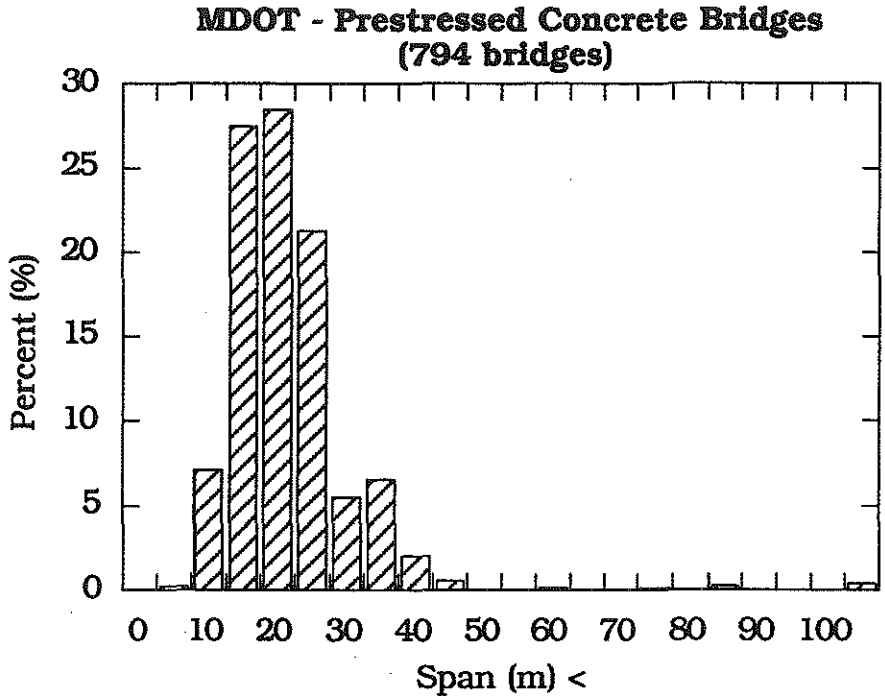


Fig. 3-3c. Span Length for Steel Bridges.



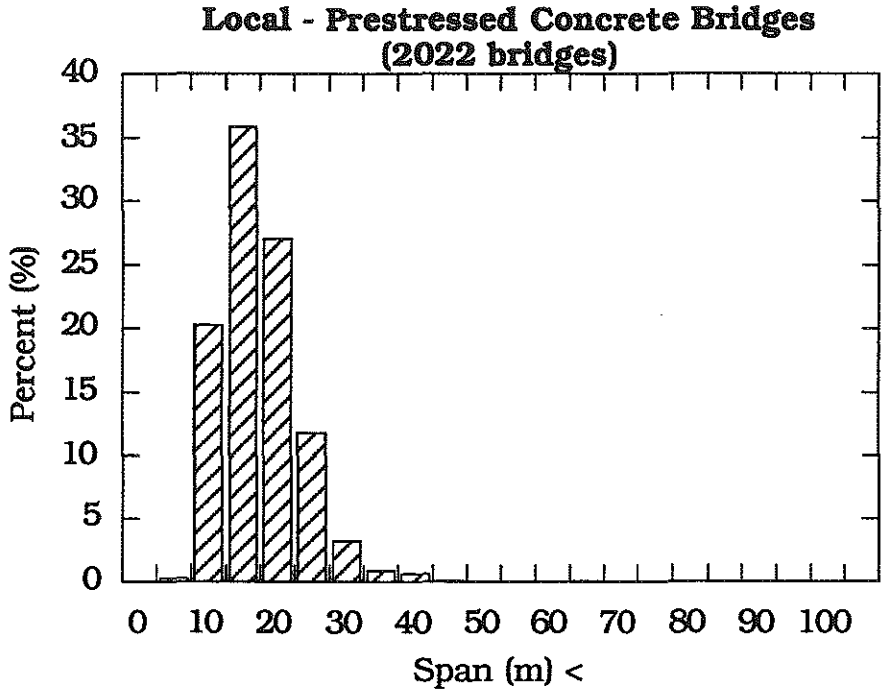
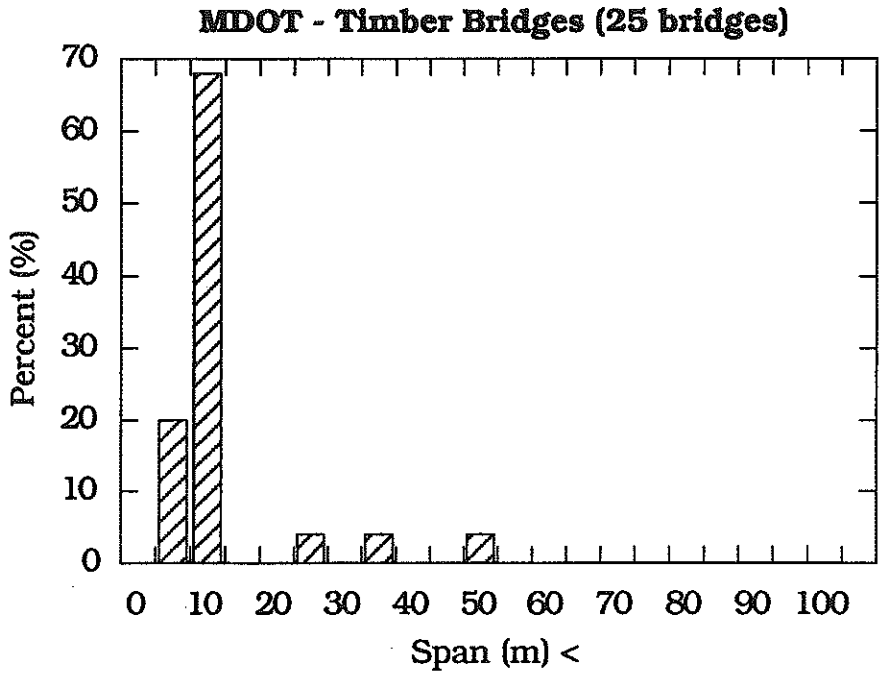


Fig. 3-3d. Span Length for Prestressed Concrete Bridges.



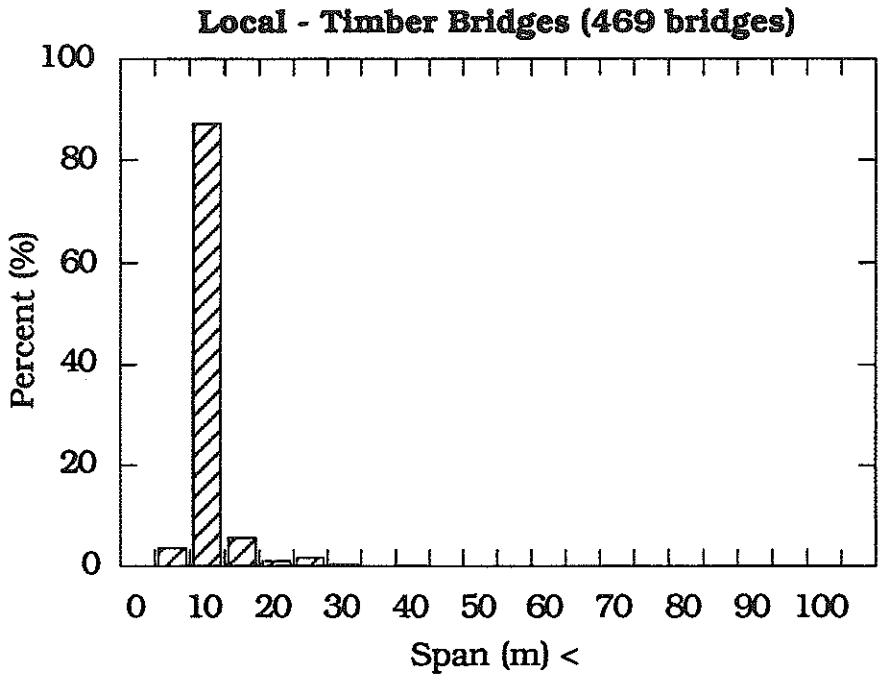
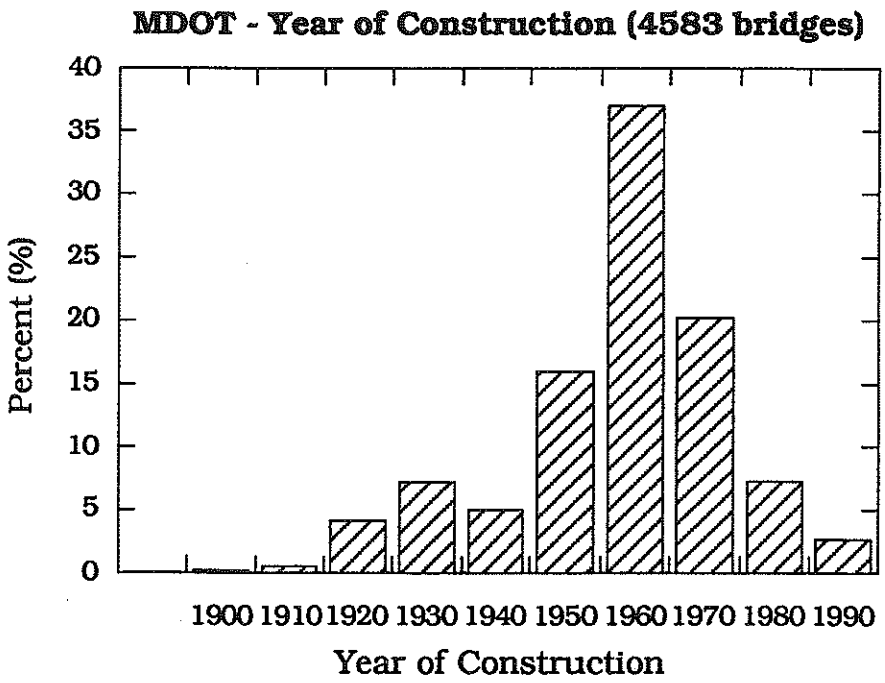


Fig. 3-3e. Span Length for Timber Bridges.



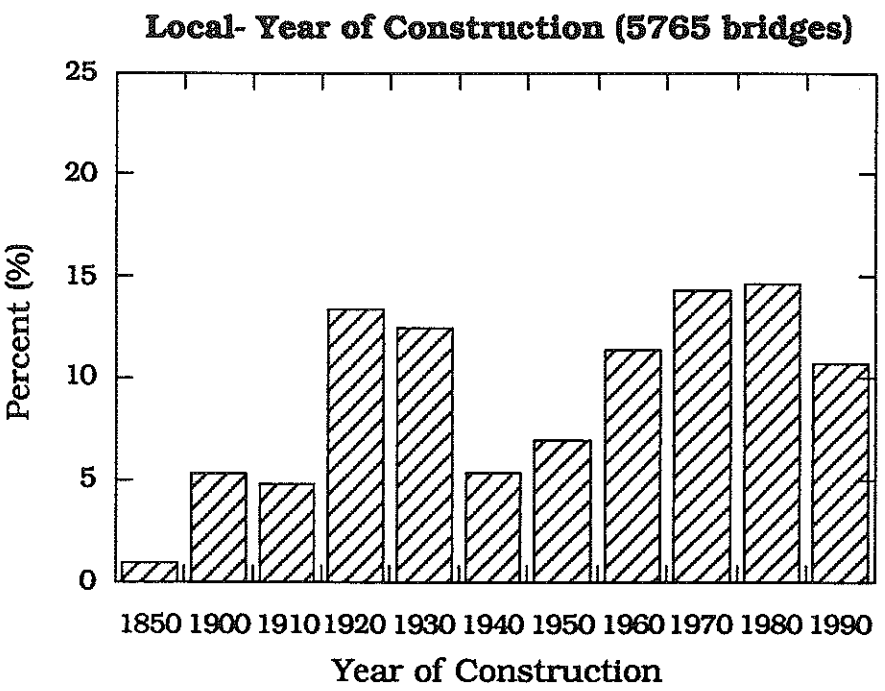
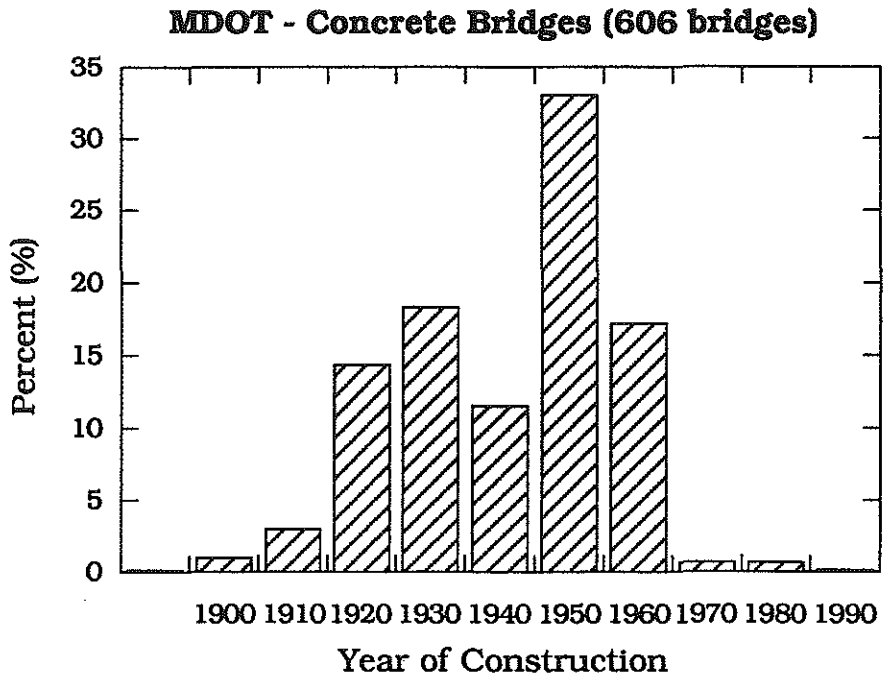


Fig. 3-4a. Year of Construction



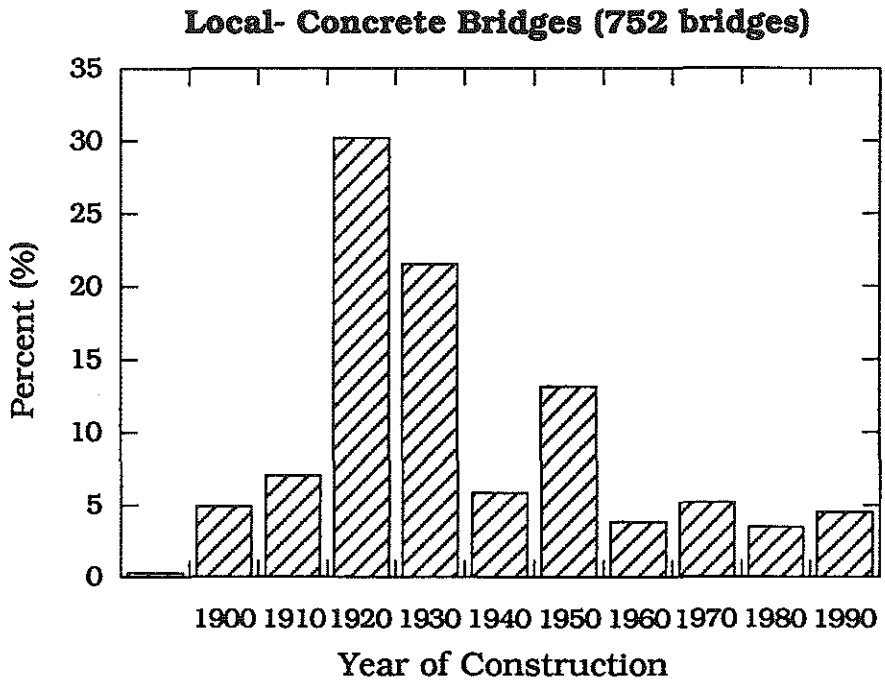
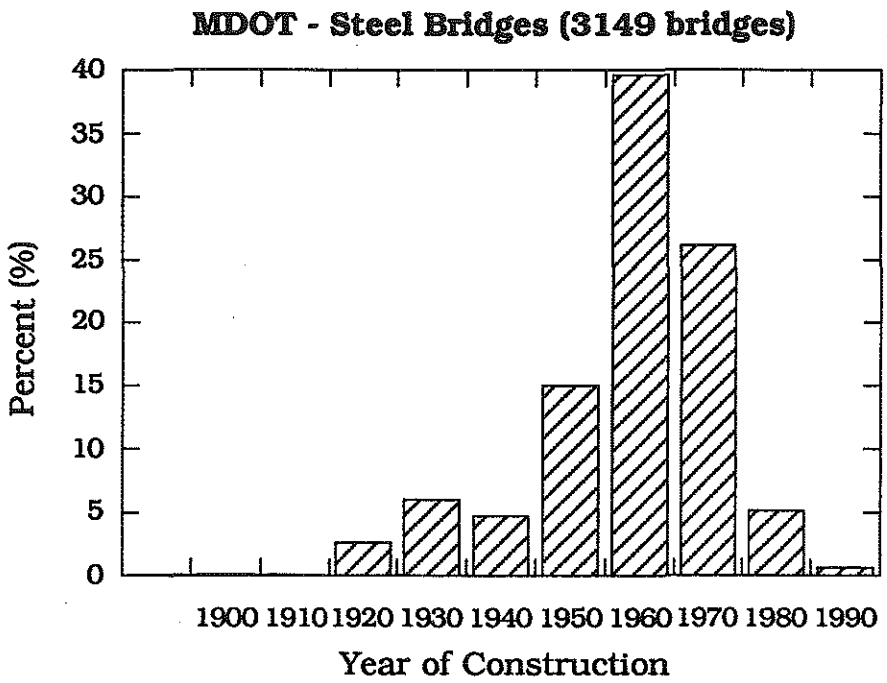


Fig. 3-4b. Year of Construction for Concrete Bridges



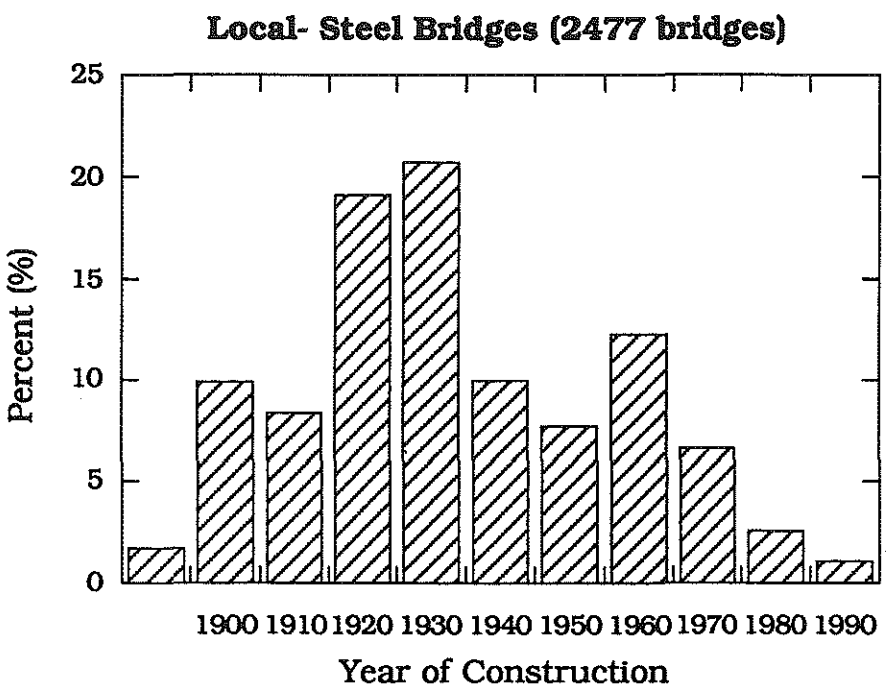
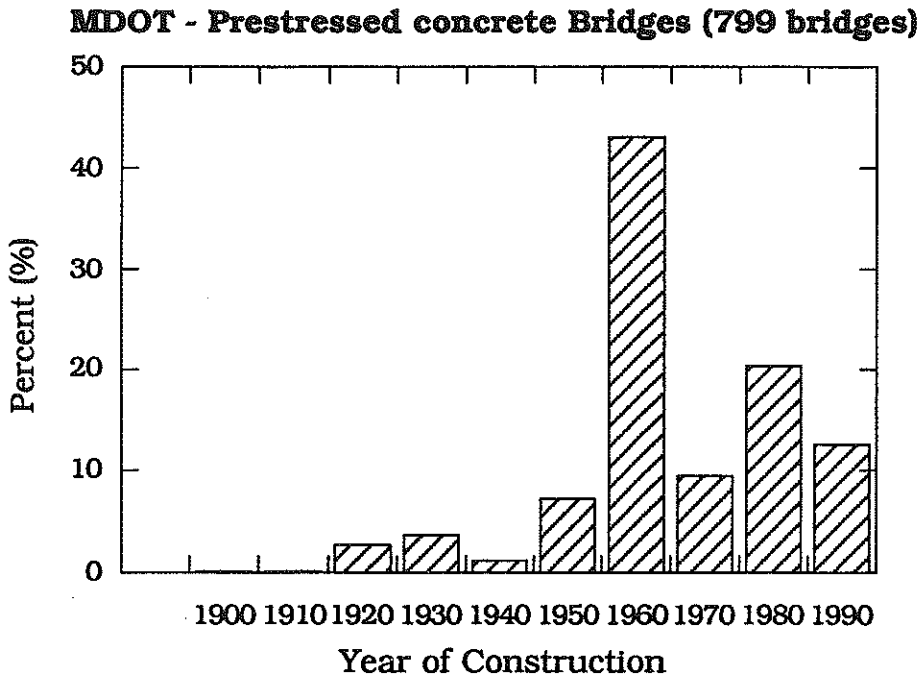


Fig. 3-4c. Year of Construction for Steel Bridges



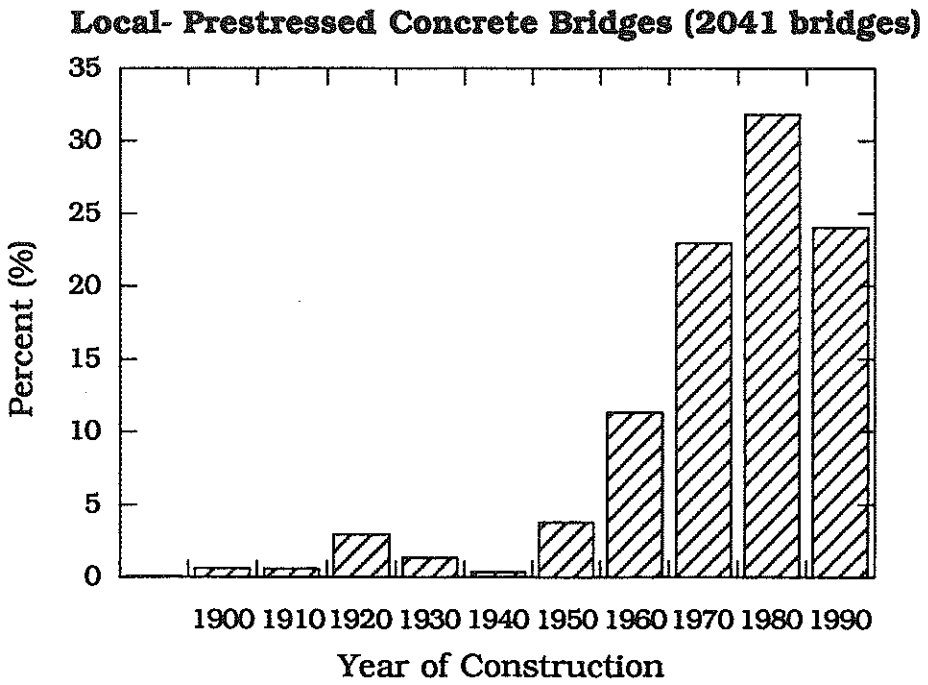
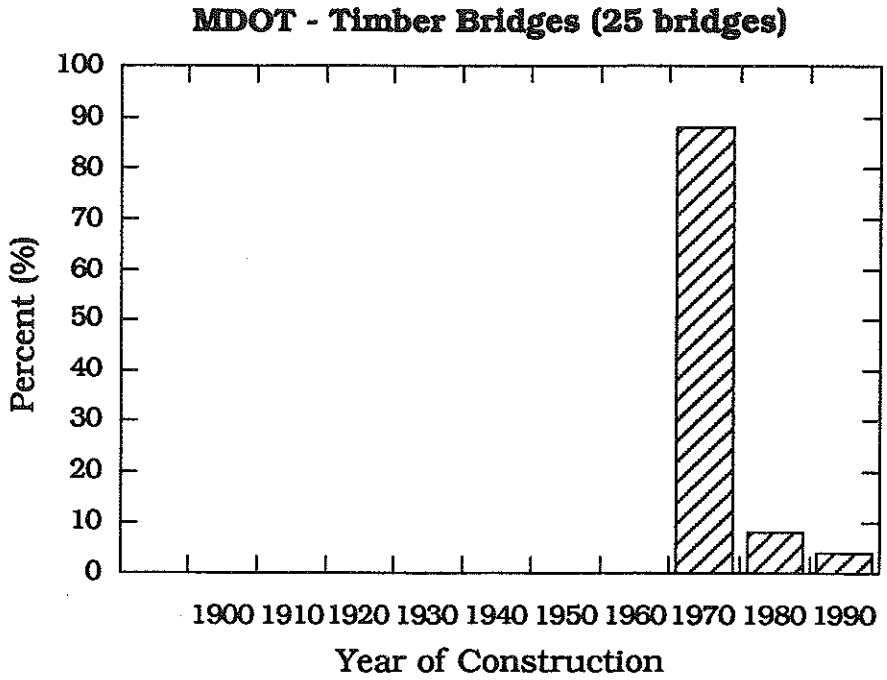


Fig. 3-4d. Year of Construction for Prestressed Concrete Bridges



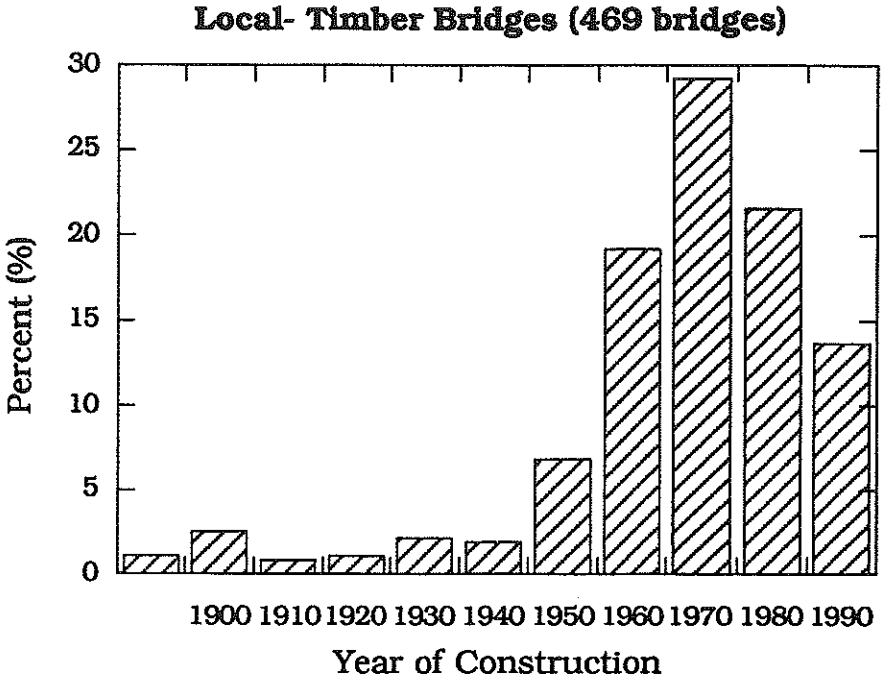
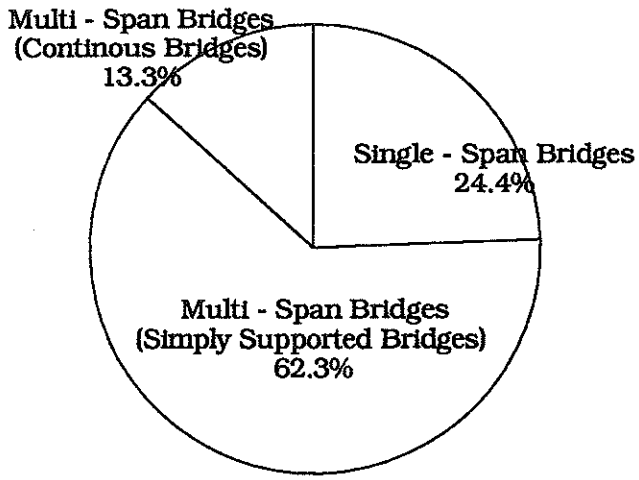


Fig. 3-4e. Year of Construction for Timber Bridges

MDOT Number of Spans (4578 bridges)



Local Number of Spans (5753 bridges)

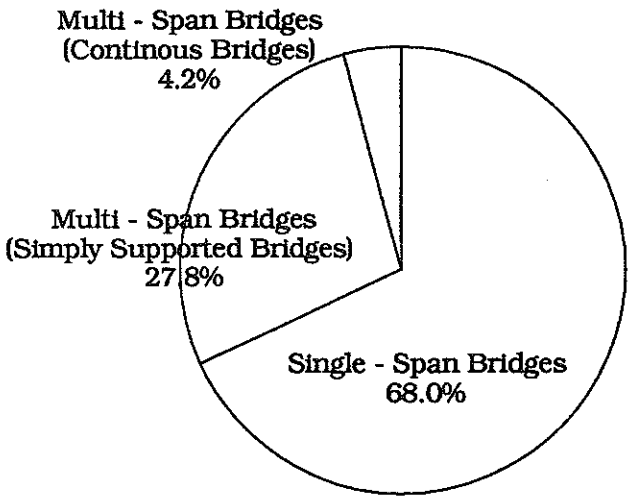
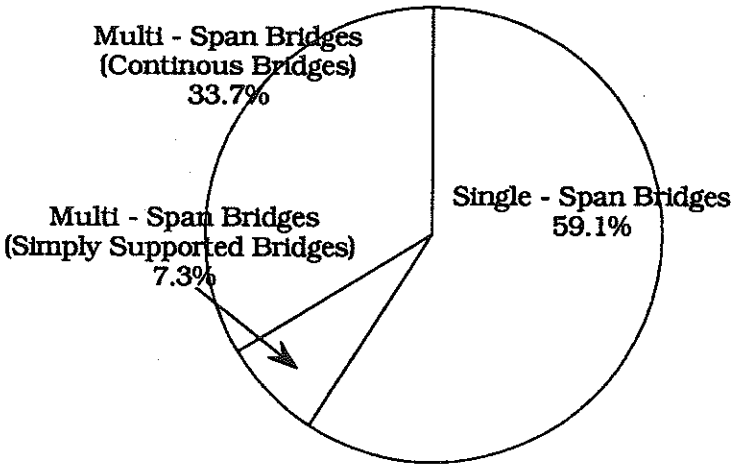


Fig. 3-5a. Number of Spans

MDOT Concrete Bridges (606 bridges)



Local Concrete Bridges (750 bridges)

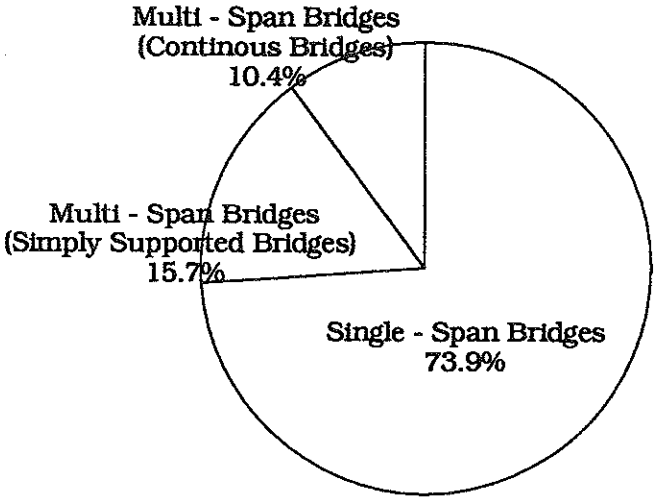
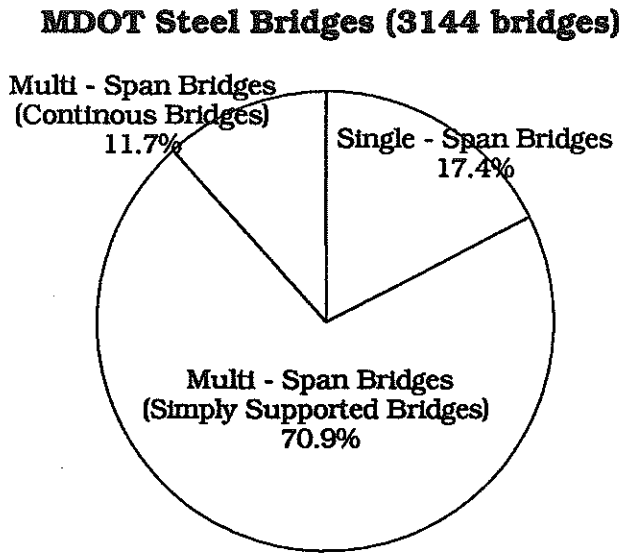


Fig. 3-5b. Number of Spans for Concrete Bridges



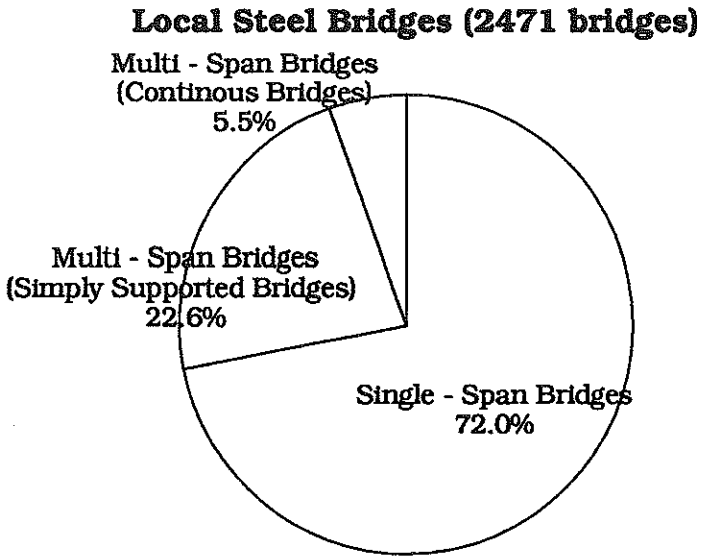
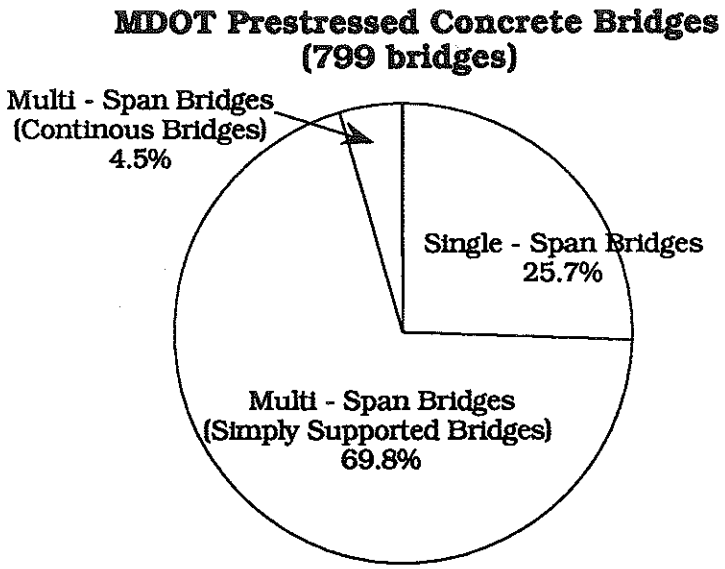


Fig. 3-5c. Number of Spans for Steel Bridges



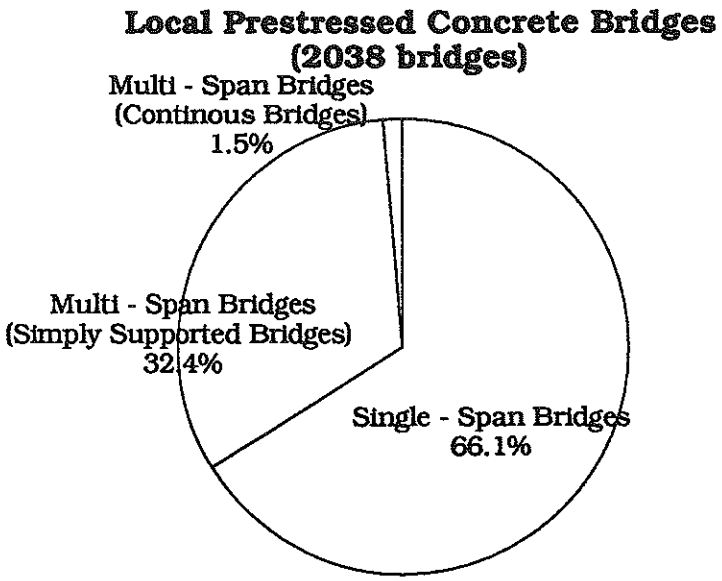
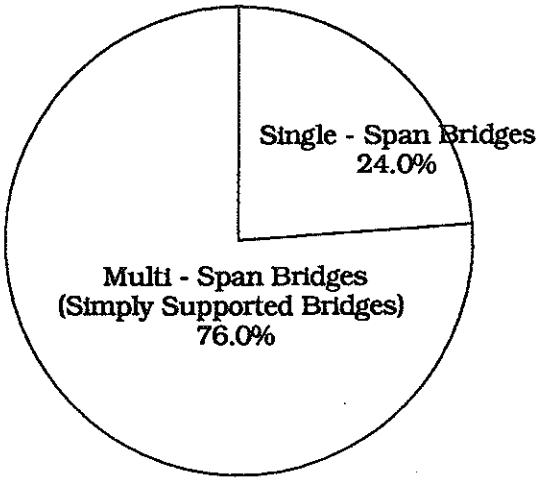


Fig. 3-5d. Number of Spans for Prestressed Concrete Bridges

MDOT Timber Bridges (25 bridges)



Local Timber Bridges (469 bridges)

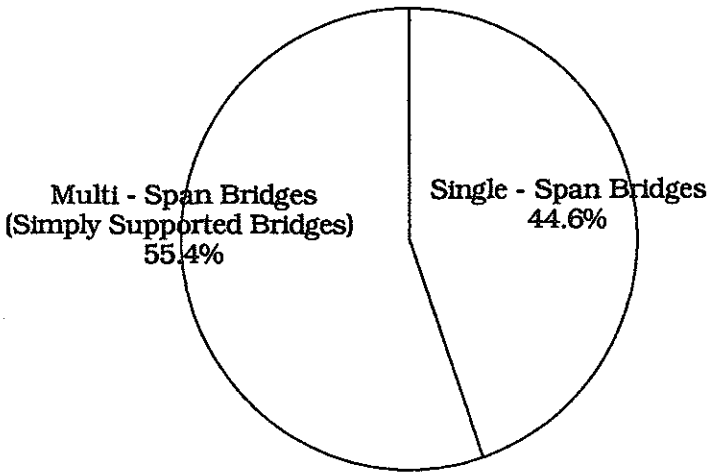
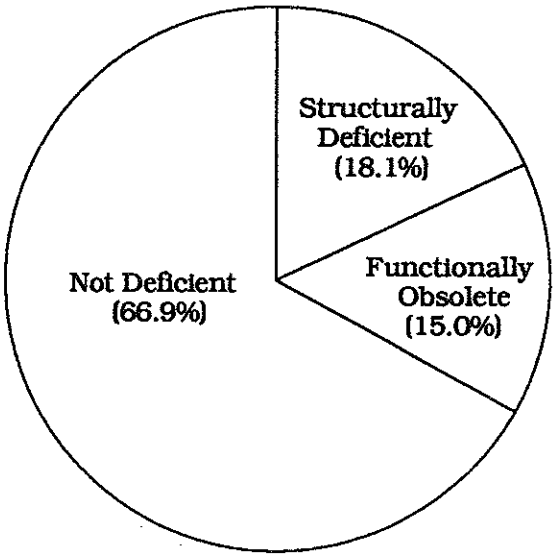


Fig. 3-5e. Number of Spans for Timber Bridges

Structurally Deficient / Functionally Obsolete
MDOT (4602 Bridges)



Structurally Deficient / Functionally Obsolete
Local (5765 Bridges)

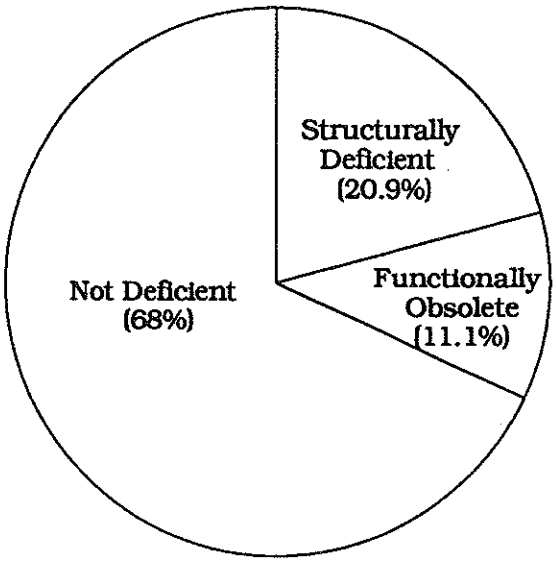


Fig. 3-6. All Deficient/Obsolete Bridges.

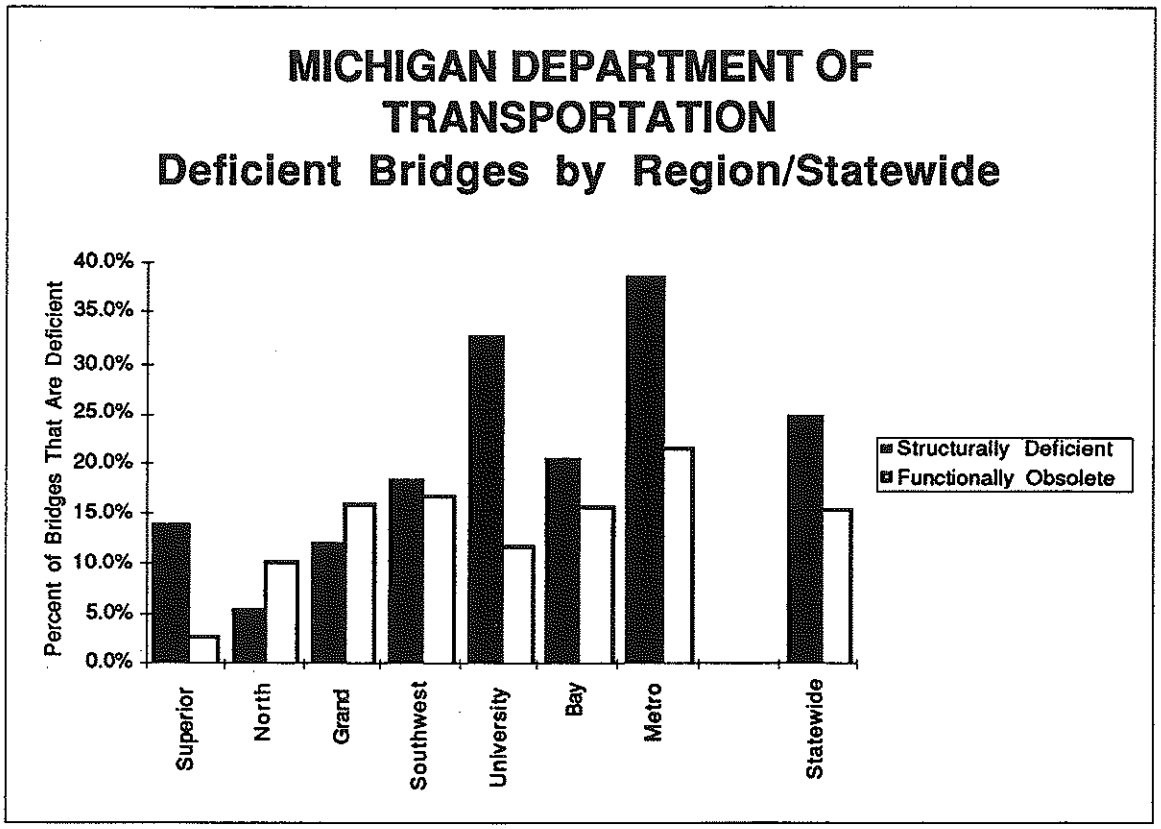
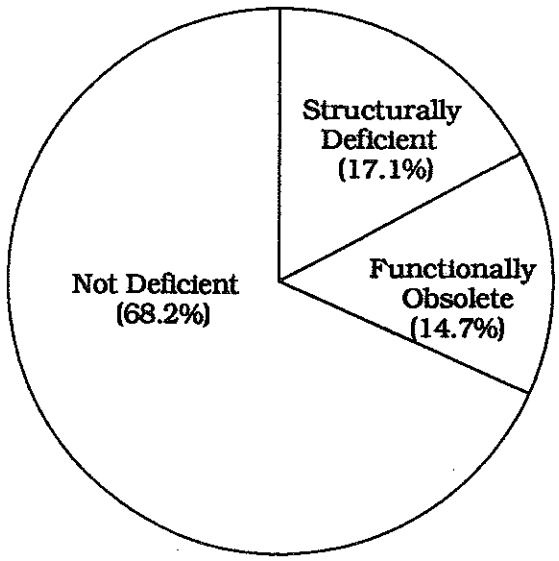


Fig. 3-7. Deficient Bridges by Region/Statewide.

MDOT Concrete Bridges (607 Bridges)



Local Concrete Bridges (745 Bridges)

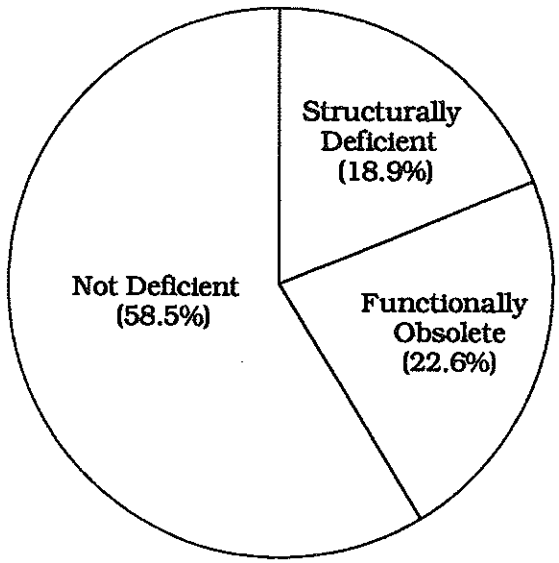
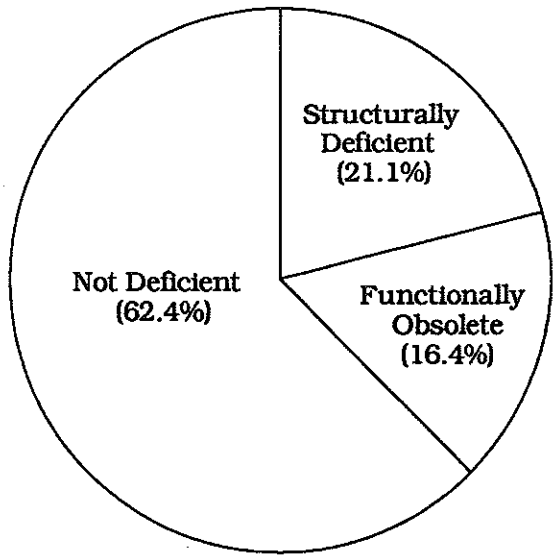


Figure 3-8. Deficient/Obsolete Concrete Bridges

MDOT Steel Bridges (3140 Bridges)



Local Steel Bridges (2441 Bridges)

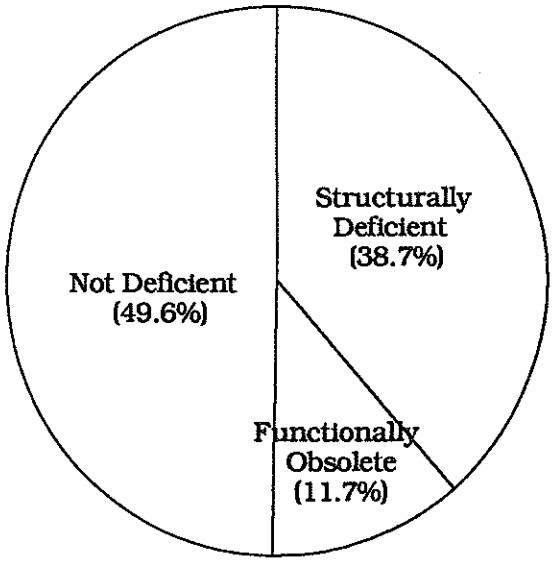
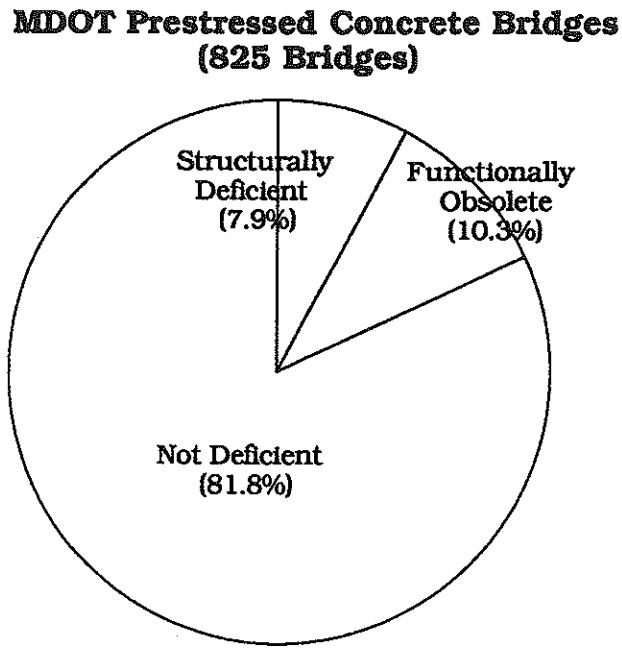


Figure 3-9. Deficient/Obsolete Concrete Bridges



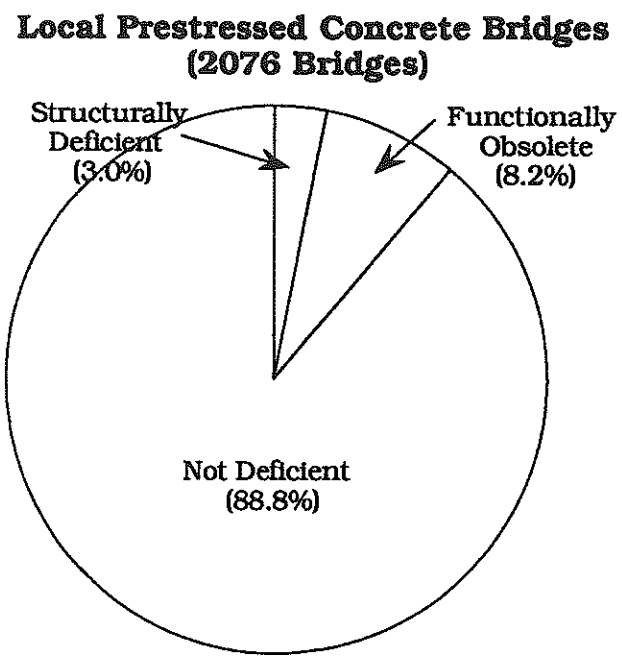
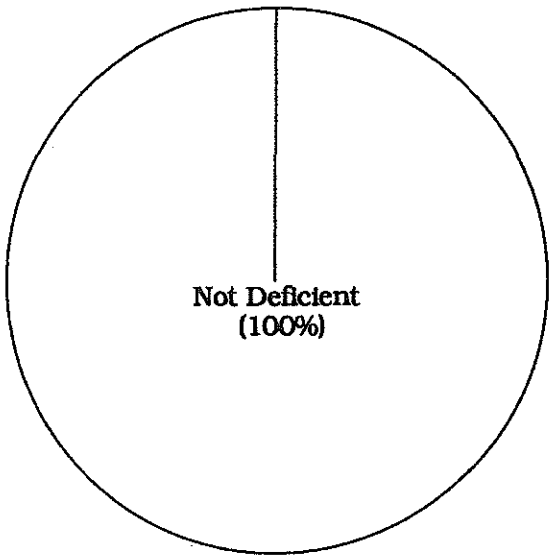


Figure 3-10. Deficient/Obsolete Prestressed Concrete Bridges

MDOT Timber Bridges (25 Bridges)



Local Timber Bridges (476 Bridges)

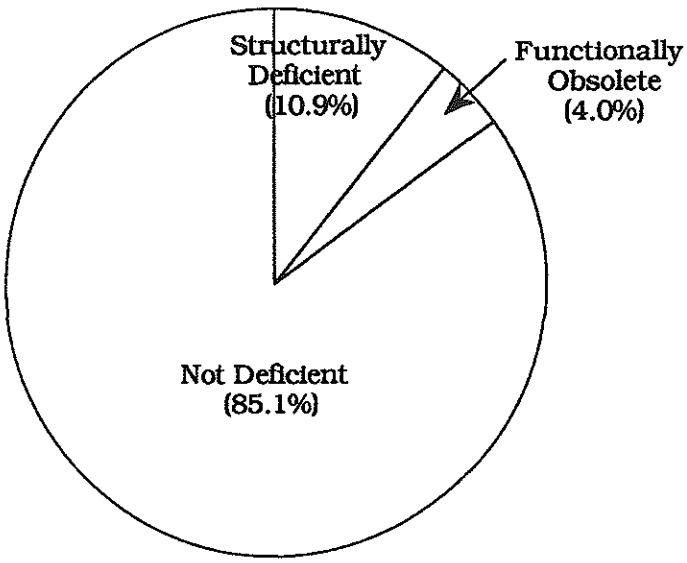
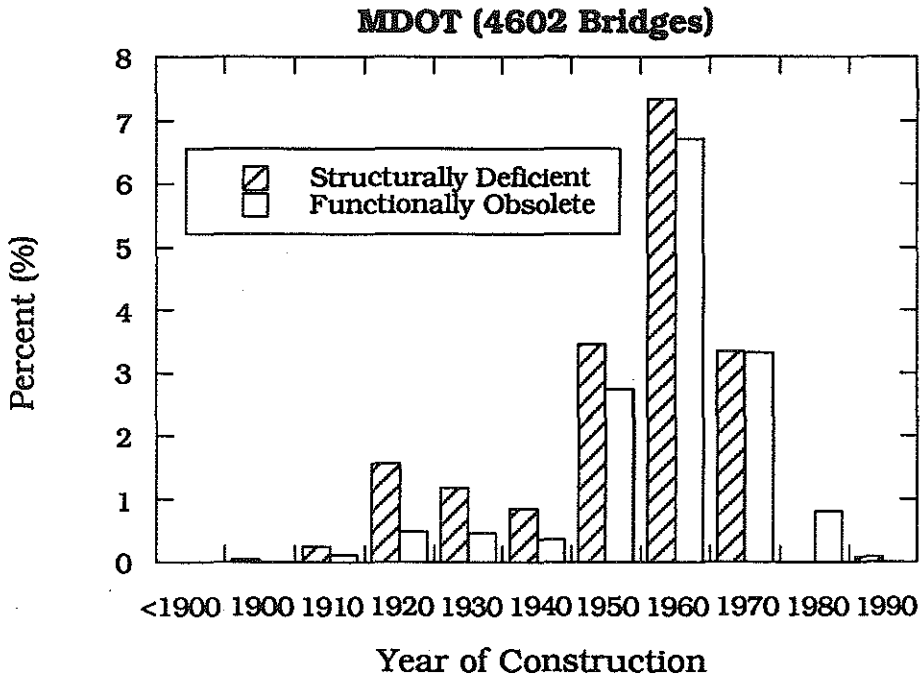


Figure 3-11. Deficient/Obsolete Timber Bridges



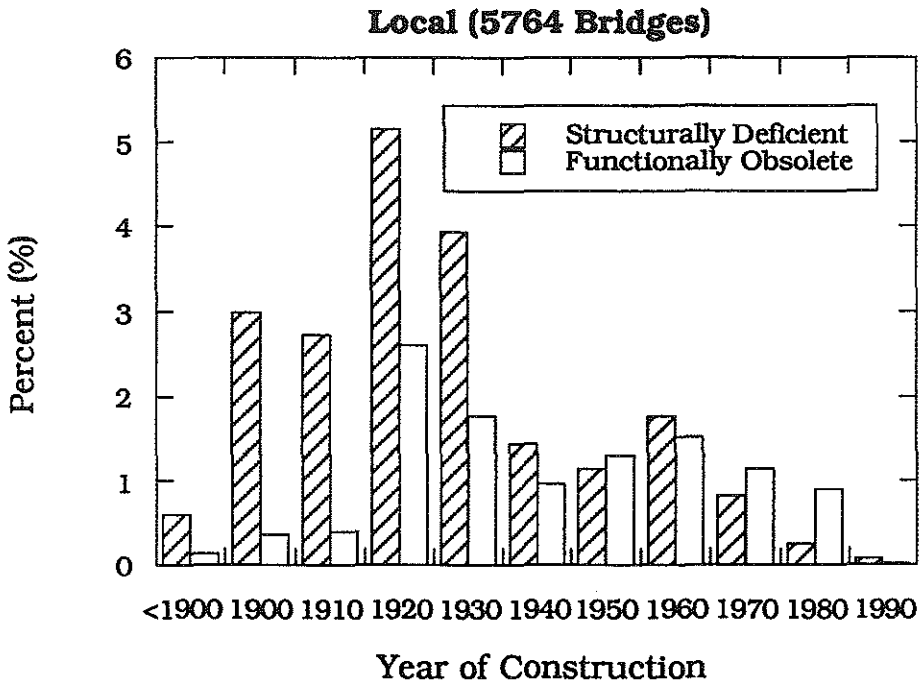


Figure 3-12. Age of All Deficient/Obsolete Bridges

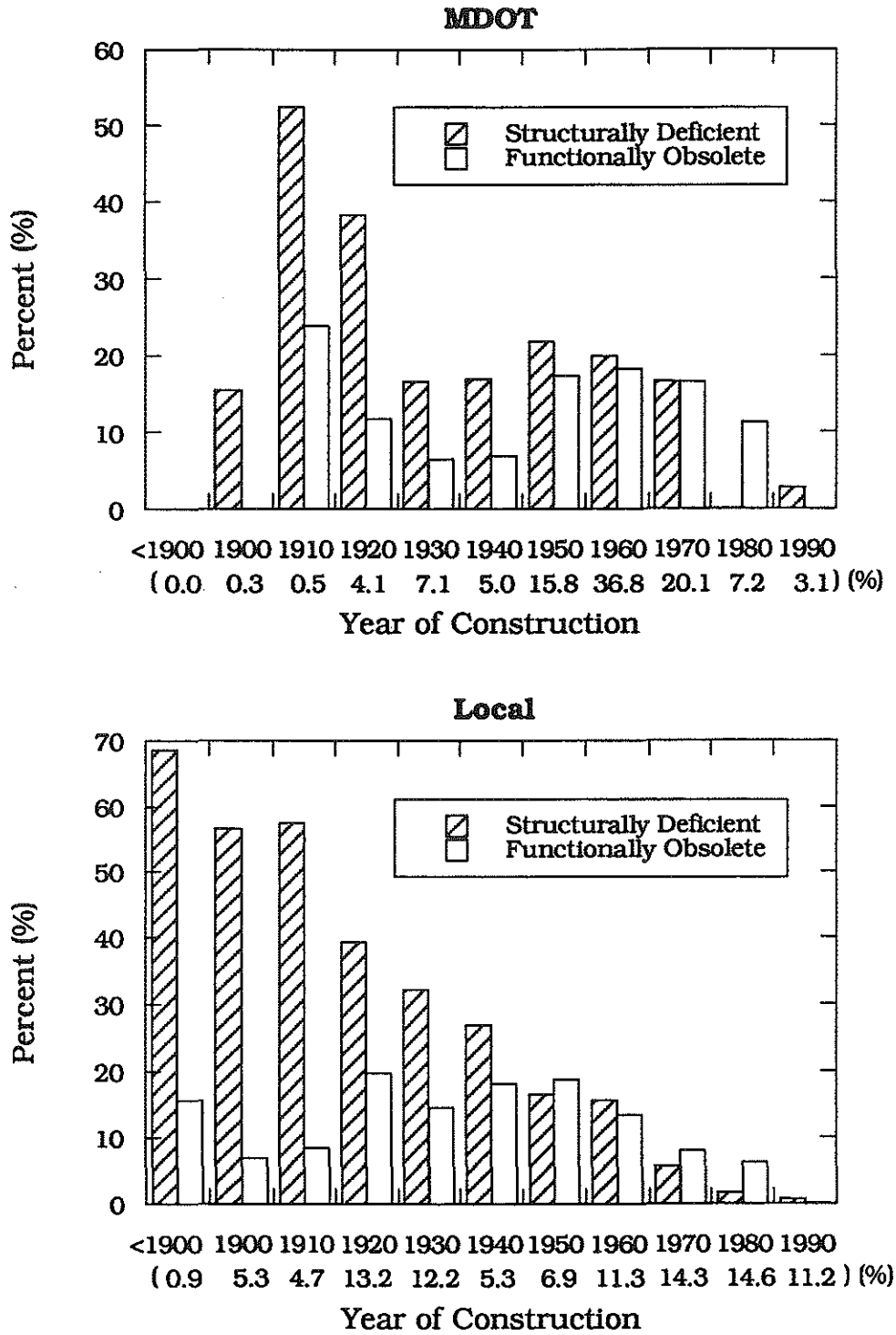
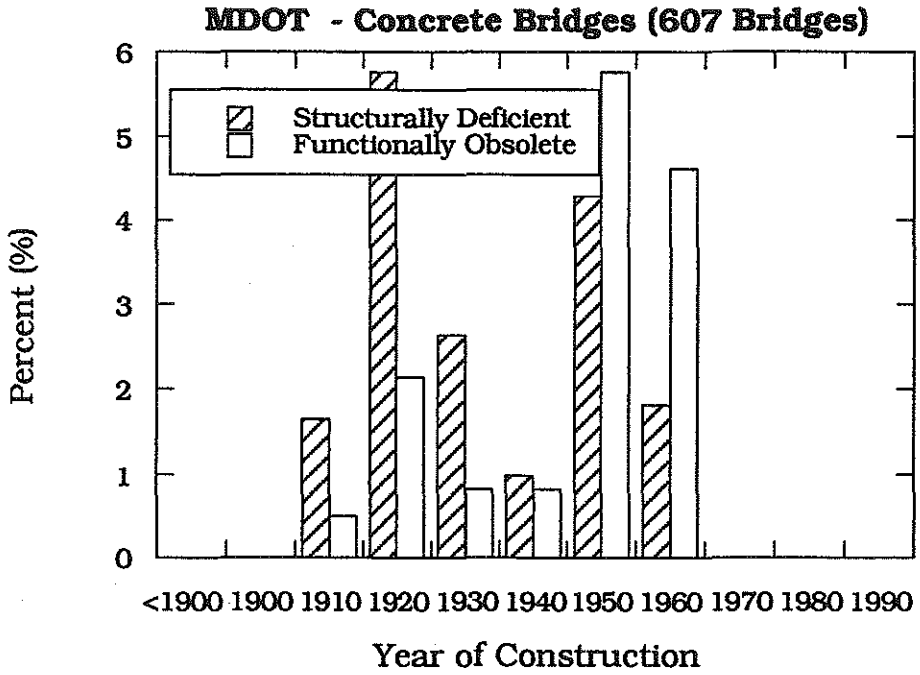


Figure 3-13. Percent of Deficient/Obsolete Bridges in an Age Category



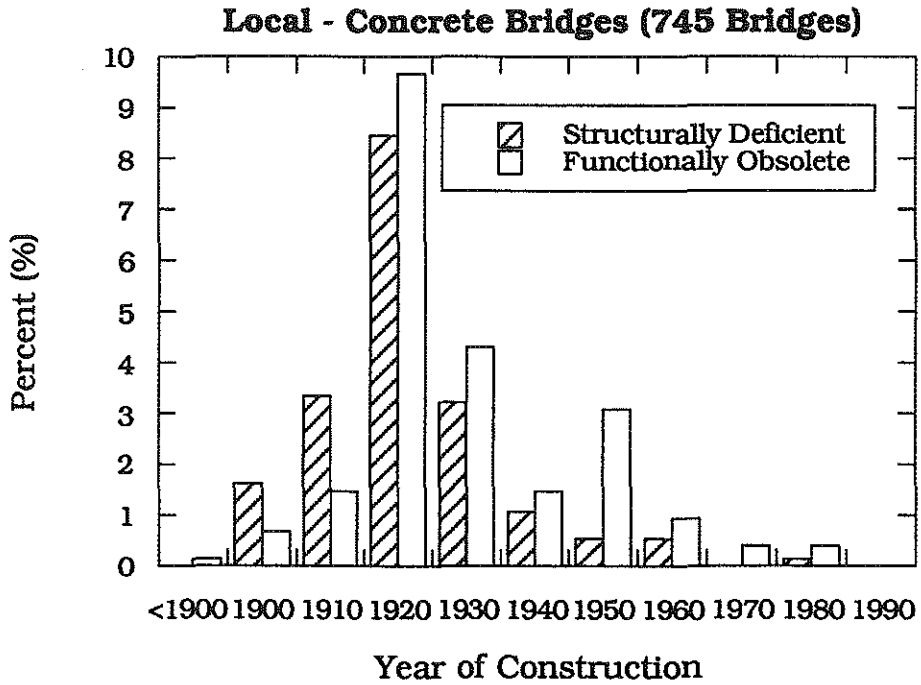
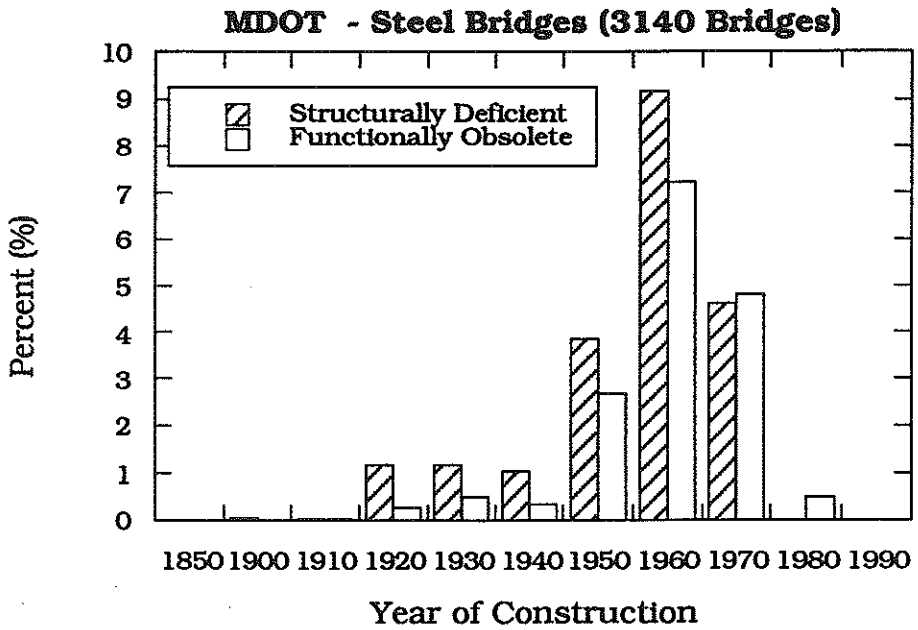


Figure 3-14. Age of Deficient/Obsolete Concrete Bridges



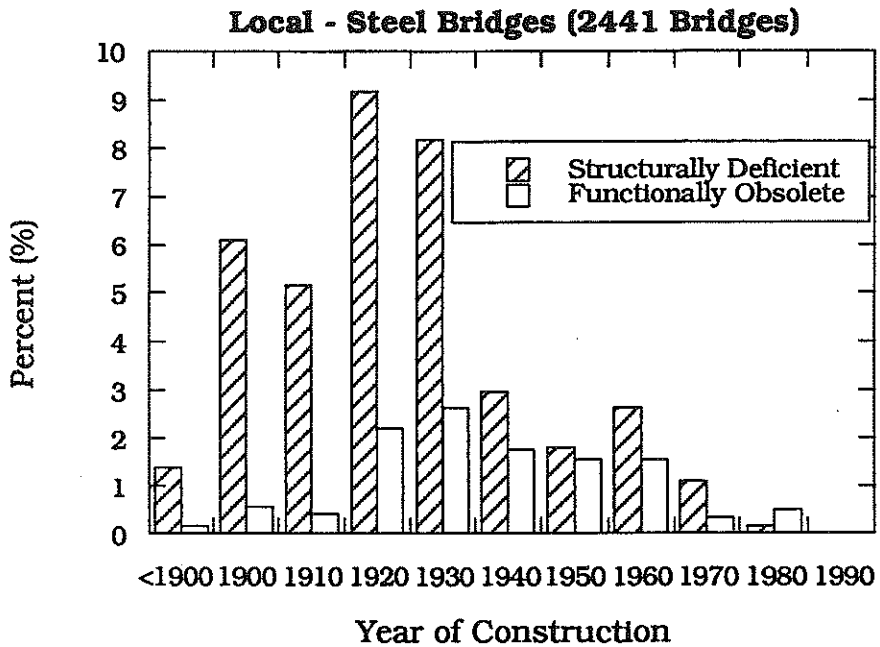
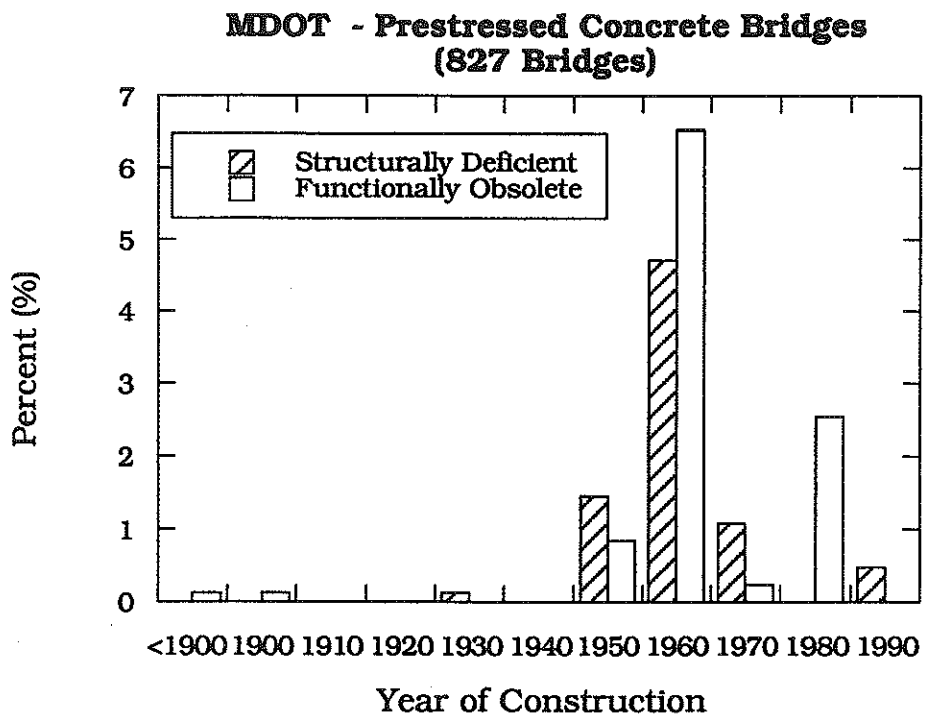


Figure 3-15. Age of Deficient/Obsolete Steel Bridges



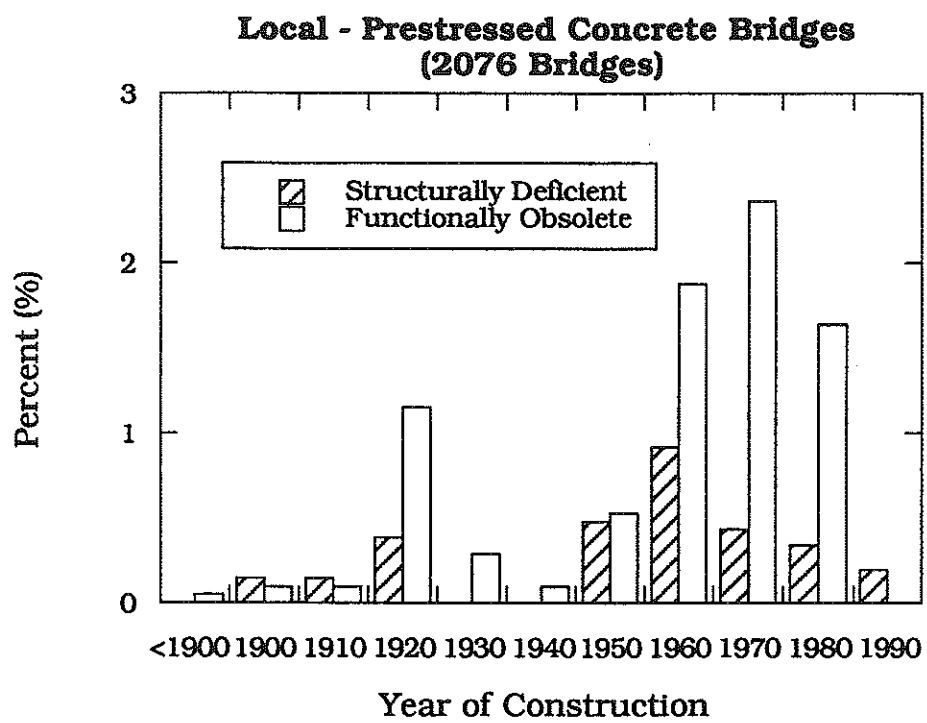
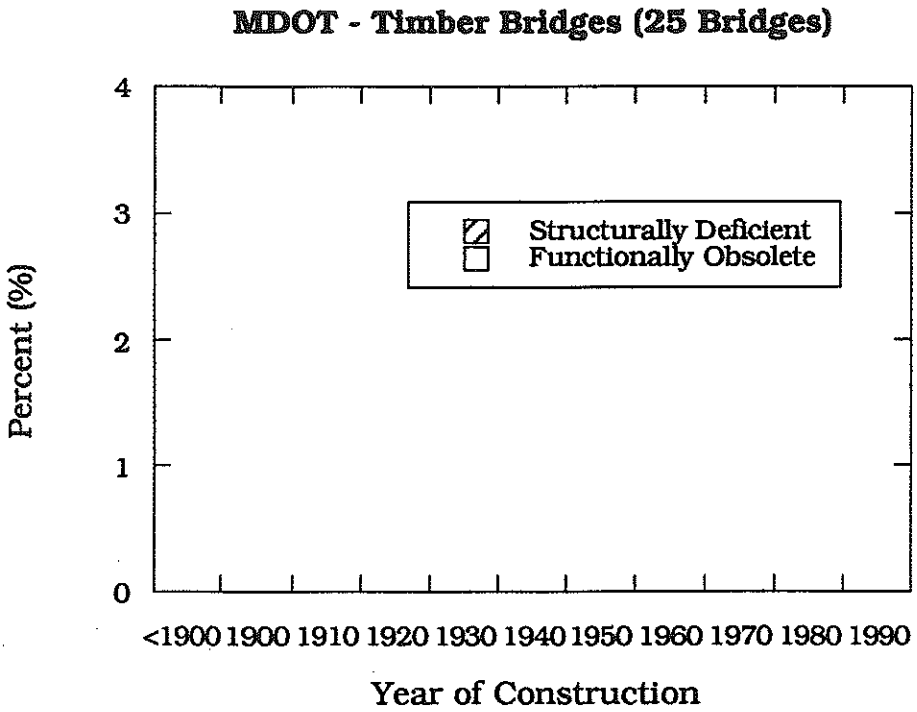


Figure 3-16. Age of Deficient/Obsolete Prestressed Concrete Bridges



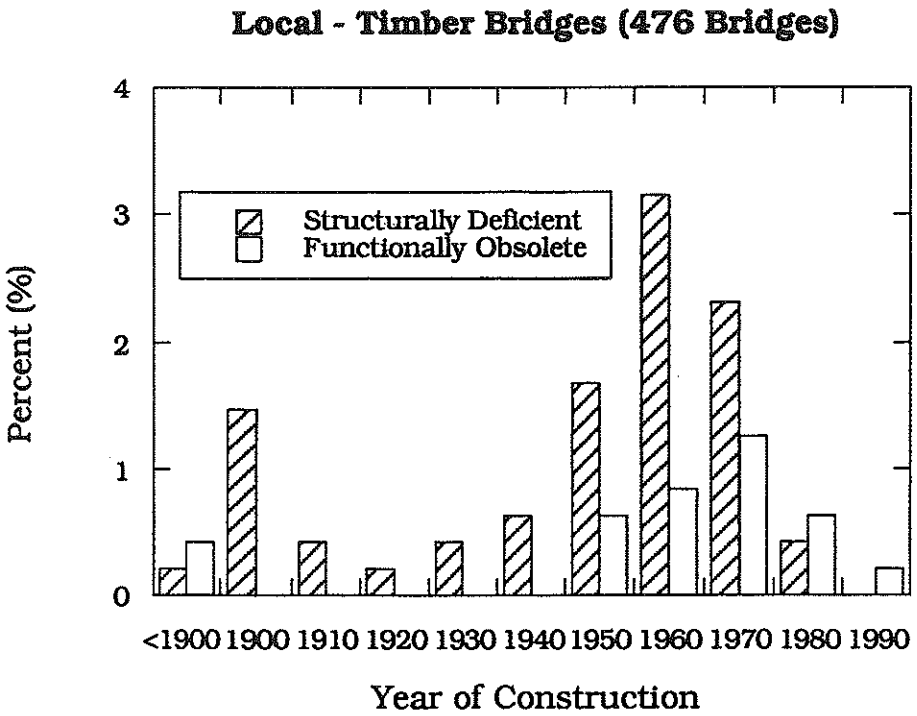


Figure 3-17. Age of Deficient/Obsolete Timber Bridges

Table 3-7a. Condition of Bridges in Michigan

	MDOT	Local	All
Not Deficient	3080	3920	7000
Structurally Deficient	833	1203	2036
Functionally Obsolete	689	642	1331
Total	4602	5765	10367

Table 3-7b. Condition Bridges in Michigan (MDOT)

	Conc.	Steel	PS	Timber
Not Deficient	414	1961	675	25
Structurally Deficient	104	664	65	0
Functionally Obsolete	89	515	85	0
Total	607	3140	825	25

Table 3-7c. Condition of Bridges in Michigan (Local)

	Conc.	Steel	PS	Timber
Not Deficient	436	1212	1843	405
Structurally Deficient	141	944	63	52
Functionally Obsolete	168	285	170	19
Total	745	2441	2076	476

Table 3-7d. Condition of Bridges in Michigan by Age (MDOT)

	Not Deficient	Structurally Deficient	Functionally Obsolete	All
<1900	2	0	0	2
>1900	11	2	0	13
1910	5	11	5	21
1920	94	72	22	188
1930	251	54	21	326
1940	175	39	16	230
1950	443	159	126	728
1960	1047	338	309	1694
1970	619	154	153	926
1980	293	0	37	330
1990	140	4	0	144
			Total	4602

Table 3-7e. Condition of Bridges in Michigan by Age (Local)

	Not Deficient	Structurally Deficient	Functionally Obsolete	All
<1900	8	35	8	51
>1900	111	172	21	304
1910	93	157	23	273
1920	312	297	150	759
1930	375	226	102	703
1940	169	83	56	308
1950	259	66	75	400
1960	463	102	88	653
1970	711	47	66	824
1980	775	14	52	841
1990	643	4	1	648
			Total	5764

Table 3-8. Structurally Deficient MDOT Bridges.

Decade Built	Steel Girder	Reinforced Concrete	Prestressed Concrete
1920	47%	40%	*
1930	20%	15%	*
1940	21%	9%	*
1950	27%	13%	25%
1960	23%	12%	12%
1970	0	*	13%
1980	0	*	0%
1990	0	*	4%

*No bridges built by MDOT during this decade.

Based on information from the 1997 Bridge Management Database in the preceding figures and tables, the following observations can be made regarding MDOT bridges:

- MDOT administers approximately 4600 total bridges.
- 32% (1500) of MDOT's bridges cross waterways.
- Approximately 69% of MDOT's bridges are steel girder, 17% prestressed concrete, and 13% reinforced concrete.
- The use of timber is limited. There are only 25 timber bridges owned by MDOT (0.5%), and only one of these is on the trunkline. The reasons for this are discussed in section 7.4.
- 18% of MDOT's bridges are classified as structurally deficient and 15% are functionally obsolete. Note that such a classification, however, does not mean that the bridge is unable to carry the full legal load.
- Very few, approximately 0.4%, of MDOT's bridges are posted with a load restriction (i.e. the structure cannot carry the full legal load).
- The percent of all MDOT bridges rated structurally deficient by material and age is given in Table 3-8. Based on this information, it seems that steel structures deteriorate faster than concrete structures.

- Referring to Figure 3-4a, approximately 75% of MDOT bridges were built between 1950-1970, and 35% were built in the 1960's. New bridge construction has since tapered sharply, and is now below the 1920's level; approximately 3% of MDOT's bridges were built since 1990.

- Approximately 10% of MDOT's bridges lie within the City of Detroit, which holds 11% of Michigan's population. 19% of MDOT's bridges are contained in Wayne county, which holds about 22% of Michigan's population. The actual numbers are given in Table 3-7.

3.2 AASHTO, FHWA, State and Local Roles

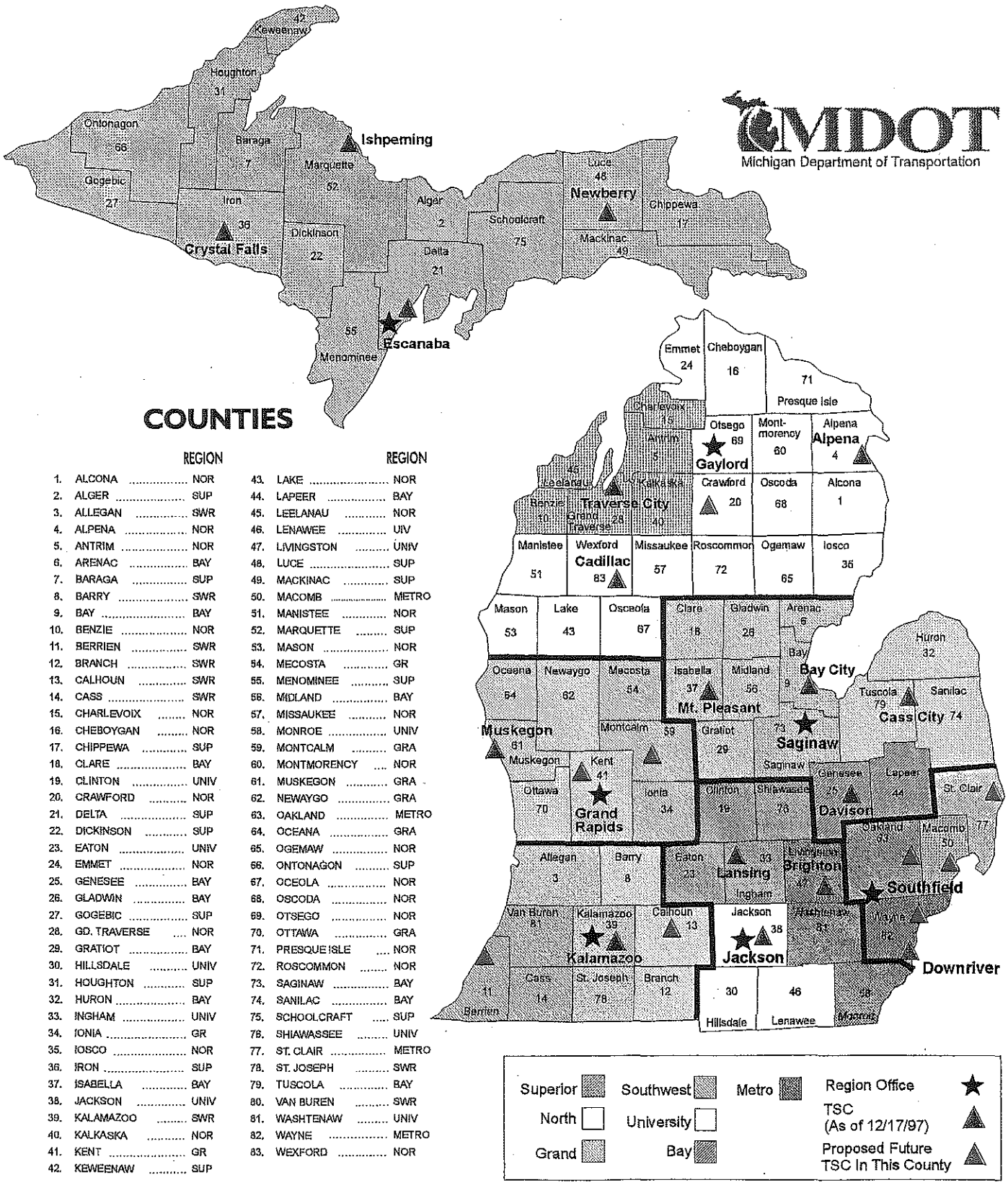
The American Association of State and Highway Transportation Officials (AASHTO) provides specifications and guides, identifies and prioritizes research needs, and provides research funding through the National Cooperative Highway Research Program (NCHRP). See section 11.3 for more detail.

The Federal Highway Administration (FHWA) provides funding for bridge related projects including design, repair, rehabilitation and replacement. MDOT must follow FHWA procedures (inspection, specifications and other regulations). FHWA has offices located in Lansing.

Through MDOT, the state develops goals, an overall strategy to obtain these goals, and a bridge management plan on the statewide trunkline system. To achieve its statewide goals, referred to as network level goals, MDOT has divided the state into seven management Regions, and each administers several Transportation Service Centers (TSC's). These are shown in Fig. 3-6. TSC administrators determine what is needed, in terms of bridge maintenance, rehabilitation, repair, or replacement, to best conform to the statewide strategy. The central administration at MDOT in Lansing monitors these Regional needs and annual program (i.e. planned work) to insure MDOT's network level goals are effectively met.

Through the Regional TSC's, MDOT is responsible only for bridges and roads owned by the state. Local bridges are those owned not by the state but by a city, county, or a private owner, and are thus not the responsibility of MDOT to maintain. However, MDOT is responsible to maintain a statewide bridge management database. Local agencies and cities are required to submit bi-annual bridge inspection and evaluation reports to MDOT. MDOT annually reports the condition of Michigan bridges to the FHWA.

M·DOT Regions and Transportation Service Centers



COUNTIES

		REGION			REGION
1.	ALCONA	NOR	43.	LAKE	NOR
2.	ALGER	SUP	44.	LAPEER	BAY
3.	ALLEGAN	SWR	45.	LEELANAU	NOR
4.	ALPENA	NOR	46.	LENAWEE	UIV
5.	ANTRIM	NOR	47.	LIVINGSTON	UNIV
6.	ARENAC	BAY	48.	LUCE	SUP
7.	BARAGA	SUP	49.	MACKINAC	SUP
8.	BARRY	SWR	50.	MACOMB	METRO
9.	BAY	BAY	51.	MANISTEE	NOR
10.	BENZIE	NOR	52.	MARQUETTE	SUP
11.	BERRIEN	SWR	53.	MASON	NOR
12.	BRANCH	SWR	54.	MECOSTA	GR
13.	CALHOUN	SWR	55.	MENOMINEE	SUP
14.	CASS	SWR	56.	MIDLAND	BAY
15.	CHARLEVOIX	NOR	57.	MISSAUKEE	NOR
16.	CHEBOYGAN	NOR	58.	MONROE	UNIV
17.	CHIPPEWA	SUP	59.	MONTCALM	GRA
18.	CLARE	BAY	60.	MONTMORENCY	NOR
19.	CLINTON	UNIV	61.	MUSKEGON	GRA
20.	CRAWFORD	NOR	62.	NEWAYGO	GRA
21.	DELTA	SUP	63.	OAKLAND	METRO
22.	DICKINSON	SUP	64.	OCEANA	GRA
23.	EATON	UNIV	65.	OGEMAW	NOR
24.	EMMET	NOR	66.	ONTONAGON	SUP
25.	GENESEE	BAY	67.	OCEOLA	NOR
26.	GLADWIN	BAY	68.	OSCODA	NOR
27.	GOGEBIC	SUP	69.	OTSEGO	NOR
28.	GD. TRAVERSE	NOR	70.	OTTAWA	GRA
29.	GRATIOT	BAY	71.	PRESQUE ISLE	NOR
30.	HILLSDALE	UNIV	72.	ROSCOMMON	NOR
31.	HOUGHTON	SUP	73.	SAGINAW	BAY
32.	HURON	BAY	74.	SANILAC	BAY
33.	INGHAM	UNIV	75.	SCHOOLCRAFT	SUP
34.	IONIA	GR	76.	SHIAWASSEE	UNIV
35.	IOSCO	NOR	77.	ST. CLAIR	METRO
36.	IRON	SUP	78.	ST. JOSEPH	SWR
37.	ISABELLA	BAY	79.	TUSCOLA	BAY
38.	JACKSON	UNIV	80.	VAN BUREN	SWR
39.	KALAMAZOO	SWR	81.	WASHTENAW	UNIV
40.	KALKASKA	NOR	82.	WAYNE	METRO
41.	KENT	GR	83.	WEXFORD	NOR
42.	KEWEENAW	SUP			

Fig. 3.18. MDOT Regions and Transportation Service Centers.

4. PLANNING AND PROGRAMMING

4.1 Needs

4.2 Public Input

4.3 Project Development - Improve/Expand

4.4 Surveys - Topological, Hydraulics, Traffic

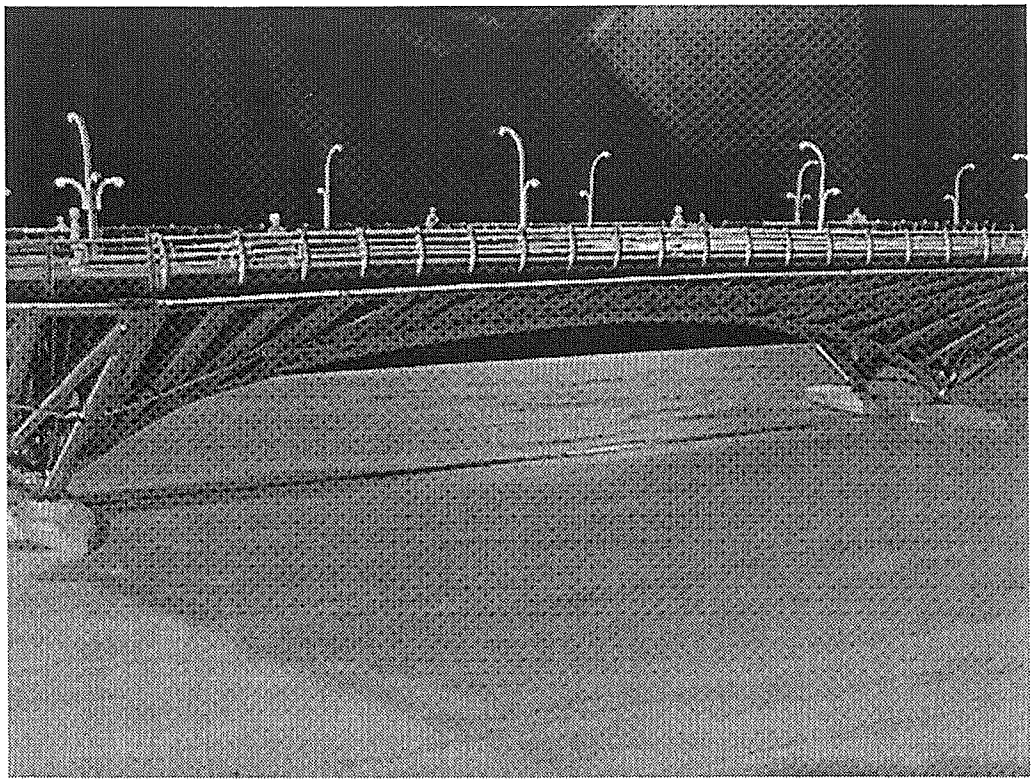
4.5 Geotechnical Investigation

4.6 Environment Impact Statement

4.7 Concepts, Design Alternates, Cost Estimates, and Value Engineering

4.8 Project Report

4.9 Bridge Programs: Preserve



4. PLANNING AND PROGRAMMING

4.1 Needs

The key needs of the public (the customer), legislative members and MDOT are as follows:

- Avoid bridge posting on the interstate highways for legal loads in Michigan.
- Improve the level of service by widening bridges, as well as by removing any load restrictions for the legal loads.
- Improve and/or maintain the overall bridge network conditions.
- Monitor success of the strategy by measuring the key indicators, such as structurally deficient and functionally obsolete bridges.
- Minimize the user delay costs (i.e. minimize traffic delays & use short detours).

To meet these needs, programming is initiated by various sources within MDOT. Needs are specified and serve as sources of assignments for bridge structural work required of the Design Division.

In order to use the available bridge funding effectively, MDOT has supported the use of a computerized system named "Pontis," a tool of the bridge management system (discussed in section 10) to support engineering decisions and prepare annual and five-year bridge preservation/rehabilitation programs. Using Pontis, program managers identify a list of potential projects. The final selection of projects is based upon the output of Pontis and the input of engineers from the areas of planning, bridge management, maintenance, construction, and from the Regions. This multi-disciplinary approach is necessary in order to meet the objectives of the bridge program, and coordinate bridge construction and rehabilitation with other highway work to minimize traffic disruptions.

4.2 Public Input

In preservation projects where bridges are repaired or rehabilitated, the general public has no direct decision-making power, except when historic bridges are involved. However, public input becomes important in the case of expansion projects (where new highways are built), when additional bridges would be added to the infrastructure.

4.3 Project Development - Improve/Expand

For the last decade, MDOT used four general funding categories to describe highway-related expenditures: Preserve, Improve (now called Increased Capacity), Expand, and Preventive Maintenance. In 1997,

MDOT funding categories were changed to more clearly reflect what the public can relate to:

1. Preservation of the existing system. This includes Preventive Maintenance (PM), Preserve, and Increased Capacity (IC) (widening projects). Preventive Maintenance is discussed in section 9 of this Report. Preserve refers to repair work that does not increase traffic capacity, and is discussed further in section 4.9, while Increased Capacity adds traffic lanes to an existing route.

2. New Routes (Expand). New Routes adds additional roads and bridges to the transportation system.

In ascending order of expected period of time until further work is required (fix life), projects aiming at maintaining and/or expanding the life of a structure can be put into the following categories: Preventive Maintenance (PM), Preserve, Increased Capacity (IC) and New Routes. The latter category always has a long fix life, as it is new construction. However, there is nothing to prevent Preserve or IC from also being completely new construction and thus having a long fix life.

IC projects might need a right-of-way (ROW). New Routes always needs ROW, while PM almost never requires ROW.

Maintaining Traffic is an important consideration with PM, Preserve, and IC, especially for the longer construction duration and higher costs associated with Preserve & IC. Maintaining Traffic on IC projects is generally a smaller cost item, since construction is occurring at a new location, although it may cross existing roads and trunklines.

Those scoping future bridge-work should determine what is planned for both the road and bridge in the next 5, 10, and 15 years, that might influence the fix currently being considered. Even if the proposed construction will not match the anticipated future work, the fix should still be planned with full knowledge of that future work.

If one considers Preserve as a base cost of 100, Increased Capacity is often 50 - 150% of this, depending on whether the fix only adds a lane to an existing structure, or completely reconstructs the bridge to the wider width. New Routes are frequently from 100 - 125% of the Preserve option. It generally costs less than IC since larger unit quantities are purchased (better prices) and usually has less Maintaining Traffic costs.

Most often, the design process is relatively shortest for PM, moderate for Preserve, moderate to long for IC, and longest for New Routes (due both to the design complexity and need to buy ROW and obtain environmental permits). Construction duration is fastest for PM (weeks or months), about the same for Preserve and IC (1-2 years), and longest

for New Routes (multiple years). These relative costs and times should of course be considered when scoping work.

4.4 Surveys - Topological, Hydraulics, Traffic

4.4.1. Topological.

The Design Engineer must determine whether sufficient survey data exists for the project. If not, additional survey information, such as a pickup survey, should be requested from the Survey Section. Surveys are typically requested for all major reconstruction jobs (such as bridge widening). On waterway crossings, survey requests should be coordinated with those of the Hydraulics Unit.

4.4.2 Hydraulics.

The Design Engineer obtains hydraulics data from the Hydraulics Unit, which determines required waterway openings and foundation depth needed to resist scour. These data should be requested from the Hydraulics Unit immediately after assignment of the project, in order to assure timely accomplishment. In most cases, the FHWA requires two comparative waterway analyses at all stream crossings where major rehabilitation is proposed, even if the rehabilitation does not involve the waterway. The Department of Environmental Quality (DEQ) also requires existing and proposed hydraulic analyses for waterway crossings, depending on the type of work involved. If the Design Engineer knows the span and bridge cross-section before a survey is conducted, this information should be given to the Hydraulics Unit.

Stream crossings are to be checked to determine whether they are a part of the county drain system, and these findings are to be recorded in the design folder.

4.4.3 Traffic

The Traffic and Safety Division will provide data on traffic counts, accident history and posted speeds, when this information is relevant to design decisions.

4.5 Geotechnical Investigation

The Design Engineer requests needed geotechnical data from the Geotechnical Unit of the Construction and Technology Division. The soil conditions and preferred method of support for the foundations (spread footing, piles, drilled shafts, etc.) must be specified. Also, it should be verified whether piles are required, and if so, the estimated length and minimum penetration.

The document "Requirements for Geotechnical Investigations and Analysis" (1990) discusses site investigation methods, geotechnical report

requirements, work supervision, and methods payment for consulting geotechnical engineers. The following comments are taken from this document.

A complete foundation investigation is needed for the adequate design and construction of bridges and other associated structures. A foundation investigation and analysis shall consist of an adequate program of field sampling, laboratory testing, and engineering analysis and evaluation, with the results presented in report form. The investigation and analysis shall be performed in compliance with the procedures outlined in "Requirements for Geotechnical Investigations and Analysis" and generally accepted principles of good engineering practice.

In the geotechnical investigation, available soils and geologic maps, water well records, reports, publications, aerial photographs, and other reference material which are available to prepare a preliminary boring program, will be made use of. Borings are then selectively located during a field check attended by the foundation analysis engineer.

In general, one soil boring should be ordered for each substructure unit less than 30 m (100') long and two borings for footings longer than 30 m (100'). For retaining walls and sewers, borings should be taken every 100 m (300'). If conditions vary appreciably, additional borings will be required.

The actual location, spacing, and depth of borings, however, are dictated by the topography, geologic conditions, visible soil conditions, and design considerations, and in accordance with the practices set forth within "Requirements for Geotechnical Investigations and Analysis."

All soil data necessary for the selection of the foundation and its design must be obtained, and all material encountered in each boring is carefully examined and visually classified at the time of boring, and a written record (boring log) should be prepared.

It is the responsibility of the geotechnical engineer to determine the equipment needs of each site and to mobilize equipment needed to perform the necessary work.

The geotechnical report is the presentation of all data obtained during the investigation, both in the field and laboratory, all engineering analyses, and recommendations for the use or satisfactory treatment of various soils and soil conditions encountered on the project. A general description of the geology and soils encountered on the project, and a description of the terrain, to include drainage, erosion patterns, high water elevation, flooding, and any other specific conditions which may be of value in the design of bridges, culverts, and other structures, is part of this report. The geotechnical report also includes general

recommendations concerning design and construction procedures for bridges, retaining walls, culverts, and other structures, as applicable.

Bridge Foundation Analysis work consists of bridge foundation analysis, including recommendations for bearing capacities and/or pile capacity. It includes all analyses and computations required to make complete recommendations for a satisfactory foundation to support the proposed loading conditions at each bridge support, such as bearing capacity, settlement, and stability and constructability, as required.

Retaining Structure Analysis work consists of the structural analysis of retaining structures, including recommendations for conventional retaining walls, bridge abutments, bin walls, and drilled-in piers.

4.6 Environment Impact Statement

An Environmental Impact Statement (EIS) is prepared when it is anticipated that a construction project may significantly effect the environment, as required by the National Environmental Policy Act. There are three stages to the EIS issuance process.

A Draft EIS is first prepared. This statement evaluates all practical project alternatives which fulfill the original project's purpose and need. It identifies the impacts of these various alternatives and any proposed mitigation measures to eliminate or minimize those impacts. Impact areas may include: social, agricultural, public lands, wetlands, floodplains, coastal, endangered species, tree removal or clearing, detours, site contamination, noise, air quality, and wild and scenic rivers, among others.

The Final EIS (FEIS) is next issued. It includes input from a public hearing and recommends a course of action. It stipulates commitments to the proposed mitigation measures, and identifies what permits will be required and what proposed wetland creation requirements, if any, will be implemented to compensate for wetlands impact.

Following the FEIS and a comment period, a Record of Decision (ROD) is issued which is the final decision document. After the ROD, the project may proceed to design, right-of-way acquisition, and construction. When the ROD is issued, the requirements and restrictions specified by the document must be carefully observed during the design process. The Project Planning Division processes this statement.

4.7 Concepts, Design Alternates, Cost Estimates, and Value Engineering

There is a standard sequence of events that leads to the completion of a project, which is detailed in section 4.8 and 5.7. Along this path of

events, Concepts, Design Alternatives, Cost Estimates, and Value Engineering occur, which are described below.

4.7.1 Concepts

Every project begins as a design concept. The concept investigates the viability of the project, establishes its scope, and roughly estimates its cost. No detailed engineering calculations or detailed design work is preformed when a concept is generated. Rather, judgement and rules-of-thumb are used, with rough calculations, to establish feasibility. A great deal of information is gathered when forming the concept. Development of the design concept is referred to as the Feasibility Study, and is discussed in section 5.7.

4.7.2 Design Alternates

Fundamental to developing the concept is the investigation of design alternates. Different methods of addressing the design problem are studied, to insure that the best solution is obtained. On a larger level, design alternates may involve adjusting project scope, such as repairing or rehabilitating versus replacing. At a more detailed level, different structural materials or structural types may be investigated, such as the use of continuous or simple spans, or steel versus prestressed concrete. At the very detailed level, specifics are considered, such as bolts versus welds at connections, the types of expansion joints, and other products used on the bridge. The objective in considering design alternates is to obtain the most cost-effective solution that works well.

4.7.3 Cost Estimates

In order to assess the adequacy of a concept or design alternate, cost estimates must be used. As described in section 5.7, cost estimates must accompany the Study, Preliminary Plans, and the Final Plans for the project. The extent of the cost estimate should be commensurate with the level of detail at which the project currently stands. For the Study and Preliminary Plans, rough cost estimates, with only the major components of construction and unit prices, are used. When the Final Plans and Specifications are prepared, a detailed cost estimate of each construction item called for should be used.

4.7.4 Value Engineering

Value Engineering is the systematic application of recognized techniques by a multi-disciplined team(s) which identifies the function of a product or service; establishes a worth for that function; generates alternatives through the use of creative thinking; and provides the needed function, reliably, at the lowest overall cost.

It is a formalized process that is required on larger projects (typically for those with a budget greater than $25 million), and for most projects, the optimum time for value engineering is approximately at 30% of plan development.

Even when not required, as for smaller projects, a designer can use the concept of adjusting the design, including structural concept, materials, construction methods and products used, to optimize a project's efficiency in terms of cost effectiveness and performance. For example, if a product is specified that is only marginally more durable than another, but twice as expensive, it would be wise to investigate the possibility of using the slightly less effective device. The money saved could perhaps be used more effectively on another part of the structure, where there may be a larger cost-performance benefit.

For smaller projects, this process can be formal and numerically rigorous, or informal and intuitive; the choice is left to the designer. One important part of value engineering is the consideration of life-cycle costing, the consideration of costs over the anticipated lifetime of the structure (typically 75 years) rather than the initial cost. Life-cycle cost considerations should be made for projects of all sizes.

4.8 Project Report

Progress reports are submitted at various points in the design process, and are best described through the Program/Project Management System.

P/PMS networks are fundamental in MDOT's approach to program management, from concept to project letting. These networks describe a critical path of tasks that must be completed to finish a project in the design phase. P/PMS and the Design Engineer are responsible for the project from the initial concept (the Study) until the project is let for bids. Once construction starts, the Construction Division and the Critical Path Method take over.

During the design phase, P/PMS is used to track the progress of a project, and to assign responsibility to specific Divisions and individuals for specific project tasks. Although each job is unique and the individual tasks differ, standard procedures have been developed to complete all projects, and these procedures are described in the Preconstruction Process Documentation Manual.

The P/PMS networks consist of two levels. Level 1 (the Summary Network) consists of approximately 16 summary blocks (see Figure 4.1). Each summary block contains a number of detail tasks. Level 2 (the Global Network) is made up of these detail tasks. Accompanying these detail tasks in the Global Network are milestone events. Milestone events serve to monitor the progress of a project; reporting the status of these milestones serves as the Progress Report.

The P/PMS Network Milestones are the following:

Milestone	Reporting Unit
• Highway Steering Committee Concurrence.	(Planning)
• Public Information Meeting.	(Planning)
• Draft Submission to FHWA.	(Planning)
• Public Hearing.	(Planning)
• Dept. Approval of Recommended Alternative.	(Design)
• Final Submission to FHWA.	(Planning)
• Utility Notification.	(Engineering)
• Department Concurrence of Design Scope.	(Design)
• Preliminary ROW Plans Distributed.	(Design)
• Pre-GI Inspection.	(Design)
• Final ROW Plans Distributed.	(Design)
• Grade Inspection.	(Design)
• Utility Meeting.	(Engineering)
• Plan Completion.	(Design)
• Final District Review Complete.	(Design)
• Certification Acceptance.	(Design)
• Project Let.	(Financial)
• Project Awarded.	(Financial)
• Post-Decision Meeting.	(Real Estate)
• ROW Certification.	(Real Estate)

Note that "Engineering" refers to the Engineering Services Unit, not the Design Engineer.

There are approximately 80 - 100 detail tasks and milestones. Managers responsible for completing the actual work for the project concentrate on the Level 2 blocks, while Level 1 tasks are mainly of interest to upper-level management.

The actual number of milestones and tasks depends on the scope of the project. Usually, the Project Manager has the opportunity to refine the network at both levels to make it unique to a specific project. The detail tasks are used to report task progress (start, finish, completion date), to schedule work for various management units and to report labor-hours through the payroll system.

Detailed information about the P/PMS system can be found in the Preconstruction Process Documentation Manual.

PROGRAM/PROJECT MANAGEMENT SYSTEM

(P/PMS)

SUMMARY NETWORK

December, 1992

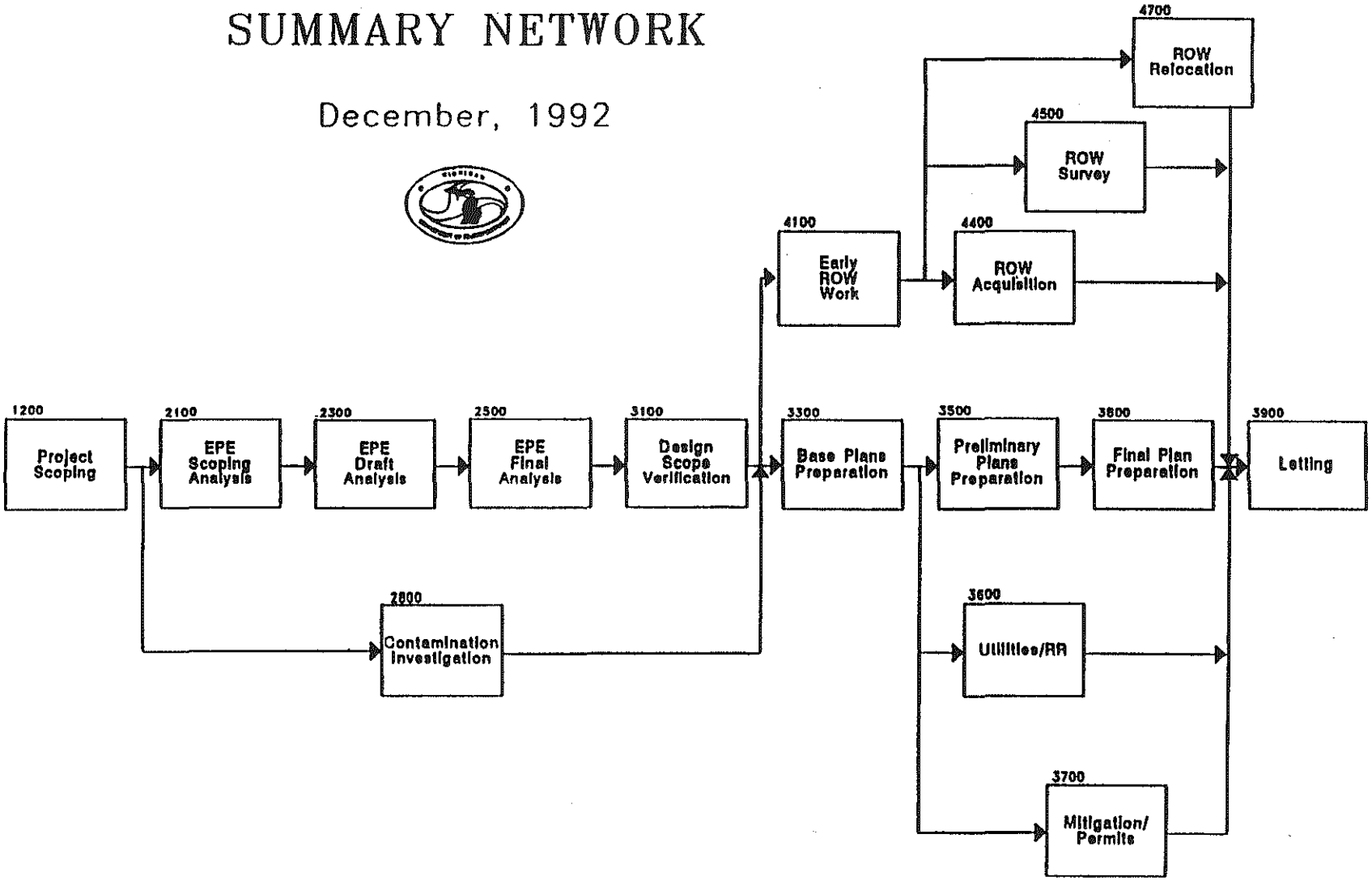


Fig. 4.1. P/PMS Summary Network

4.9 Bridge Programs: Preserve

The Preserve program refers to maintenance work that does not add capacity (i.e. traffic lanes) to an existing bridge; it generally does not require an additional right-of-way (ROW). Most of this work is done on the trunkline.

The Preserve program does not differentiate between National Highway System (NHS) routes and non-NHS routes in terms of design standards, or in terms of MDOT or public processing procedures. This is true for both planning and project development.

During the annual planning process, local authorities help to develop the Statewide Transportation Improvement Program (STIP) and the Transportation Improvement Program (TIP) at the Metropolitan Planning Organization (MPO) level. STIP's are composed of the TIP's from all MPO's and all non-MPO areas of the state. Each region within the state with a population greater than 50,000 is clustered into a MPO. To qualify for federal funds, the MPO must develop and approve a 3-year project and expenditure plan. MDOT jobs using federal funds cannot be let for bids unless they appear on a current STIP/TIP.

If the bridge is not in a MPO, the MDOT Region or System Scoping team meets with the local engineering authority to help guide the development of overall Trunkline plans and projects.

The Critical Bridge Program was developed to repair or replace inadequate bridges in Michigan. It is funded by the State, and also by the federal government through the Highway Bridge Replacement and Rehabilitation Program. The State directly contributes approximately $5 million to the program, and another $30 million is delivered through the Build Michigan Program. Federal funds vary yearly, and are in the range of $30 million. Any local government agency (county road commission, city, or incorporated village) is eligible to apply for funds from this program. Eligible structures must span 6.1 m (20') or more, carry a public road, and be structurally deficient or functionally obsolete for the road it serves. The selection of projects for funding is based on priority ratings established by the Michigan Critical Bridge Advisory Committee. Priorities are based on the physical condition of the structure, the financial resources of the applying agency, and the importance of bridge ("Michigan Local Critical Bridge Program," O'Connor 1998).

5. DESIGN

5. 1 Structures - Types

5.2 Analysis

5.3 Design Criteria

5.4 Construction Requirements

5.5 Computer Aided Design - Bridge Design System

5.6 Computer Aided Drafting

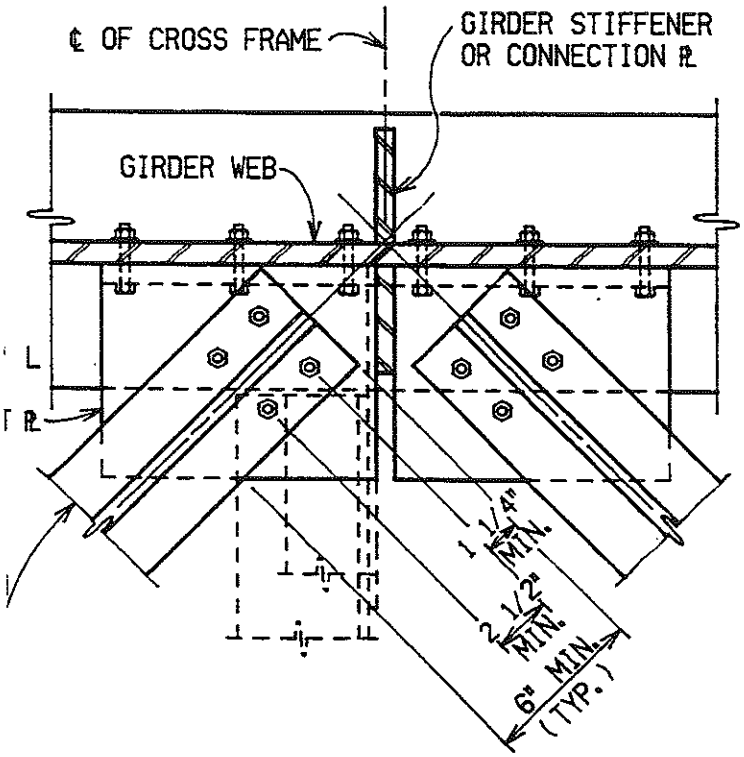
5.7 Contract Plans

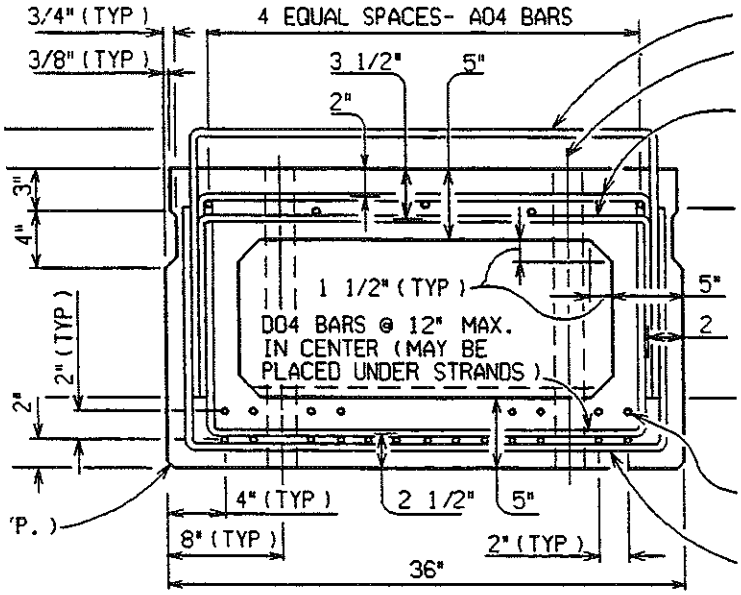
5. 8 Specifications and Cost Estimates

5. 9 Reviews, Advertisement and Letting

5. 10 Bridge Design for Better Maintenance

5.11 Other Design Issues





TYPICAL SECTION - 17" & 21" BEAMS

5. DESIGN

As stated in the AASHTO LRFD Code, the objective of bridge design is to develop a structure that is constructable, safe, and serviceable, with proper attention to inspectability, economy, and aesthetics. At MDOT, beyond safety, the constructability, durability, and ease of maintenance of the bridge are particularly important over the anticipated 75-year lifetime of the structure.

MDOT bridge design is primarily based on the AASHTO Standard Specifications (1996). Many of these code specifications, along with additional requirements and procedures specific to Michigan, are found in two main texts written for the bridge engineer at MDOT: (1) the Michigan Design Manual - Bridge Design (referred to in this report as the Bridge Design Manual), and (2) the Bridge Design Guides. The Michigan Design Manual is a compilation of the guidelines and procedures issued by various agencies which bear upon the preparation of bridge plans for the State of Michigan. The Bridge Design Guides present samples of detail sheets, which refer to steel and concrete structures, and can be used as guides in preparing plans of highway bridges. Many of these examples are the results of past experience. The available examples include:

- Situation Plan
- Location Diagram
- General Plan of Structure (with cross-sections)
- Pier Details
- Abutment Details
- Structural Steel Details
- Prestressed Concrete I-Beam Details
- Prestressed Concrete Box Beam Details
- Superstructure Details, Bearing Details
- Standard Bridge Slabs

5. 1 Structures - Types

The selection of structural type and material is based on economic analysis, span length, traffic volume, terrain configuration, type of crossing, and other local conditions.

The structural types and recommended span ranges are summarized in Table 5-1.

Major criteria considered in the selection of material are:

- Economic analysis (initial cost of material and construction). Long-span designs (> 40 m, 130') are carried out for two alternative materials, prestressed concrete and structural steel.
- Exposure to high concentration of salt spray and atmospheric corrosion; concrete is preferred in these situations rather than structural steel.

Particularly corrosive environments are near sharp turns (due to salt windrowing on the high side of the curve), low clearance bridges (4.25 m, 14'), and bridges over depressed freeways. Because of the high use of deicing salts, however, most Michigan roads present a corrosive environment, and prestressed concrete (PC) girders are generally first considered.

Table 5-1. Recommended Structural Types

Material	Type	Typical Strength, f_c'	Max. Recommended Span
Prestressed-Concrete	Box beam	35 MPa (5ksi)	30m (100')
		42 MPa (6ksi)	33m (110')
	I-beams:		
	AASHTO type I-IV	35 MPa (5ksi)	27m (90')
		42 MPa (6ksi)	32m (105')
	Michigan 1800	48 MPa (7ksi)	42m (140')
Structural Steel	Rolled Beams		27m (90')
	Welded Plate Girder	spans over	27m (90')

In general, the strengths listed in Table 5-1 are typical, and do not include all possible options. MDOT currently uses 15 mm (0.6") prestressing strands, which may allow the use of higher strengths of concrete than listed in Table 5-1.

PC I-beams and box beams are preferred to spread-box beams (box beams not placed directly next to one another). As indicated in Table 5-1, MDOT usually uses AASHTO-type PC I-girders, and the Michigan 1800 Girder, which is described in Informational Memorandum #458-B. Box beams are typically 0.9 m (3') wide, with a depth range of 305 to 1,065 mm (12"-42"). 1.2 m (4') wide box beams are also available, with a depth from 535 to 1525 mm (21" - 60"), although this width is rarely used.

For long spans (42 m, 140' and greater), steel often becomes the material of choice, due to the transportation problems involving PC girders, which are difficult to splice. Steel may also be needed when a shallow

structural depth is required and PC beams are not sufficient. Curved bridges are typically made of (curved) steel girders, although straight concrete beams, placed tangent to the bridge curve, are also possible.

Whenever possible, multi-span steel structures shall be continuous. This is also recommended when replacing existing simple spans in a rehabilitation project. Girder continuity is desired not only because it increases structural efficiency, but it also eliminates leaky expansion joints over piers, a prime deterioration problem.

Again to avoid joints, when girders are prestressed concrete I-beams, decks should be continuous over piers.

Generally, beam spacing should not exceed 3050 mm (center-to-center). When designing deck slabs, for concrete beams, spacing refers to the distance between flange edges, and for steel beams, to the distance between flange edges plus 1/2 of the flange width. Typically, slab depth is kept constant and the amount of transverse reinforcement is varied based on beam spacing.

For the reconstruction of existing structures, it is recommended to use newer portions similar in appearance to that which exists, but with current materials and construction procedures.

Other structural types and materials, such as truss bridges, reinforced concrete and timber materials, are possible but are not typically used. It was found that these structures are usually too costly, though some small pedestrian bridges may be constructed from timber. MDOT is occasionally involved in special programs, funded by the federal government, that sponsor wooden bridges. The local community might also push for a particular non-typical structure.

Suspended cantilever structures of any type should also be avoided. Further recommendations can be found in section 7 of the Bridge Design Manual.

5.2 Analysis

In general, bridges for vehicular or pedestrian traffic are currently analyzed according to the 16th Edition (1996) of the Standard Specifications for the Design of Highway Bridges, published by the American Association of State Highway and Transportation Officials (AASHTO). Throughout this report, it is this edition (1996) that is referred to. This code is not applicable to the design of railway bridges, which is governed by specifications published by the American Railway Engineering Association (AREA). MDOT has added some special analysis provisions which supersede the AASHTO Code, which are found in the Bridge Design Manual and the Michigan Bridge Analysis Guides, and will be discussed below. It should be noted that in coming years, MDOT

expects to design according to the AASHTO LRFD Code (1994). In this report, it is the First Edition (1994) of the LRFD Code that is referred to.

The objective of the analysis is to determine the load effect for each structural component. For the large majority of bridge structures encountered by MDOT, the load analysis can be performed using specified formulas. This process has been computerized, and most bridges can be designed by the Bridge Design Program. In unusual cases, a more refined structural analysis method should be used. Limitations to the use of formulas are given in the AASHTO code and the Bridge Design Program Documentation. The Bridge Design Program follows current AASHTO bridge design specifications, and uses Load Factor Design procedures.

Structural analysis of bridge superstructures can be performed using methods of different refinement levels. The AASHTO code allows numerous methods depending of the level of structure complexity. In the large majority of cases the Distribution Factor (formula) Method is utilized, which is discussed below.

5.2.1 Slabs

A concrete slab is analyzed as if it were a beam of unit width. For slabs supported by PC I-girders that have a top flange width to minimum thickness ratio less than 4.0, the span is taken as the clear span of the slab. For slabs supported by PC I-girders that have a top flange width to minimum thickness ratio greater than 4.0, or for slabs supported by steel girders, the span is taken as the distance between the edges of the top flange plus one-half of the stringer top flange width.

5.2.2 Girders

According to the AASHTO Standard Specifications, the live load (HS-20) bending moment for each interior girder is calculated by applying to the girder the fraction of the truck weight. This fraction is the girder distribution factor (GDF). All GDF's in this report are specified based on the entire truck weight rather than a wheel line (1/2 truck) load. In the AASHTO Standard Specifications, for bridges with concrete decks, the corresponding GDF is:

For single lane loading:

Steel and prestressed concrete girders,	GDF = S / 4.27	(S/14)
Concrete T-beams,	GDF = S / 3.96	(S/13)

For multiple lane loading:

Steel and prestressed concrete girders,	GDF = S / 3.36	(S/11)
Concrete T-beams,	GDF = S / 3.64	(S/12)

where S = girder spacing in meters (feet).

Note that in the AASHTO Standard Specifications, GDF's are specified for a wheel line load rather than the entire truck weight.

The accuracy of the GDF's given in the AASHTO Standard Specifications, however, varies with bridge span and girder spacing. The code is unconservative with structures characterized by closely-spaced girders and short spans, while overly conservative in most other cases. This is illustrated in Figure 5.1, which compares GDF's found from finite element (FEM) modeling to those from the AASHTO formulas.

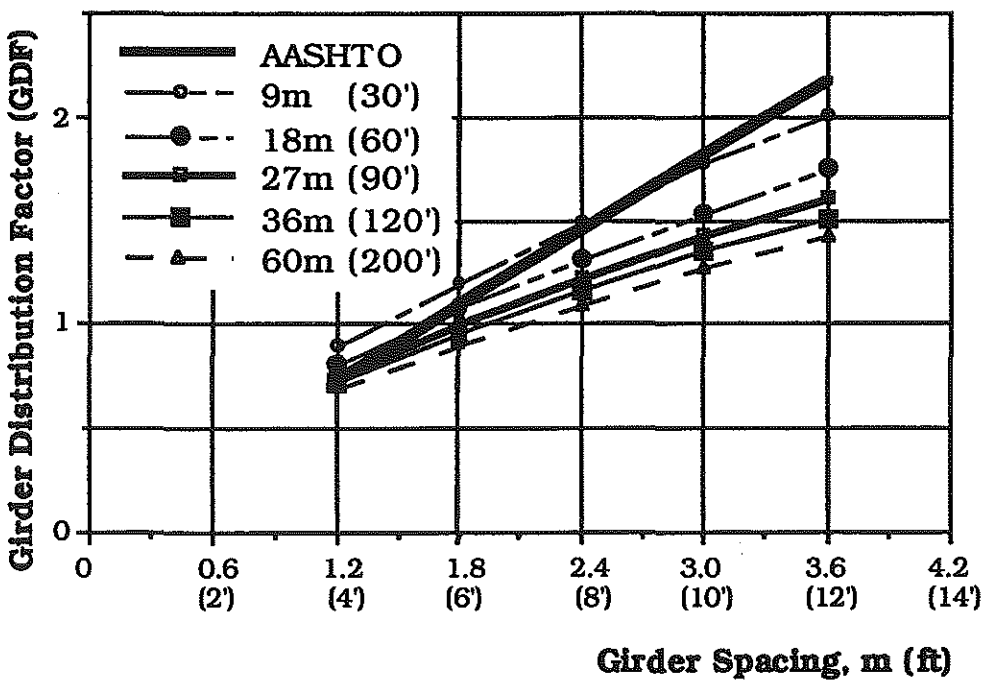


Fig. 5-1. Actual GDF's and AASHTO Specified GDF's.

For bridges with four or more girders, The AASHTO LRFD Code specifies the girder distribution factor (GDF) as a function of girder spacing, span length, stiffness parameters, and bridge skew. For moment in interior girders, the GDF is as follows:

For single lane loading,

$$GDF = \left\{ 0.06 + \left(\frac{S}{4300}\right)^{0.4} \left(\frac{S}{L}\right)^{0.3} \left(\frac{K_g}{Lt_s^3}\right)^{0.1} \right\} \left\{ 1 - c_1 (\tan\theta)^{1.5} \right\} \qquad (5\text{-}1)$$

For multi-lane loading,

$$GDF = \left\{ 0.075 + \left(\frac{S}{2900}\right)^{0.6} \left(\frac{S}{L}\right)^{0.2} \left(\frac{K_g}{Lt_s^3}\right)^{0.1} \right\} \left\{ 1 - c_1 (\tan\theta)^{1.5} \right\} \qquad (5\text{-}2)$$

$$c_1 = 0.25 \left(\frac{K_g}{Lt_s^3}\right)^{0.25} \left(\frac{S}{L}\right)^{0.5} \qquad \text{if } 30° < \theta < 60° \qquad (5\text{-}3)$$

$$c_1 = 0 \qquad \text{if } \theta < 30°$$

$$\text{use } \theta = 0 \qquad \text{if } \theta > 60°$$

where:

S = girder spacing (mm)
L = span length (mm)
$K_g = n(I + Ae_g^2)$
t_s = depth of concrete slab (mm)
n = modular ratio between girder and slab materials
I = moment of inertia of the girder (mm^4)
A = area of the girder (mm^2)
e_g = distance between the center of gravity of girder and slab (mm)
θ = skew angle in degrees, measured as the angle between the centerline of a support and a line normal to the roadway centerline.

The code allows the term $K_g/(Lt_s^3)$ to be taken as 1.0 for preliminary design. The applicability ranges for these equations are:

$1100 \le S \le 4900$ $\qquad$ $110 \le t_s \le 300$ $\qquad$ $6000 \le L \le 73000$

The LRFD GDF formulas are significantly more accurate than those specified in the AASHTO Standard Specifications, and closely mirror values found by FEM modeling. For the design of new bridges, it is recommended to use GDF's specified in AASHTO LRFD.

To determine the positive moment in PC I-beams, it is MDOT's policy to analyze spans as if they were simply supported. PC I-beams are not reinforced for the effects of negative moment generated by live load (which occurs when a continuous deck is added, forming a composite section). When analyzing the effects of superimposed live loads, the deck slab is treated as continuous, and extra reinforcement is added to the deck to resist the negative live load moment.

5.2.3 Refined Methods of Analysis

In special cases, the AASHTO LRFD Code (section 4) recommends refined methods of analysis, such as:

- Finite Difference Method
- Finite Element Method
- Finite Strip Method
- Grillage Analogy Method
- Series or other Harmonic methods
- Folded Plate Method
- Yield Line Method

These special cases rarely but sometimes occur in the work done by MDOT. The engineer must determine which method is appropriate and when it is needed. In such methods of analysis, consideration shall be given to aspect ratios of elements, positioning and number of nodes, and other topology features that may affect the accuracy of the solution.

The refined analysis method currently used by MDOT is the finite element method (FEM).

For simple but unusual frame structures, the program SODA is available for use. For the analysis of bridges with pin & hanger details, special programs written by MDOT are also available. Slab and beam analysis and design can be completed with these programs, and slab screed data can be obtained.

5.2.4 Dynamic Analysis

In the majority of applications, a refined dynamic analysis for vehicle- and wind-induced vibrations is unnecessary. MDOT does not carry out special dynamic analyses, but rather accounts for dynamic effects by relying upon code-specified procedures. The designer is provided with the Dynamic Load Allowance factor (AASHTO code, section 3.8) which takes into account the effects of impact and structural vibrations. Dynamic load is expressed as a fraction of the live load, and is as follows:

$$I = 50/(125 + 3.3L) \leq 0.30 \qquad (5\text{-}6)$$

where L is the bridge span in meters.

The AASHTO LRFD code specifies the dynamic load for girders as:

$$I = 0.33 \qquad (5\text{-}7)$$

but it is applicable to the truck load effect only, with I = 0 for lane load portion of live load.

When evaluating and rating the main girders of existing bridges for load carrying capacity, it is recommended to use a dynamic load equal to 0.10

of the static live load, unless field data suggests otherwise or in the presence of particularly unique conditions. This is based on the field measurements performed by the University of Michigan (Nowak et al. 1998).

5.3 Design Criteria

5.3.1. Load

AASHTO requires that a bridge be designed to carry the following loads:

- Dead load (D)
- Live load (L)
- Impact/dynamic load (I)
- Wind load
- Seismic load
- Other loads

5.3.1a Dead Load

Dead load shall include the weight of all components of the structure, appurtenances and all utilities permanently attached to the structure. Dead load should also include the weight of earth cover, wearing surface, future overlays and planned widening, if applicable. Typical material unit weights are given in section 3.3.6 of the AASHTO code.

5.3.1b Live Load

The basic design load is specified in the AASHTO code, section 3.6.1.2.2. This truck is referred to as MS18 (HS-20) loading. The MS18 design truck has axle weights and spacing as identified in Fig. 5-2. The spacing between the two 145 kN (32 kip) axles shall be varied between 4.3 m (14') to 9 m (30') to produce the maximum force effect. When needed, the transverse spacing of wheels shall be taken as 1.8 m (6').

Maximum moments and shears (unfactored and without impact) as a function of span for MS18 loading are presented in Table 5-2, together with MS23 and LRFD design loads.

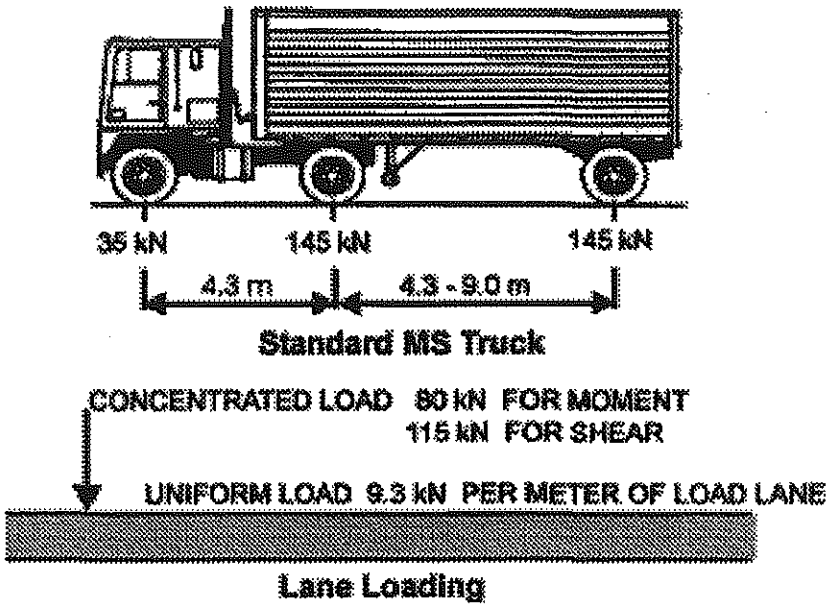


Fig. 5-2. The MS18 (HS-20) Design Truck in the Michigan Design Manual (1992).

MS18 (HS-20) loading is used on members designed for a single wheel or axle load, such as slabs and end diaphragms. This is also the minimum design load which can be used for streets or primary county roads.

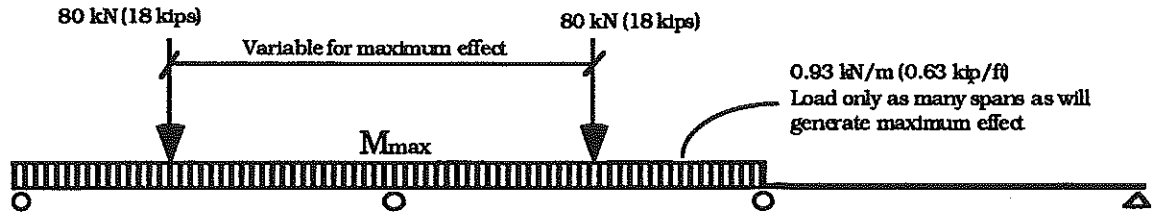
MS23 (HS-25) loading is the load required for structures on interstates or trunklines, and for the on and off ramps to these routes. The MS23 truck has the same configuration as the MS18 truck, but its axle weights are 125% of the MS18 loading.

The alternate military loading specified in the AASHTO code need not be investigated, as MS23 loading produces greater load effects.

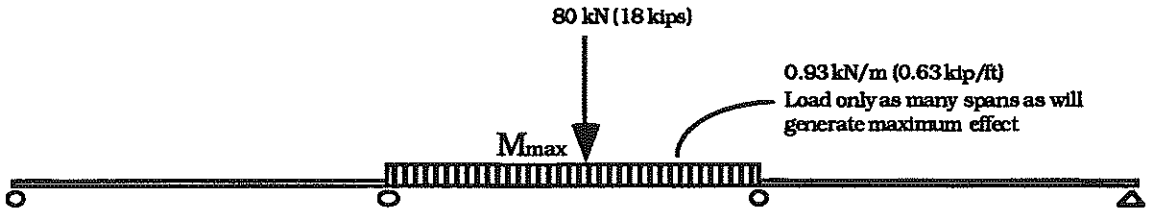
When either MS18 or MS23 loading is used, a second type of loading must be investigated, lane loading. This is a 9.3 kN/m (0.63 kip/ft) uniform load applied along the bridge span, in addition to a single point load of 80 kN (18 kips) to investigate moment effects and 115 kN (26 kips) to determine shear effects. Transversely, the design lane load shall be uniformly distributed over a 3 m (10') width. More detailed specifications referring to the tire contact area and distribution of wheel loads through earth fills are stated in AASHTO LRFD 3.6.1.2.5 and 3.6.1.2.6. For investigating continuous girders, the lane load should be modified as follows: For positive moment, place the uniform portion of the load only on as many spans that will produce the maximum moment. For negative moment, an additional concentrated load should be placed on the bridge, such that the combination of the uniform load and the two point loads generate the maximum moment (Fig. 5-3).

Table 5-2. Design Load Moments

Span	Moment (MS18)	Moment (MS23)	Moment (HL-93)
m (ft)	kN-m (k-ft)	kN-m (k-ft)	kN-m (k-ft)
3 (10')	109 (80)	136 (100)	120 (88)
6 (20')	246 (181)	307 (226)	295 (217)
9 (30')	428 (315)	536 (394)	543 (399)
12 (40')	612 (450)	766 (563)	800 (588)
15 (50')	854 (628)	1068 (785)	1132 (832)
18 (60')	1097 (807)	1371 (1008)	1486 (1093)
21 (70')	1340 (986)	1676 (1232)	1871 (1376)
24 (80')	1584 (1165)	1980 (1456)	2278 (1675)
27 (90')	1828 (1344)	2286 (1681)	2705 (1989)
30 (100')	2073 (1524)	2591 (1905)	3159 (2323)
33 (110')	2317 (1704)	2897 (2130)	3630 (2669)
36 (120')	2561 (1883)	3201 (2354)	4126 (3034)
39 (130')	2806 (2063)	3507 (2579)	4643 (3414)
42 (140')	3050 (2243)	3813 (2804)	5179 (3808)
45 (150')	3366 (2475)	4208 (3094)	5739 (4220)
48 (160')	3764 (2768)	4706 (3460)	6321 (4648)
52 (170')	4185 (3077)	5231 (3846)	6925 (6092)
55 (180')	4627 (3402)	5784 (4253)	7551 (5552)
58 (190')	5091 (3743)	6363 (4679)	8198 (6028)
61 (200')	5576 (4100)	6970 (5125)	8867 (6520)



Negative Moment Investigation.



Positive Moment Investigation.

Figure 5-3. Application of Lane Load to Continuous Spans.

Whichever produces the maximum load effect, truck or lane loading, must be used. The lane load and its concentrated load must be increased by 125% when investigating MS23 loading. Lane loading usually governs on longer (> 40 m, 130') spans.

When determining the load effect on a girder, if the distribution factor method of analysis is used, regardless of the number of design lanes on the bridge, a single design lane shall be loaded to find the total load effect. A design lane is not necessarily a traffic lane; this difference is discussed below. This total load effect is then multiplied by the distribution factor to find the shear or moment that a single girder is subjected to.

When a method other than the distribution factor method is used to determine the load effect, all design lanes must be loaded with the design load. This load effect is reduced for bridges with three or more design lanes, as specified in section 3.12.1 of the AASHTO code.

Longitudinally, the design truck is placed wherever it will generate the maximum load effect. Transversely, the bridge width between curbs is divided into 3.6 m (12') wide design lanes. Fractional lane sizes are not used, and bridges from 6-7.2 m (20-24') wide shall have two design lanes, each equal to half of the roadway width. Note that the design lane may not coincide with the actual traffic lanes of the bridge; the actual traffic

lanes are not used for design. Both the design lanes and the position of the 3m wide lane load shall be positioned to produce extreme force effects. The design truck shall be positioned transversely such that the center of any wheel load is not closer than 0.6 m (2') from the edge of the design lane or curb. To determine the load effect on the slab, this distance should be decreased to 0.3 m (1') when the slab overhangs an exterior girder.

5.3.1c Fatigue Load

Steel components subject to periodic stress variations or stress reversals can be prone to fail at stresses below their normal design values. Allowable fatigue stresses are given in section 10.3.1 of the AASHTO Code, as a function of the type of component, the type of connection detail, and the number of load cycles that the component will experience during its design lifetime. In the AASHTO Code, the number of cycles is determined based on the expected truck traffic ADT (average daily traffic) at the bridge opening, for a design life of 75 years.

For structures with unknown or unpredictable measures of ADT, an alternate approach is used at MDOT to account for fatigue. Selected structures are instrumented with strain gauges, and for a period of approximately four hours, a stress range caused by truck traffic is measured. Based on this information, a determination is made whether fatigue may be a problem, and if so, how to remedy it. It is also MDOT's policy to remove fatigue-prone (Type E) details when painting, repairing, or otherwise retrofitting structures.

5.3.1d Impact (Dynamic) Load

The value for impact is given above. Impact load is included for computing the load effect on:

- Superstructures
- Piers
- The portion of concrete or steel piles which are above the ground line and support the superstructure

Impact is not included for:

- Abutments, retaining walls, and portions of piles below the ground
- Foundation pressures and footings
- Timber structures
- Sidewalk loads
- Culverts and structures having 1 m or more of cover

5.3.1e Wind Load

Wind load is calculated primarily to check bridge overturning. AASHTO specifies that a 2.4 kPa (50 PSF) uniform load be applied to the bridge elevation, with a minimum of 4.5 kN/m (0.3 kip/ft) of span on girder bridges. Further provisions and special loading for truss and arch bridges are in section 3.15 of the AASHTO code.

5.3.1f Seismic Load

MDOT follows the seismic design provisions of Section 5: Design Requirements for Bridges in Seismic Performance Category A, in the AASHTO Specifications. The Seismic Performance Category (SPC) is determined from the Acceleration Coefficient (A) and the Importance Classification (IC). Bridges in Michigan have A-values from 4 to 2, which means that the structure has a 10 percent probability of experiencing lateral forces greater than 0.04-0.02 g's in a 50 year time period. For bridges with such low A-values, IC is not considered. In general, for Category A bridges, there is no need to design for seismic forces. One exception is for the design of bearing support lengths, which is detailed in Section 5.3 of the AASHTO Code. MDOT does no seismic retrofitting.

5.3.1g Other Loads

Other loads include longitudinal forces, centrifugal force, thermal forces, earth pressure, buoyancy, shrinkage stresses, rib-shortening, erection stresses, ice and current pressure. Sidewalk, curb, and railing loading are also possible. Provisions for these forces are described in section 3 of the AASHTO code.

The temperature gradient, used to determine thermal forces and movements, shall be in conformance with the AASHTO "cold climate" temperature range. The type of structure used in determining the temperature range shall be defined by the material of the main supporting members of the superstructure.

Pedestrian bridges are to be designed for a live load of 4.1 kPa. (85 PSF) Bicycle (non-motorized) bridges are to be designed for a truck with one axle of 9 kN (2 kips) and one axle of 36 kN (8 kips) spaced 2.1 m (7') apart. Transversely, the wheels are 1.8 m (6') apart.

5.3.2. Design Methodologies

Design procedures have been developed to provide satisfactory margins of safety. These procedures were based on the analysis of the load effects and the strength of the materials.

MDOT currently uses two design methods: Allowable Stress Design and Load Factor Design. In the future, MDOT will adopt the Load and Resistance Factor Design method, as found in the AASHTO LRFD Code.

These design procedures are as follows:

5.3.2.a Allowable Stress Design (ASD)

Safety in the design is obtained by specifying that the effect of the loads should produce stresses that are a fraction of the yield stresses (about 50%). This value is equivalent to providing a safety factor of 2.

ASD is used to design:

- Deck slabs
- Elastomeric bearing pads
- Bolted connections
- Footings and piles
- Prestressed concrete beams (for service limit stresses)

It is a requirement of the AASHTO code that prestressed concrete beams be designed by ASD.

The general AASHTO allowable stress formula is:

$$D + (1 + I)\, L < F_b \qquad (5\text{-}7)$$

where:

D = stress due to dead load,
L = stress due to live load,
I = impact or dynamic load factor, where applicable (equivalent fraction of live load stress due to dynamic load),
F_b = allowable stress.

Allowable material stresses are found in the AASHTO code, and for slip-critical (bolted) connections, in section 7.01.03 of the Bridge Design Guides.

5.3.2.b Load Factor Design (LFD)

Load factors are specified for various load components. It is required that the factored load be less than resistance (load carrying capacity) multiplied by a resistance factor (ϕ). If the resistance factor is not defined, it is to be taken as 1.0.

All components not designed by ASD are designed by LFD. Prestressed concrete (PC) beam capacity must also be checked by LFD.

The AASHTO strength design formula is:

$$1.3\ D + 2.17\ (1 + I)\ L < \phi\ R \qquad (5\text{-}8)$$

where:

D = effect of dead load (moment or shear force due to dead load),
L = effect of live load (moment or shear force due to live load),
I = impact or dynamic load factor, where applicable (equivalent fraction of live load moment or shear force due to dynamic load),
R = resistance, the load carrying capacity (moment or shear force capacity),
ϕ = resistance factor.

5.3.2.c Load and Resistance Factor Design (LRFD)

The design formula in the AASHTO LRFD Code is:

$$1.25\ D + 1.5\ D_A + 1.75\ (1 + I)\ L < \phi\ R \qquad (5\text{-}9)$$

The difference between LFD and LRFD is in the procedure leading to the calculation of load and resistance factors. LRFD is based on a reliability-based calibration. LRFD design procedures are found in the AASHTO LRFD Code.

5.3.3. Deflection Limitations

To prevent serviceability problems and user dissatisfaction, bridge deflection must be limited.

The Bridge Design Manual, section 7.01.06, provides deflection limitations according to design load and span. For a girder bridge with constant depth, $f_{(L+I)}$ can be calculated by treating the whole bridge as a single beam, with the stiffness equal to the sum of the stiffnesses of all of the girders. Live load can be considered as a sum of live loads in each lane (total live load = n x live load per lane, where n = number of lanes).

Table 5-3. Deflection Limits

Loading	Simple and Continuous Span	Cantilever
MS23	L/800	L/300
MS18	L/1,000	L/375
M18 (with sidewalk)	L/1,000	L/375
M18 (without sidewalk)	L/800	L/300
Pedestrian only	L/800	L/300
Timber bridges	L/375	---

L = beam span

5.4 Construction Requirements

5.4.1 Deck Slabs

The standard MDOT deck slab supported by prestressed concrete I-beams or steel girders is shown on sheet 6.41.01 in the Design Guides, and discussed in section 7.02.19 of the Bridge Design Manual. As noted, the standard design is valid for a slab continuous over three or more beams of similar structural capacity. The deck is 230 mm (9") thick, but the top 40 mm (1.5") is considered a wearing surface and is not included in the design depth. Even if portions of the slab extend underneath a sidewalk, the slab should still be designed for full highway loading. A typical section through a slab overhang with sidewalk is shown in sheet 6.29.07 through 6.29.09 in the Design Guides. Overhangs greater than those shown should be avoided. If greater overhangs are used, the slab should be checked for negative moment capacity.

5.4.1.a Haunches

A haunch shall be provided to allow for variance in the elevations of the tops of the beams. The design should have an allowance for a 25 mm (1") uniform haunch for steel beams and a 25 mm (1") minimum haunch for prestressed concrete beams, though the haunch should be shown on the details as variable. For continuous spans greater than 30 m (100'), a 50 mm (2") nominal haunch is required.

5.4.1.b Elevations

On the plans the bottom of slab elevations are shown at the beam locations and at equal spacing across the spans. These elevations should be calculated based on the condition that only the beams have been erected. In other words, the elevations should be such that when the weight of the slab and all other dead loads are added the final elevations will be achieved.

5.4.1.c Slab Thickness

The slab thickness is to be uniform throughout the bridge. In order to create a crown in the roadway, the beams must be stepped in elevation to follow the crown. The slab shall be designed for highway loading even if it is under a sidewalk. Where the bridge is continuous or otherwise configured as to produce a negative moment region, additional longitudinal slab reinforcement is required in those regions. All slabs shall have a uniform thickness of 230 mm (9").

5.4.1.d Reinforcement

As shown on sheet 6.41.01, for the standard condition, the amount of reinforcement needed is pre-calculated and depends on girder spacing. The reinforcement pattern and quantity shall be as given in section 6.41.01 of the Bridge Design Guides. Transverse bars are to be lapped in the following manner: top reinforcement shall be lapped between the beams, and bottom reinforcement shall be lapped over the beams. These are the regions of smallest moment for negative and positive moment, respectively. All reinforcement shall be epoxy coated. This reduces the susceptibility of the reinforcement to corrosion and lengthens the lifespan of the slab.

The standard slab requires reinforcement in two directions: parallel to the direction of traffic (longitudinal reinforcement) and perpendicular to the direction of traffic (transverse reinforcement). Longitudinal reinforcement is referred to as distribution steel. Additional longitudinal reinforcement is required in regions of negative moment, as specified in section 10.38.4.3 of the AASHTO code. Although transverse bars are generally placed perpendicular to the beams, they may be placed parallel to the reference line on large-skew bridges, as noted on Sheet 6.41.01 of the Bridge Design Guides. It is important to insure adequate protection for the reinforcement. All decks should have 75 mm (3") of clear concrete cover over the top transverse reinforcement, and 38 mm (1.5") of clear cover over bottom transverse reinforcement.

5.4.1.e Concrete Cover

The concrete cover over the reinforcement will be 75 mm (3") over the top transverse reinforcement, a cover depth which increases the ability of the reinforcement to resist corrosion. All new bridges and bridge replacements shall be designed for a 1.2 kPa (25 PSF) future wear surface (FWS) (IM #476-B). All bridge decks scheduled for a concrete overlay shall be hydrodemolished. Two-stage construction, using laytex overlays, is not to be used (IM #473-B).

5.4.2 Prestressed Concrete Girders

There are two types of prestressed concrete (PC) beams: pre-tensioned, where strands are tensioned before the concrete hardens, and post-tensioned, where strands are tensioned after the concrete hardens. Practically, only pre-tensioned bridges are built in Michigan.

The pre-tensioned beam is produced by placing strands in their proper positions in the beam formwork, tensioning them to the needed level, then casting the concrete. When the concrete hardens the ends of the strands are released, and the concrete is compressed as the strands try to return to their original lengths but are anchored in the ends of the concrete beam. The post-tensioned beam is cast as a concrete beam with conduit through which the strands will later be placed. After the concrete hardens, the strands are inserted into the conduit, tensioned to the desired level, and anchored to the beam ends. Over time, the strands lose some of their initial tension as the beam undergoes strain due to elastic shortening, concrete creep and strand relaxation under the prestress load.

Two stages need to be considered when designing PC beams: the initial stage, where the beam must resist the prestress force and the stresses due to its own weight, but no external loads are applied; and the final stage, when all prestress losses have occurred and the beam must resist the stresses caused by all applied service loads. The PC design procedure is based on three fundamental assumptions:

- Strains vary linearly
- Before cracking, stress is proportional to strain
- After cracking, tension in concrete is neglected

The flexural capacity of PC I-beams must be checked by two design methodologies: the allowable stress method and the LFD method. Shear capacity is checked by the LFD method. The accepted PC design procedure is detailed in section 9 of the AASHTO code, and section 7.02.18 of the Bridge Design Manual.

Over time, prestressing strands lose their initial stress level. This loss is important to account for because it reduces the capacity of the beam to carry load. Some of these losses occur instantaneously at transfer, the point in time when the strands are anchored to the beam ends and begin to compress the concrete. Other losses are gradual and occur over long periods of time. It may take years before these losses practically no longer occur.

For pretensioned members, immediate prestress losses are due to elastic shortening of the concrete Δf_{pES}. Long-term prestress losses are due to concrete shrinkage Δf_{pSR}, concrete creep Δf_{pCR}, and relaxation of the

prestressing tendons Δf_{pR}. The total prestress loss Δf_{pT} is the sum of the losses that occurred at the different load stages through out the life of the member:

$$\Delta f_{pT} = \Delta f_{pES} + \Delta f_{pSR} + \Delta f_{pCR} + \Delta f_{pR} \tag{5-10}$$

To estimate the losses due to elastic shortening, it is necessary to know the concrete stress f_{cgp} at the centroid of the prestressing tendons due to the prestressing force at transfer. It is also necessary to include the self-weight of the beam. According to section 5.9.5.3 in the AASHTO LRFD Code, the losses due to elastic shortening in the concrete are:

$$\Delta f_{pES} = \frac{E_p}{E_{ci}} f_{cgp} \tag{5-11}$$

where:

E_p = modulus of elasticity of prestressing steel
E_{ci} = modulus of elasticity of concrete at transfer

Table 5.9.5.3-1 in AASHTO LRFD gives equations that estimate the sum of time-dependent losses resulting from concrete creep, concrete shrinkage, and relaxation of the steel. Values are given for both strands and bars. A portion of this table is reproduced in Table 5-4, below. "Loss Level" refers to the estimated level of prestress loss; either the average anticipated loss or the upper bound of this loss. It is recommended that the latter value be considered when a combination of adverse conditions exist, such as low concrete strength, low relative humidity, and moist curing conditions.

Table 5-4. Equations to Predict Time-Dependent Losses (MPa)

Type of Beam Section	Loss Level	Wires & Strands f_{pu}=1620,1725 or 1680MPa	Bars f_{pu}=1000, 1100MPa
Box Girder	Upper Bound	145 + 28PPR	100
	Average	130 + 28PPR	100
I-Girder	Average	230{1-0.15[(f'_c-41)/41]}+41PPR	130+41PPR

Where PPR is the Partial Prestressing Ratio, and is given by:

$$PPR = \frac{A_{ps} f_{py}}{A_{ps} f_{py} + A_s f_y} \tag{5-12}$$

where:

A_{ps} = area of prestressing steel
f_{py} = yield strength of prestressing steel
A_s = area of non-prestressed tensile reinforcement
f_y = yield strength of the reinforcing bars

Additional requirements for reinforcement are given below.

5.4.2.a Maximum and Minimum Tensile Reinforcement

The maximum amount of tensile reinforcement allowed in the beam depends, as in reinforced concrete, on the resulting ductility of the section. Ductility, the ability of the section to deform without breaking, is needed to avoid a brittle failure, by which the concrete crushes before the steel yields. Such types of failures occur when large amounts of steel are present in the section. These failures can occur without warning and are thus particularly dangerous.

According to section 5.7.3.3.1 of AASHTO LRFD, to assure minimum ductility in the member, the ratio c/d_e shall not exceed 0.42, where c is the distance from the extreme compression fiber to the neutral axis, and d_e is the effective depth of the section, defined as:

$$d_e = \frac{A_{ps} f_{ps} d_p + A_s f_y d_s}{A_{ps} f_{ps} + A_s f_y} \tag{5-13}$$

where:

f_{ps} = average stress in prestressing steel
d_p = distance from the extreme compression fiber to the centroid of prestressing tendons
d_s = distance from the extreme compression fiber to the centroid of non-prestressed tensile reinforcement

A minimum amount of tensile reinforcement is required to prevent a sudden tensile failure. If the moment strength provided by the tensile reinforcement is less than the cracking moment strength of the gross concrete section, then a sudden tensile failure could occur. Section 5.7.3.3.2 of the AASHTO LRFD code gives the criterion to insure minimum tensile reinforcement. It states that the moment resistance M_n provided by non-prestressed and prestress tensile reinforcement shall be greater than moment resistance M_{cr} provided by the concrete tensile strength:

$$\phi M_n \geq 1.2 M_{cr} \quad \text{(N-mm)} \tag{5-14}$$

where:

$$M_{cr} = \frac{f_r I_g}{y_t} \quad \text{(N-mm)} \tag{5-15}$$

$f_r = 0.63 f'_c{}^{0.5}$ (concrete tensile rupture stress for normal density concrete, MPa)
I_g = gross moment of inertia of the cross section (mm^4)
y_t = distance from the neutral axis to the extreme tensile fiber (mm)

5.4.2.b Shrinkage and Temperature Reinforcement

In reinforced concrete or prestressed concrete beams, reinforcement for shrinkage and temperature stresses shall be provided near the surface of concrete exposed to daily temperature changes. The minimum required reinforcement depends on the size of the member. For beams less than 1200 mm (48") thick, the area of reinforcement for shrinkage and temperature, in the form of bars or welded wire fabric in each direction shall not be less than:

$$A_s \geq 0.75 A_g / f_y \tag{5-16}$$

where:

A_g	=	gross area of section
f_y	=	specified yield strength of reinforcing bars

The bars shall be equally distributed on both faces of the beam, and placed in a single layer. The maximum space between bars shall not be less than 3.0 times the beam thickness or 450 mm (18").

It is possible to avoid shrinkage and temperature reinforcement in PC beams if certain conditions regarding the prestressing tendons are met. The tendons must provide a minimum average compressive stress (based on the effective prestress after losses) of 0.75 MPa (0.11 ksi) on the gross concrete area in the direction being considered. Tendon spacing should not exceed 1800 mm (72"), and if the spacing exceeds 1400 mm (54"), then bonded reinforcement shall be provided.

The Bridge Design Manual recommends five types of prestressed concrete beams with maximum spans shown in Table 5-1, above. The choice is generally governed by the economics of design and expected span lengths. Concrete is preferred in areas with a high concentration of salt spray or atmospheric corrosion. For reconstruction of existing structures, it is recommended to use new portions similar in appearance, but with

current materials and construction procedures. Generally, beam spacing should not exceed 3050 mm (10') center-to-center.

The Bridge Design Guides give the designer two general suggestions. The first refers to strand selection; strands should be specified as ASTM A416 Grade 270 (1860 MPa) low relaxation steel. The second is regarding bond breakers. Bond breakers should not be placed on peripheral strands. Where required, they should be placed on strands in the lower rows, symmetrically about the centerline of beam. In extreme cases, where bond breakers must be placed on the strands in the bottom row, they should be placed on every third strand with the corner strands bonded. Bond breakers (a plastic sleeve around the strand) are used to debond the ends of the strand from the concrete. This reduces the number of draped strands required in the beam.

Two types of prestressed concrete girders are recommended: prestressed concrete box beams and prestressed concrete I-beams.

Typical cross sections of box beams with reinforcement details are shown in the Bridge Design Guides 6.65.10, 6.65.11 and 6.65.12. The spacing of prestressed concrete box beams is to be the nominal width of the beam plus 40 mm (1.5"). In a skew bridge, the ends of the box beams shall be skewed to be parallel to the reference line. The bearing pads shall be designed according to the bearing pressure. For pressure less than 690 kPa (100 psi), 13 mm (0.5") joint filler can be used. When the pressure is greater than 690 kPa, an elastomeric pad 150 mm (6") (minimum) by 865 mm (34") with a minimum thickness of 20 mm (0.8") shall be used.

5.4.2.c PC I-Beams

The cross-section of a typical beam, beam properties and details are shown in sheet 6.60.01 of the Bridge Design Guides. Prestressed concrete I-beams require diaphragms made as reinforced concrete beams, located perpendicular to the girders. End diaphragms are to be set back 250 to 300 mm (10" to 12") from the end of the beam. One intermediate diaphragm shall be placed in the mid-point of the span. Over piers, at independent backwalls and at hangers, diaphragms should be used. Diaphragm section, elevation and reinforcement details are shown on sheet 6.60.12 in the Bridge Design Guides. All diaphragms are to be cast separately from the slab.

To support PC I-beams, it is necessary to use bearing pads. For single-span structures 12 m (40') or less in length, a fixed backwall with 25 mm (1") elastomeric pads under the beam, and joint filler under the backwall, can be used. For spans over 12 m (40'), for both single and multiple-span structures, an allowance for expansion in designing the bearing pads is required. On skew bridges, the ends of the PC I-beams shall be made square, regardless of the angle of skew.

5.4.2.d Box beams

Box beams which are less than 840 mm (33") deep must have a transverse post-tensioning tendon, placed at mid-depth. Beams, which are 840 mm (33") or deeper, have two transverse tendons installed at the 1/3 points of the beam depth. Details describing the location of post-tensioning tendons, tensioning force, required joint filler, elastomeric pad and the cross-section of the end block at abutments are given in sheets 6.65.12 and 6.65.13 in the Design Guides. There is a requirement that the surfacing over box beam deck shall be a 150 mm (6") thick reinforced concrete slab. To provide a composite section, the beams and slab shall be connected by stirrups.

The Bridge Design Guides also provide information about reinforcing steel. Tables with bar size, designation and nominal dimensions are given in sheet 7.11.01 and in Informational Memorandum # 469-B. Required development and lap length, depended on bar size, for tension and compression zones, are in sheets 7.14.01, 7.14.01A, 7.14.02, and 7.14.02A. The Guides also describe when welded or mechanical connections are required. All standard reinforcing bar types (small details), such as hooks and loops, with geometry for particular bar numbers and the length which must be embedded in concrete, are shown in sheets 7.14.03, 7.15.01 and 7.15.02 in the Bridge Design Guides. The Design Manual notes that in MDOT metric projects, all dimensions must be metric and metric size reinforcement should be used.

5.4.3 Steel Girders

Multi-span steel structures should be designed as continuous to avoid locating expansion joints over piers. Suspended cantilever designs should be avoided. When replacing simple spans of existing structures, replacement with continuous beams is preferred.

Steel grades recommended for bridge designs are summarized in Table 5-5. Values of allowable stresses for ratings of existing bridges (inventory rating and operating rating) can be found in the Bridge Analysis Guide. For the Operating Rating, allowable stresses must conform to the AASHTO requirement of being 75% of the yield point. The Guide provides an example of rating calculations for a simple span steel stringer. If the grade of steel is unknown (e.g. the bridge is old and its specifications are unavailable), one should determine the year of original construction and refer to "AISC Iron and Steel Beams 1873 to 1952" for the values of old design stresses.

Grade A36M may be used, instead of A572M and A588M steels, for bearings, diaphragms and cross-frames.

Table 5-5. Structural Steel Grades.

Structural Steel	Design Stresses	Available Thickness
M 270M Grade 250	F_y=250 MPa (36 ksi)	up to 200 mm (8")
M 270M Grade 345	F_y=345 MPa (50 ksi)	up to 100 mm (4")
M 270M Grade 345W	F_y=345 MPa (50 ksi)	up to 100 mm (4")

With the exception of bolted connections, steel girders are designed by the LFD method. Appropriate procedures can be found in section 10 of the AASHTO code, and in section 7.02.21 of the Bridge Design Manual. If 345W steel is used, it must be painted, and can be substituted for 345 steel.

5.4.3.a Bearings

The following rules apply in the design of bearings (Bridge Design Manual, section 7.01.05):

- *Sole Plates:* Plate thickness should be specified in 6 mm (0.25") increments. For steel girders, the sole plate is to be beveled when the calculated bevel is greater than 1% for curved steel bearings and greater than 0.5% for elastomeric bearings.
- *Lead Plates:* Lead plates are required under steel masonry plates. They should extend 40 mm (1.5") beyond steel plates in both directions.
- *Elastomeric Bearings:* Elastomeric bearings from plain material should be 70 durometer; laminated bearings shall be 50 durometer.

Examples of detailing and calculations for laminated elastomeric expansion bearings are given in the Bridge Design Guides, sections 8.46.01 to 8.46.06. A table of bearing types for steel structures, both continuous and simple span, taken from section 8.31.01, is presented below.

5.4.3.b Beam Spacing

The distance between steel beams or girders plus flange width shall not exceed 3050 mm (10') (Bridge Design Manual, section 7.02.02).

Table 5-6. Guide for Selection of Bearing Types

Length of expansion	Type of Movement	Type of Bearing	Bevel Sole Plate
Through 36,576 mm (120')	Fixed Expansion	Curved Steel Plates	Yes
		Elastomeric Bearings	Yes
Over 36,576 mm (120')	Fixed Expansion	Built Up Pedestals	No
		Built Up Rockers	No

5.4.3.c Pre-camber of Steel Girders

The Bridge Design Manual, section 7.01.06, requires compensating camber when the dead load deflection and deflection due welding are greater than 6 mm (0.25"). The pre-camber should be parabolic. The camber is to be measured with the beam lying on its side. Heating is to be used (if necessary) to provide the camber at the center within a tolerance of:

- *Rolled beams:* ±6 mm (0.25").
- *Plate girders:* According to AWS Specifications.

An example of a camber diagram can be found in the Bridge Design Guides, section 8.06.02.

5.4.3.d Multiple Span Design

The following rules are to be followed in the design of multiple span structures (Bridge Design Manual, section 7.02.08):

- *Beam Depth:* The same beam depths for all spans should be used with the longest span controlling the beam depth.
- *Composite Design:* Composite design should be used where economical to do so.
- *Suspended Spans:* The suspended spans should be poured first.

5.4.3.e Rolled Beam Design

According to the Bridge Design Manual, section 7.01.09, cover plates should be designed according to AASHTO Standard Specifications. The following rules apply:

- *Steel Grade:* Cover plate steel must be the same as the beam steel or matched as closely as possible.
- *Welds:* A continuous fillet weld of the size indicated in the table in the Bridge Design Manual, section 8.06.05, is required.
- *Cover plate width:* For new beams, plate width must equal the beam flange width minus 40 mm (1.5"); for old beams, it must equal the beam flange width plus 40 mm (1.5").
- *Cover plate thickness:* Plate thickness is the greater of 10 mm (0.4") or 1/24 of the plate width.
- *Length:* Cover plates shall extend beyond the theoretical cut-off point a distance equal to the greatest of:
  - 1.5 times cover plate width
  - Cover plate stress development length
  - To a section where the allowable stress range is not exceeded for tension or reversed stress
  - To a section where the bottom flange is always in compression

Additional requirements and calculation examples for rolled beam cover plates are given in the Bridge Design Guides, section 8.06.05 to 8.06.08.

5.4.3.f Plate Girder Design (Welded)

A *homogeneous girder* utilizes the same strength of steel throughout its cross-section. A *hybrid girder* consists of load-bearing plates of varying steel types. For example, in this girder the web is often made of a lower strength steel than the flanges.

The following rules apply in the design of welded plate girders (Bridge Design Manual, section 7.02.10):

- *Web Plates:* The depth should be in 50 mm (2") increments, while the thickness is a minimum of 10 mm (0.4").

- *Flange Plates:* Width can be varied, with a minimum of 300 mm (12"), while the minimum thickness is 14 mm (0.55") when shear connectors are used and 20 mm (1") when shear connectors are field welded to the flange.
- *Hybrid Designs:* Hybrid designs shall not be used.

5.4.3.g Stiffeners

The following recommendations should be followed in the design of stiffeners (Bridge Design Manual, section 7.01.11):

- *Orientation:* Stiffeners should be set normal to the girder web. When the angle of crossing is between 70° and 90°, skew stiffeners can be

designed so that the diaphragms and cross-frames may be connected directly to the stiffeners.

- *Bearing Stiffeners:* Bearing stiffeners should be avoided at abutments with a dependent backwall. The lower portion of the backwall should be poured and allowed to set before the deck is cast.
- *Bearing Stiffeners at Temporary Supports:* Bearing stiffeners should be provided at temporary supports for all plate girders, to prevent the possibility of web buckling. Only stiffeners on one side are required. Stiffeners should be placed on the inside of fascia girders.
- *Bearing Stiffeners for Rolled Beams:* If a beam end is under a superstructure transverse joint, two 14 x 100 mm (0.55" x 4") bearing stiffeners should be provided, as a safety measure in the event of corrosion and section loss of the web.

Examples of stiffeners can be found in the Bridge Design Guides, sections 8.06.02 and 8.06.02A. Deflection and camber coefficients are included in section 8.06.04.

5.4.3.h Welding

Welding procedures should be done according to American Welding Society (AWS) specifications. It is required to show welding details on the plans. Sizes should be shown as intended, if different from AWS specifications. An example detail of a plate girder weld is presented in the Bridge Design Guides, section 8.06.03.

5.4.3.i Field Splices in Plate Girders

According to the Bridge Design Manual, section 7.01.13, the following rules apply in the design of field splices in plate girders:

- *General:* Rules are listed in Table 5-7.

Table 5-7. Rules in design of field splices

Girder length, mm (ft)	Field Splice
0-38,000 (125')	None Provided
38,000 - 48,000 (125-158')	Shown on plans as optional. Designed and detailed but not paid for.
Over 48,000 (158')	Designed, detailed and paid for

- *Location:* Field splices are to be located in low-stress areas, at or near the point of contraflexure for continuous spans.

- *Bolts:* All high strength bolts are to be galvanized.

Field connections shall be designed with M20 high-strength bolts, except when otherwise noted (see the Bridge Design Manual, section 8.07.07).

5.4.3.j Diaphragms and Cross-frames

Diaphragms and cross-frames may be placed at the end of the structure, across interior supports and intermittently along the span. The necessity of these components is described by the AASHTO LRFD Code, section 6.7.4, and they are used to:

- Transfer lateral forces due to wind.
- Maintain the stability of the bottom girder flange in compression areas.
- Maintain the stability of the top girder flange in compression areas, prior to concrete deck curing.
- Assist in the distribution of vertical dead and live loads applied to the structure.

The following rules apply in the design of diaphragms and cross-frames (Bridge Design Manual, section 7.01.14):

- *Orientation:* Diaphragms and cross-frames should be set normal to the girder web.
- *End Diaphragms:* End diaphragms or cross-frames are required at beam ends to support the end of the slab, unless other support means are used. Clearance of at least 600 mm (2') from the beam end needs to be provided for painting access.

Examples of diaphragm details and cross-frames are given in the Bridge Design Guides, sections 8.11.03 to 8.11.08. Examples for end diaphragms are given in section 8.60.01.

5.4.3.k Composite Girders - Shear Developers

The following rules apply to the design of shear developers (Bridge Design Manual, section 7.01.15):

- *Type:* The shear developers are to be the type shown in the Bridge Design Manual, section 8.07.01. Details and spacing for 9 mm (0.35") studs should be shown on the plans. For bridge deck rehabilitation or repair, existing shear developers are not to be salvaged.
- *Spacing:* The spacing is to be constant, governed by the design. Shear developers are not to be used in areas of negative moment. They should extend beyond the point of contra-flexure, being closest to the

support over which the negative moment will occur. When shear developers are used in negative moment regions, the maximum tensile stress at the point of attachment should not exceed current AWS specifications.

5.4.3.l Coating.

Structural steel should be coated with MDOT's three-coat painting system, which is the following:

A zinc-rich primer coat is first applied, followed by a second coat of epoxy, followed by a final coat of urethane for protection. For most steel surfaces, minimum dry film thicknesses are: 2.5mils for the primer, 3.5mils for the epoxy, and 1.0mils for the urethane protective coat.

The Contractor selects a complete coating system form the Qualified Products List (QPL). Minimum curing time between coats is listed in the QPL.

5.4.3.m Continuous Beam Design of Steel Girders

According to the Bridge Design Manual, section 7.02.21, the following rules should be followed when designing continuous steel girders:

- *Pour Sequence:* The pour sequence has to be taken into account to ensure that deflections occur as assumed in the design.
- *Pre-loading:* Where shoring is not provided, the pouring sequence should be carefully designated to prevent cracking of deck slabs in composite continuous-span bridges. Also, pre-loading should be considered. Tail spans should in general be poured first, and the pre-load placed in the center span. When removed, the pre-load should induce compressive stresses in the concrete deck of tail spans in order to offset the tensile effect of middle span concrete pours.
- *Haunch Thickness:* In continuous structures, a nominal 50 mm (2") haunch will be used for spans exceeding 30,000 mm 100').
- *Nighttime Casting Of Concrete:* Nighttime casting of concrete superstructures is required on all bridge decks. This minimizes temperature fluctuations, which reduces shrinkage cracks in the decks.

5.5 Computer Aided Design - Bridge Design System

Throughout the 1960's, MDOT automated the design of various bridge components (beams, abutments, piers, etc.) in a series of stand-alone programs. In 1969, these programs that assisted in bridge layout and superstructure design were integrated together into a single program called the Bridge Design Program (or Bridge Design System, BDS). The design of abutments and piers modules were added in 1975 and 1976

respectively. The program is capable of designing all bridge components in a single run. Since then, the program has been updated and expanded to address the changes in AASHTO codes, MDOT specifications, and advances in bridge technology. The design assumptions and program limitations are documented and should be fully understood by the engineer; program users are strongly encouraged to review the documentation. When required, other software for unique bridges or bridge components can be used as described in Section 5.2.3 of this Report.

5.6 Computer Aided Drafting

All MDOT bridge designs are now completed using CAD. In most cases, it is now possible for working drawings to be produced automatically by computer, once a structure is designed.

5.7 Contract Plans

The contract plans are the final drawings and specifications that are used by the contractor to bid a project, and for the project to be constructed. The following steps are required to complete Contract plans:

- Data Collection.
- Develop Feasibility Study.
- Prepare Preliminary Plans and Cost Estimate.
- Develop Final Plans and Cost Estimate.

These steps are described below.

5.7.1 Data Collection

The Design Engineer must gather data before preparing Contract plans. This data includes:

- *Engineering Reports.* These detail geometric, architectural, or other constraints on the project. These parameters must be closely followed.
- *Environmental Impact Statement.*
- *Road Design Plan.*
- *Survey Data.* If insufficient survey data exists, the Survey Section should be consulted for additional information. Surveys are usually ordered for all major reconstruction jobs.
- *Geotechnical Data.* The Geotechnical Unit of the Construction and Technology Division should be consulted to determine the soil bearing capacity and what foundation type is needed. See section 3.01 of the Bridge Design Manual for more information.

- *Hydraulic Data.* If the bridge spans water, the Hydraulics Unit should be consulted to determine the required waterway opening, or if a scour analysis is required.
- *Railroad Data.* If a railroad is involved in the project, the Railroad Contact Engineer should be contacted for load and clearance information for railways. See section 13 of the Bridge Design Manual for more information.
- *Aesthetic Recommendations.* Aesthetic considerations need to be addressed in both new and rehabilitation projects. The Roadside Development Section should be consulted for recommendations.
- *Utility Presence.*
- *Permits.* See chapter 14 of the Bridge Design Manual for information.
- *Screening Requests.* Work in the City of Detroit may require pedestrian screening. Consult the City Engineer's Office for details.
- *Maintenance Reports.* If the work is to be done on an existing structure, the current maintenance report should be consulted to help determine the scope of needed work.
- *Construction and Technology Survey.* The Construction and Technology Division should be consulted to determine the condition of existing bridge elements.
- *Traffic and Safety Data.*
- *Pre-G.I. Inspections.* The scope of work should be verified by a site inspection.
- *Grade Inspections (G.I.).*
- *Region maintaining Traffic Recommendations.* The Region Traffic Engineer should be asked for traffic control recommendations during construction.

More detail is provided in section 2 of the Bridge Design Manual.

5.7.2 Feasibility Study

The Feasibility Study is the first set of plans produced by a bridge design unit. It shows immediate topography and the concept for the structure. The structural type, cross-section, span arrangement, and alignment of the bridge are determined in the feasibility study.

The Study is submitted by the Unit Leader to the Design Supervising Engineer for approval. The Studies of federally financed projects for new bridge construction and major rehabilitation projects must be approved by FHWA, before proceeding to the preparation of Preliminary Plans. Detailed information can be found in Chapter 3 of the Bridge Design Manual.

For minor rehabilitation projects, a Study is required only in unusual cases. For routine rehabilitation work, such as deck repair or railing replacements, the Study can be neglected.

As detailed in section 3.01 and 4.01 of the Bridge Design Manual, the following information should be gathered and consulted for the Study:

- Engineering Reports.
- Site topography data.
- Traffic data.
- Soil data.
- Maintenance Reports (for rehabilitation projects).
- The location of existing and/or proposed utilities.
- Waterway data for stream/river crossing structures.
- Programming Section's estimate.
- The minutes of city, county, or other meetings relevant to the project.
- Correspondence files.
- Microfilm and photolog (for rehabilitation projects).
- Aesthetic recommendations of the Roadside Development Unit.

5.7.3 Preliminary Plans

The Preliminary Plans, in which the type, size, and location of the bridge are specified, are the second set of plans prepared by the bridge Design Unit. Preliminary Plans are prepared by the Design Unit for distribution to and approval by FHWA and other concerned agencies such as counties, cities, and both municipal and private utility companies. Preliminary Plans are required for all new construction and major rehabilitation projects, but not for minor rehabilitation or repair projects. Information on traffic volume must be included in the Preliminary Plans, as must a proposed concept for maintaining traffic through the construction zone (see IM #472-B for details). The Preliminary Plans are submitted by the Unit Leader to the Design Supervising Engineer for approval. Detailed information can be found in Chapter 3 of the Bridge Design Manual.

Full details are given in section 3.02 and 4.02 of the Bridge Design Manual.

5.7.4 Cost Estimate

A cost estimate must accompany the Feasibility Study and Preliminary Plans. At these stages, cost estimates consist only of the major items for the project. Unit prices are obtained from the Specifications, Estimates and Plan review Section.

Rough cost estimates for the Feasibility Study are described in section 3.01.02 of the Bridge Design Manual for new and reconstruction projects, and in section 4.01.02 for rehabilitation projects. Preliminary Plan cost estimates are described in section 3.02.02 of the Manual. If the scope of work changes, or if there is a long time delay for project letting, the cost estimate should be recomputed.

The "status of plan" (i.e. percent of work dated complete) estimates should be reviewed at the following stages of plan development:

- Upon completion of the Study
- Upon completion of the Preliminary Plans
- Whenever the scope of work changes.
- When lettings are delayed appreciably (review yearly).

The Programmed Cost Estimate shall be updated whenever the current cost estimate exceeds that shown on the Status of Plans.

5.7.5 Final Plans & Bid Proposals

This is the third and final set of plans that the bridge Design Unit produces for a project. Work on the final plans begins after the FHWA has approved the Preliminary Plans. The Final plans contain all structural details, the quantities of materials and the specifications to be included in Bid Proposals. Final Plans are required for all projects. Before Final Plans are distributed, it is the responsibility of the Unit Leader to ensure that various agencies have sent back the Preliminary Plans and that their comments, additions, and requests have been incorporated in the Final Plans, when acceptable. Unit Leaders should review the proposals to verify that the specifications and special provisions agree with the plans.

More details are provided in sections 2, 3, and 4 of the Bridge Design Manual.

5.8 Specifications and Cost Estimates

5.8.1 Specifications

The Design Engineer is responsible for the specifications. These are the notes that accompany the plans which describe how the work is to be done, the materials and equipment that are to be used, and the method of measurement and payment for the work. There are three types of specifications, which are as follows:

- Standard Specifications. These are found in Standard Specifications for Construction. Unless otherwise specified, work will be done according to these specifications.

- Supplemental Specifications. These are official additions and revisions to the Standard Specifications. The Design Engineer must determine which supplemental specifications should be included in the contract documents.

- Special Provisions. The Design Engineer may need to specify a work item that is absent or different from that described in the Standard Specifications. In this case, the engineer should write a special provision.

Correct Specification format can be found in Appendix 15.02 of the Bridge Design Manual.

5.8.2 Final Cost Estimates

A final cost estimate must accompany the final plans and proposal for bidding purposes. This is a detailed, accurate estimate of project cost.

5.9 Reviews, Advertisement and Letting

5.9.1 Plan Review.

There are three stages of plan checking for plans drawn by MDOT, as detailed in the Bridge Design Manual (Sec 2.04.03). First, the drafting supervisor reviews plans drawn by the Bridge Design Program or drafter, and makes corrections as necessary. Second, the Engineer verifies that the plans were prepared with accepted specifications and procedures. Third, the Design Engineer completes a final review of the plans. Reviews are discussed in more detail in Section 8 of this report.

5.9.2 Shop Drawing Review.

The Bridge Fabrication Engineer usually reviews shop drawings for structural steel, prestressed concrete beams, and fabricator designed bearings. The Design Division must ultimately approve all drawings. It is not necessary to check exact dimensions, which is the responsibility of the contractor. It is MDOT's responsibility to check that the fabricator is supplying the items specified.

As described in Section 10 of the Bridge Design Manual, prior to fabrication, MDOT must review and approve shop drawings for:

- Structural Steel
- Prestressed Concrete Beams
- Bearings
- Railings

- Expansion Joints
- Steel reinforcement sheets (where applicable)
- Water mains, mechanical and electrical equipment

5.9.2.a Structural Steel.

These shop drawings must be reviewed for the following items:

- Erection Diagram. The layout of the steel, and the marking scheme for member identification must be shown.
- Members. Size and number for all members must be specified.
- Splice details. The number, size, and type of bolts must be identified, as must the length of all welds and a section showing the size of all splice materials.
- Field connection details. The number, size, and type of bolts should be shown, as should the locations where reaming is required.
- Shear developers. The number, size, and spacing must be specified.
- Camber. The amount and location of camber, and the permissible tolerances, must be shown.
- ASTM designation of steel.
- Steel surface preparation. The type of shop painting also must be specified.
- Notes. All notes on the design plans must appear on the shop drawings.
- Structural steel weights.
- Blocking and lifting diagrams.

5.9.2.b Prestressed Concrete.

- Erection Diagram. The layout of the elements must be shown.
- Members. Size and number for all members must be specified.
- Bearing Details. Size, type, and materials must be shown.
- Support Points. The location and details of lifting devices and of support points, if the beam does not rest on its bearings while being transported.
- Inserts. The location and type of inserts required for attachment.
- Bond breakers. Location and length.
- Reinforcing Steel. Details and type.
- Notes. All notes on the design plans must appear on the shop drawings.

5.9.2.c Bearings.

- Location Diagram. Layout of the structure and locations of the bearings must be specified.
- Number, type, and sizes.
- Details. Materials, dimensions, and welding.
- Steel surface preparation. The type of shop painting also must be specified.
- Notes. The material and design specifications must be shown.

Shop drawings for railings and expansion joints are not required. Provisions are detailed in section 10.01 of the Bridge Design Manual. Shop drawings for mechanical and electrical equipment, and for water mains, must be reviewed for general conformance with the design specifications and plan details.

5.9.3 Advertisement & Letting

Letting is the process of project advertisement, accepting and evaluating bids for the work, and determining the low bidder.

Once final plans of the structure are drawn, an advertisement is developed and placed in trade publications to inform contractors of the proposed work. The advertisement provides general project information including the project description, bid items, the project completion date, and the category and level of pre-qualification needed of the bidding contractor.

Two types of letting proposals are made available: the courtesy proposal, which is not for bidding, and the bidding proposal which is provided to qualified bidders. A pre-bid meeting may be held to answer questions that bidders may have concerning the work.

The bidders then prepare and submit their sealed bids, and at a predetermined time the bids are opened for the pre-qualified bidders. The bid opening is open to all bidders and the general public. The bid amounts read at the bid opening are unofficial. The bids are examined in detail to verify, screen and check the bidding document which includes evaluating for authorized signatures, proper completion of bid item pages and special requirements. The totals are also computer verified using the pay items and quantities. An internal review committee reviews all bidding irregularities and bids recommended for rejection. A determination is then made of the low bidder.

Arrangements are made to resolve letting-related problems. One problem that may arise is the need for the justification of bids when all bids are 10% or more over the engineer's estimate. This justification is sent to the department's management for approval.

5.10 Bridge Design for Better Maintenance

Joint deterioration is one of the biggest bridge maintenance problems, and good joint detailing (or joint elimination, when feasible) can save significant costs over the lifetime of the structure. This is one area in which lifecycle costs should especially be taken into account.

As discussed in section 5.1, multi-span steel structures shall be continuous whenever possible. When girders are prestressed concrete I-beams, decks should be continuous over piers. This is also recommended when replacing existing simple spans in a rehabilitation project. Girder continuity is desired because it eliminates expansion joints over piers, a prime deterioration problem. Semi-integral abutments are also favorable, as again, this removes the joint from the bridge and prevents girder deterioration.

5.11 Other Design Issues

5.11.1 Utilities

Projects constructed with federal funds may require a water main relocation study. This study will be performed if the water main is located: a) under existing pavement which will be removed; b) outside existing pavement but under proposed pavement widening; c) under new roadways. It should also be performed when a review of the water main characteristics (age, material, type of joint, maintenance history, etc.) indicates a possibility that leaving the water main in place could adversely impact the proposed design life of the pavement.

Relocation studies will not be performed if a water main which is not to be removed is located under existing pavement that is not to be removed (i.e. only resurfaced), unless the life expectancy of the proposed resurfacing is greater than 15 years. Examples of projects not requiring a water main study are: pavement joint placement, resurfacing with 1.46 kN/m^2 (270#/syd) of bituminous or less, shoulder repair, milling and resurfacing with 1.46 kN/m^2 or less of bituminous, curb and gutter removal and replacement, etc.

The governing Region and the Lansing Municipal Utility Design Unit will make a recommendation whether or not to relocate the facility. Information about costs of a relocation and who pays for the relocation can be found in Informational Memorandum #441B and #402R, although in general, the municipality must pay 50% of the non-federal costs of the main.

MDOT is to relocate sanitary sewers, storm sewers, power lines, power poles, street lights, communication lines, etc., only when they are in direct conflict with proposed construction.

This information is taken from the Design Division Informational Memorandum #441B and #402R, April 13, 1992.

5.11.2 Lighting

Light standard foundations should be located, and the Geotechnical Unit should be consulted to determine the constructability and foundations needed for lighting units. To avoid a hazard, the top of the foundation should not protrude above the ground slope. Light standards and mast arms require approved shop drawings.

A frequently overlooked electrical utility problem is insufficient overhead clearance, which requires utility relocation. Relocation of utility facilities is usually referred to the regional real estate agent or utility engineer.

Electricians employed by the construction contractor are trained to produce work according to the National Electrical Code. This code may be at variance with MDOT plans and specifications, however. Because of this, it is recommended that before construction, the resident engineer should carefully study the plans and special provisions so MDOT specifications are well known, and during construction, the work should be watched carefully so possible discrepancies can be caught. Underground electrical work must be inspected while under construction, as it cannot be seen once the work is completed.

It is the responsibility of the resident/project engineer to review regional office files and contact the regional traffic and safety engineer and utility engineer concerning all existing electrical utility agreements.

Important lighting reference guides are the Standard Specifications, Supplemental Specifications, Shop Drawings and Special Details of particular projects, the Michigan Electrical Administration Act, and the Electrical Construction Inspector's Check List.

5.11.3 Geotechnical

The Geotechnical Services Unit recommends to the structural engineer the foundation type, construction method, and the water surface elevation to use, among other geotechnical aspects of design.

For spread footings, the geotechnical unit investigates resistance to sliding, dead and live load, and edge pressure on the footing. They determine the allowable bearing pressure and provide adequate footing dimensions based on these criteria. For deep foundations, recommendations are provided for pile type, length, and minimum penetration.

The Geotechnical Unit bases its design recommendations on methods found in the MDOT Field Manual of Soil Engineering (1975). It is still used by MDOT for geotechnical design, construction, and investigation. This manual is based on the methodology of Professor Housel. Most consultants work with the methods of Dr. Peck, however, and MDOT is currently moving toward this approach. The primary difference between the methods of Housel and Peck is that Housel does not consider soil consolidation when investigating settlement, while Peck does. The geotechnical investigation is further described in section 4.5 above.

It is important that the structural engineer consult the geotechnical unit to minimize foundation construction costs. To avoid the expense of unnecessary borings, the engineer should supply as much existing information as possible to the Geotechnical Unit. Basic information that the geotechnical unit requires is the following:

- Size and structural type of the bridge
- Location of the foundation units
- Elevation controls, such as those from benchmarks or existing plans or borings

This information can be found in the Plan File. This list is not exhaustive, and additional information may be needed in specific circumstances.

Although the Geotechnical Unit provides recommendations, it is the responsibility of the structural engineer to ultimately determine the type of foundation and method of construction to use.

5.11.4 Hydraulics/Scour

Scour is the result of erosive action of flowing water, which excavates and carries away material from the bed and banks of streams. Loose granular soils are most susceptible. Excessive scour, if not prevented by countermeasures, may cause substructure lifting and bridge collapse.

For any waterway crossing that the engineer must deal with in the bridge project, the scour potential must be checked (as discussed in section 4.4). This information is available from the Hydraulics/Hydrology Unit.

Bridges are given scour ratings of 0 through 9, 0 meaning a failed/out of service condition and 9 meaning that the foundations are completely clear of water. A scour critical bridge is one with abutment or pier foundations which are rated as unstable due to (1) observed scour at the bridge site or (2) scour potential as determined from a scour evaluation study. A bridge is classified as scour-critical if it has a scour rating of 3 or below.

There are two types of scour analyses. A Level 1 analysis is a qualitative study to determine hydraulic effects, the overall long-term stability of the crossing, and the potential for waterway response to change. For the most part, this is an assessment by identifying scour trends in previously collected data and from field inspections. The Hydraulics/Hydrology Unit has completed a Level 1 scour analysis for all bridges over water in Michigan.

A Level 2 analysis involves the basic engineering assessment of scour problems at highway crossings, by which scour depths are calculated. In this stage, scour equations are used to estimate and evaluate scour. The Hydraulics Unit will provide the Design Engineer a scour depth, below which the foundations of new structures are to be placed.

A status report of scour advancement is filed with the FHWA for all scour-critical bridges every six months, and these bridges may be put on an accelerated inspection schedule. Preventing and fixing scour damage is a priority when rehabilitation/replacement funds are allocated.

Although the structural engineer does not complete scour or hydraulics analyses at MDOT, it is his or her responsibility to use engineering judgment when considering the recommendations given by the Hydraulics Unit. In general, abutment scour calculations done by the Hydraulics Unit are conservative. However, past experience has shown that it is almost always more cost effective to provide a foundation that does not fail, rather than providing a less adequate foundation that is initially less expensive. It is important that the engineer inform the hydraulics unit of design changes as soon as possible, as these may require a re-evaluation of scour potential. The engineer should also send a copy of the proposed bridge plans to the County Drain Commissioner.

Some bridge design recommendations that consider hydraulic issues can be found in "Evaluating Scour at Bridges, Third Ed." (Report HEC-18) US DOT, Richardson and Davis, 1996.