6. CONSTRUCTION

6.1 Construction Contract - Project Management

6.2 Bridge Construction

6.3 Post Construction Review

6. CONSTRUCTION

The Construction Manual and the Standard Specifications are the two guides used to govern construction. In this report, the 1998 and 1996 versions of these documents are referred to, respectively. All construction is done by contractor, as MDOT only designs and manages construction.

The Construction Manual is organized in divisions that parallel sections in the Standard Specifications. These divisions are the following:

Division I:	General Provisions
Division II:	Earthwork
Division III:	Base Courses
Division IV:	Drainage
Division V:	Bituminous Pavements and Surface Treatments
Division VI:	Portland Cement Concrete Pavements
Division VII:	Structures
Division VIII:	Incidental Construction
Division IX:	Materials

A new construction manual is currently being developed. This will primarily reflect changes in options for contractor staking and quality control.

As of 1998, there is approximately $160 million available for construction. This money is divided into separate funds. These are:

- big bridge/movable bridge fund, $10 million.
- emergency repairs, $10 million.
- general "preserve" fund, $140 million. Most of this money is spent for maintenance and replacement.

Private firms sometimes staff field offices.

A "resident" engineer is an engineer in the construction division.

6.1 Construction Contract - Project Management

The resident/project engineer is responsible for directing and supervising the construction work. The engineer's duties include: measurement and payment; maintenance of complete and accurate records; preparation of changes, extras, pay estimate, and progress reports; coordination of contractors work and public utilities; and the use and care of assigned furniture and equipment. It is also the engineer's duty to instruct the contractor when needed.

Additional duties of the resident/project engineer are:

- to establish the construction staking lines and grades for control of the work
- inspection for quality assurance of the work
- to establish efficient use of manpower via the methods described in the "Procedure Manual for the Construction Manpower Management System."
- to maintain the on-the-job technician training program, as detailed in "Work Element Certification Procedures and Personnel Classification Plan for Construction Technicians."

One of the most significant documents used to monitor construction is the Inspector's daily report (IDR). This report lists the pay (work) items together with their codes, quantities or field measurements. Traffic device checks should also be recorded daily. It is the senior technician's responsibility to collect all reports daily, review them and turn them in to the office technician.

The bi-weekly (or weekly) construction estimate report includes work item codes and quantities. The report is prepared for the purpose of making a computer estimate of the progress and final payments to the contractor. As this document is also used for reporting final estimates, the information has to be as accurate as possible.

The bi-weekly construction progress report is used to record the progress of the work on a project. The purpose is to inform the FHWA, engineer of construction and Regional engineer about the progress of work, its quality, construction methods and difficulties encountered. The construction progress reports are submitted the same day as the estimate. In cases of work suspension for extended periods of time, the reporting can be terminated until work is resumed. The construction progress report contains the information about the progress and location of work items and the percentage of completion.

Construction contracts are handled by the Construction Finance Division; it is not the duty of the design engineer to write contracts.

6.2 Bridge Construction

6.2.1 Layout and Foundations

As stated in the Construction Manual, a large portion of engineering costs are effected by construction staking, and errors can be expensive. The survey crew is responsible for staking, and proper procedures are detailed in the Manual.

Plans should be checked for:

- right of way (R.O.W.) conflicts
- proper under-clearance and bridge alignment with the roadway
- sewer grade/utility, etc. conflicts and proper drainage
- proper vertical alignment and correct super-elevation lengths
- horizontal alignment and correct curve data

Foundation piles are usually cast-in-place (CIP) concrete in steel shells, or steel H-sections. Fluted shells and treated timber piles can be used but are rare. Steel sheet piling can also be used, as a temporary or permanent element, or as part of a cofferdam. Drop hammers are not permitted for driving foundation piling. Pile bearing capacity can be determined by the pile formulas, found in the Construction Manual. Additional information on foundation types can be found in sections 4.5 and 5.10 of this document.

Although not normally required, sub-footing concrete is sometimes placed to provide a working surface on which footing forms can be erected. This concrete has no structural significance.

Over-excavation for the footings is to be avoided, as the allowable bearing pressure is computed based on undisturbed soil, and digging followed by back-filling weakens it.

6.2.2 Substructure

It is very important that the bridge abutments are rigidly supported by stable embankments, a condition that can be achieved by correct excavation and backfill procedures. Although foundation excavation, rock foundation excavation, and unclassified foundation excavation are all listed in the Standard Specifications, unclassified excavation is most often used. Proper backfill, excavation, and measurement of excavation quantities are described in the Construction Manual.

When bridge substructures need repairs, the engineer should be aware that the cost of extensive patching may be greater than the removal and replacement of a portion of the substructure. Where removal of the substructure is feasible it should be considered. A prime example of this is removing a portion of a pier cap on a project that includes superstructure replacement (IM #446-B).

A cofferdam, a water-tight enclosure to permit construction of the substructure in the dry, is often used in bridge construction. It most commonly consists of steel sheet piling, anchored at the base by the sub-footing or tremie seal concrete. Tremie seal concrete, a specially-designed mix, provides lateral support to the cofferdam sheeting and resists hydrostatic pressure from below when the cofferdam is dewatered.

The contractor is responsible for the design, construction, and use of the cofferdam. The resident engineer should ensure, however, that it does not hinder navigation in the river, is safe and stable, and that it has DNR approval if needed.

Details for concrete formwork are in the Standard Specifications, which describe the covering material, size, stud and wailer spacing, required moldings, bracing, oiling, and removal procedure. Forms should be inspected as soon as they arrive on site for job adequacy.

6.2.3 Superstructures

6.2.3.a Concrete Construction

The contractor has the responsibility for the adequate bracing of all forms. If the deck is a cast-in-place T-beam type, then falsework, a temporary support structure, is needed. Falsework is to be supported by piling if another foundation support is not detailed on plans. The approval of falsework and forms is required before concrete is placed.

The barrier, curb, and railing lines are important for the appearance of the bridge, and these forms should be placed and inspected with extreme care.

For satisfactory performance, expansion joints must be straight and true; the forming around the joint is to be well-secured before casting. Premolded joints must be tested prior to use, and the material is best placed in the largest pieces possible. Neoprene joints are to be in full-length pieces across the width of the bridge.

6.2.3.b Deck Construction

Deck construction usually involves repairing or replacing existing concrete, most often in the form of an overlay. A deck surface is prepared for an overlay by removing bit patches, unsound concrete, and removing the deck to the top mat of reinforcement. Although this top layer of concrete is usually contaminated with salt and oil and thus removed, additional areas of the deck are demolished to a needed depth to eliminate all unsound concrete. The removal is done by hand chipping, scarifying and hydrodemolishing as outlined in section 7 of the Standard Specifications. The new concrete is then placed, textured, and covered. Slump and air tests must be conducted on the new concrete. Complete construction instructions are found in the Construction Manual.

6.2.3.c Steel Construction

Before placement, superstructure steel should be checked for damage and the MDOT approval mark. Before girders are placed, masonry plates are first set on the concrete bridge seats and their proper fit verified.

When the steel girders are placed, the required gaps at pin connection joints for expansion can be found in the Construction Manual. It is important to provide lateral bracing to the girders during construction to prevent collapses due to possible instabilities. Diaphragms, falsework, or other temporary bracing can be used.

All welders must be pre-qualified. Qualification tests are conducted by the construction inspector, a welding inspector from the materials and technology division, or a welding approval agency.

6.3 Post Construction Review

A Post Construction Review may be initiated at the end of each project. It is an optional evaluation, usually carried out for large or unique projects, or for those in which something particularly good or bad occurred. It is used to identify what needed improvement and what worked well in the construction process. This last point, the identification of successes, is particularly important to document.

Specific design recommendations or recommendations dealing with specific problems encountered during construction should be noted on the Design/Construction Package Evaluation Form. This form is used at several stages of the project's development, including the Post-Construction Project Review Meeting. These recommendations are considered for future construction projects by a design/ construction recommendation committee.

On the Evaluation Form, items are rated as unsatisfactory, below average, satisfactory, above average, or excellent. Some of these items are: plan clarity, accuracy, and completeness; the accuracy and completeness of surveys; adequacy of maintaining traffic plans; utility information; meeting MDOT/FHWA requirements; cooperation; timeliness (completion of P/PMS milestones); general constructability; accuracy of cost and quantity estimates; environmental requirements addressed; consistency of as-built plans with final plans.

At the end of construction, if the as-built structure differs from the plans, the plans are marked with these "as constructed" changes, and the plans are submitted to the Design Division in Lansing for future reference. The following is a list of changes that must be noted:

- Horizontal control: changes in alignment, bearings, curve data, witnesses, and ROW fencing.
- Vertical control: changes in curves, benchmarks, grade changes, elevation.

- Drainage and topographical: changes in location, elevation, length, and size of drainage features, and guardrails, slopes, roads, utilities. Minor changes in earthwork and surfacing not necessary to note.

Another important purpose of the Post Construction Review is to note what cost overruns occurred. A common cost overrun is due to an inaccurate assessment of the initial project conditions; for example, not accurately estimating quantities for deck demolition. Cost overruns are also common, and sometimes unavoidable, because unit prices change over time. Because some projects may take years to complete, from the cost estimate to construction completion, inflation and other market forces can raise prices significantly.

7. MATERIALS

7.1 Concrete

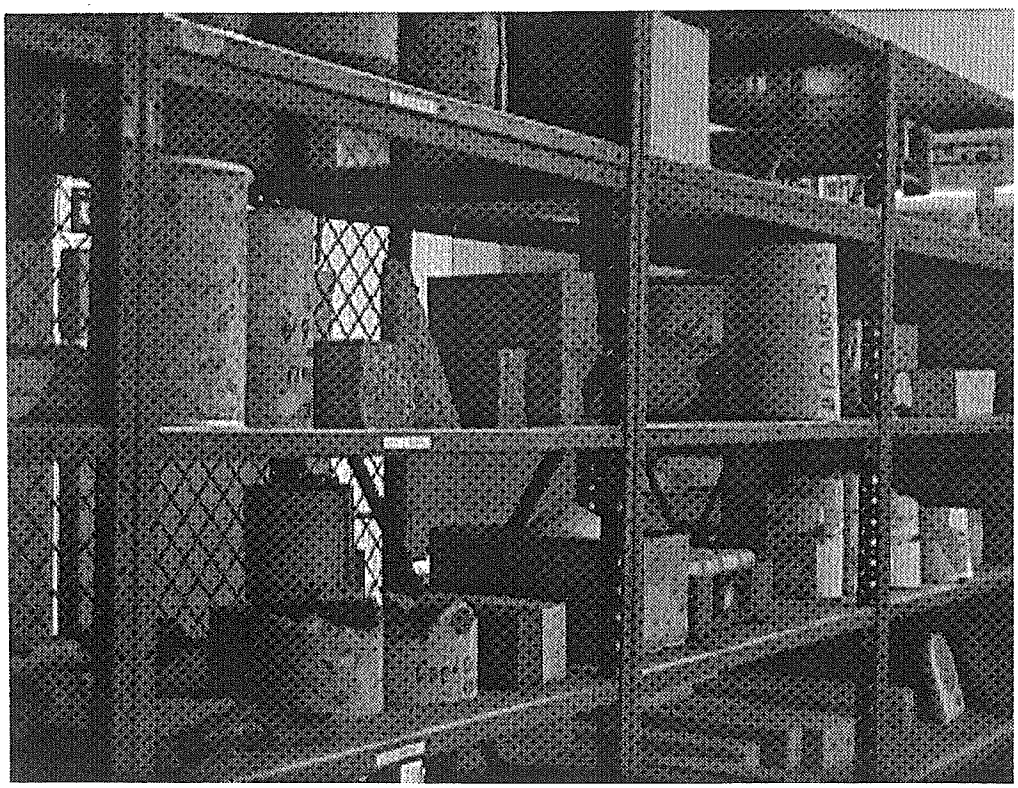
7.2 Structural Steel

7.3 Reinforcing and Prestressing Steel

7.4 Wood

7.5 Bearings and Expansion Joints

7.6 Sealants and Epoxy



7. MATERIALS

MDOT recommends the use of the following materials in design and construction of bridge structures:

- Portland Cement Concrete,
- Structural Steel,
- Wood,
- Metal and Elastomeric Bearings,
- Sealants, Epoxy and other.

7.1 Concrete

Concrete consists of a mixture of Portland cement, coarse and fine aggregate and water. Admixtures will be used when required or permitted. Unless otherwise specified, air-entrained concrete is required. The material requirements for Portland cement concrete are specified in the Standard Specifications for Construction.

The following grades of concrete are specified: D, S1, T, S2, S3. The concrete mixture proportions will be selected by the Engineer in compliance of Table 7.01-1 in the Standard Specifications. MDOT currently uses concrete with compressive strengths up to 48 MPa (7000 psi), although there are plans to use higher strengths in the future. Concrete and mortar mixtures used for patching and resurfacing can be different from mixtures used in new construction. Details are found in the Construction Manual. Concrete strength shall be checked by compressive tests and by beam tests in flexure, according to MDOT procedures.

Proper curing is essential for quality concrete construction. To retain water in the concrete as it cures, the surface must either be kept wet or sealed to prevent evaporation. As per the Standard Specifications, exposed top surfaces such as floors, wearing surfaces, and bridge seats, are cured for 6 days, while other surfaces are cured for 5 days. Appropriate curing methods vary depending on structural component. Bridge decks are covered with a modified linseed oil membrane spray, and later are wet-cured. Structural concrete used on piers, abutments, and beneath deck expansion joints is coated with a two-component liquid polysulfide-epoxy resin seal. The Standard Specifications should be consulted for more detail.

7.2 Structural Steel

Steel grades recommended for bridge design are summarized in Table 5-4 of section 5.4.3 in this document.

7.2.1 Fabrication

The material requirements for structural steel and steel structures are specified in Standard Specifications for Construction. Unless otherwise specified, the requirements for delivery of structural steel should conform to ASTM A 6M. All main member material, but not limited to, rolled beams, cover plates, flange and web plates, link bars, end diaphragms, and intermediate cross-frames, shall meet the requirements of longitudinal Charpy-V notch impact requirements indicated in section 9 of the Standard Specifications. Structural steel furnished to the construction site needs to have: Mill Test Reports, records of chemical composition and physical properties, and an affidavit stating that the material meets requirements.

7.2.2 Coatings

Structural steel should be painted light gray or light blue. In the case of repair work, it is recommended that the paint match the existing structure color.

7.2.3 Structural Steel Fabrication Inspection

The requirements concerning the inspection of structural steel fabrication are given in the Materials Quality Assurance Procedures Manual, section d-13. Two major types of inspection are specified: welding inspection and painting inspection. The Manual covers the following topics:

- Required qualifications and responsibilities of the Inspection Agency.
- Duties of the Inspector Engineer. The Inspector shall be qualified and certified under the AWS Standard for Qualification and Certification of Welding Inspectors, QC-1. The responsibilities of the inspector comprise: checking the quality of materials and equipment, observing the welding techniques and procedures, and checking the quality of the welds and compliance with the design plans and specifications.
- Welding Inspection Procedures; Inspection procedures can be classified as: prior to welding, welding in progress, and after welding.
- Nondestructive Testing (radiographic, ultrasonic, magnetic particle, liquid dye penetrant). By contract, nondestructive testing is the responsibility of the fabricator's Quality Control personnel.
- Cleaning and Coating Inspection Procedures. Environmental conditions, materials, equipment, surface conditions, surface preparation, and coating application are covered.
- Inspection Equipment.
- Inspection Documentation.

Inquiries received by the Design Division from fabricators should go through the Structural Fabrication Engineer for inspection and approval.

The final decision on acceptance or rejection of structural fabrication comes from the Materials and Technology Division, not the Design Division, though there may be overriding considerations that supercede their decision (IM #456-B).

Michigan Specifications require that all welding procedures be qualified by testing prior to any job welding. This rule overrides any considerations of AWS Specifications. Each inspection test must be performed as indicated by the contract plans and specifications. The following documents apply to testing:

- AWS Welding Code.
- ASTM E 709 "Magnetic Particle Examination."
- ASTM E 165 "Liquid Penetrant Inspection Method.

7.3 Reinforcing and Prestressing Steel

7.3.1 Deformed Bars Grades

The following grades of deformed bars are permitted in the design of bridge structures in Michigan:

- Grade 400 (ASTM A 615M, A 616M, ASTM A 617M), as bar reinforcement in reinforced concrete beams.
- Grade 300 (ASTM A 615M, A 617M) and Grade 350 (ASTM A 616M), as bar reinforcement in prestressed concrete beams.

Spiral reinforcement shall meet the requirements for plain or deformed Grade 300 bars.

7.3.2 Epoxy Coating

Steel reinforcement shall be epoxy coated in accordance with the requirements of ASTM D 3963M-93a. The coating shall be selected from the list of Department Qualified Products.

7.3.3 Strands for Pre-tensioned Prestressed Concrete

MDOT recommends the use of 15.24 mm (0.6 inch) nominal diameter strands meeting the requirements of ASTM A 416, Grade 270, Supplement I (Low Relaxation Strand). Other types can be used if specified.

7.3.4 Tendons for Post-tensioned Prestressed Concrete Box Beams

MDOT requires that tendons meet the requirements as specified for Grade 270 steel strand of ASTM A 416, or high strength bars of ASTM A 722.

7.4 Wood

There is only a single wood bridge on the Michigan trunkline, a timber arch structure across Eagle River in the Upper Peninsula. Wood is not used on a bridge as the primary structural material by MDOT for two reasons: it was usually found to be uneconomical when compared to other materials, and the wearing surface on wooden bridges deteriorates quickly.

Locally, however, wood bridges are much more common. Some roads that cross through "wild and scenic" areas must sometimes use wood bridges, as stipulated by the DNR for a permit to build.

Although ended in 1998, the Timber Bridge Program provided federal funds for timber bridges, and with this capital approximately 5-6 structures were built yearly in Michigan by local authorities (counties and cities). Wood bridges that had innovative designs were given priority. Another source of funding for timber bridges is the Critical Bridge Program, through which local authorities throughout Michigan build from 3-5 bridges each year.

MDOT reviews bridge designs for code compliance and determines which local projects will be funded. Designs are done by consultants or local agencies, as MDOT's Design Unit does not design for local authorities.

7.5 Bearings and Expansion Joints

7.5.1 Elastomeric Bearings

Elastomeric bearings shall conform to the requirements for 100% virgin polychloroprene (neoprene) bearings as specified in the AASHTO Code. Grade 50 durometer shall be used for laminated bearings and Grade 70 durometer for plain bearings unless otherwise specified on the plans.

7.5.2 Metal Bearings

Washers, bearings and expansion plates should meet the following requirements:

- Bronze castings: as specified by ASTM B 22.
- Copper-alloy plates and sheets: as specified by ASTM B 100

Bronze castings should be free from defects: casting faults, inclusion of foreign material, blow holes or other. Finished parts should meet the dimension tolerance of ±5% on thickness, and ±0.32mm (±1/8") on width or length.

7.5.3 Expansion Joints and Devices

Expansion joints should be used in concrete structures only where provided on the plans or by authorization. The requirements for joints are specified in the Standard Specifications for Construction, section 9, and it covers the following items: sealer, fiber joint filler, neoprene joint seals and expansion joint devices. Additional information about the performance and areas of application of different expansion setups can be found in the Construction Manual. This covers pre-molded joints, dams, expansion devices, neoprene, hot-poured rubber asphalt type filler and cold applied joint seal.

Due to continued deck cracking problems, at transverse deck joints where the reinforcement steel does not continue through the slab, only an approved expansion joint device (shown on the EJ sheet) should be used. Elastomeric concrete joints have not provided good performance, and are no longer used by MDOT for this application. Sawed deck joints, typically 13mm deep and 6mm wide, filled with either hot poured rubber or cold applied sealant, are now used.

Neoprene compression seals also give poor performance on bridge decks. Other than the neoprene pressure joint (i.e. Jeene joint), neoprene compression seals fail frequently. With the exception of the neoprene pressure joint, these seals are not to be specified. At joints where movement is anticipated, an expansion joint device shall be used. At joint locations where no movement is anticipated, a hot poured joint shall be used.

7.6 Sealants and Epoxy

The material requirements for waterproofing and protective covers are specified in the Standard Specifications. Fiber joint filler should not be in a broken or deformed condition due to twisting, bending or handling.

7.6.1 Sealants

Joint sealants described in the Standard Specifications for concrete include Hot-Poured Joint Sealant, Single-Component Joint Sealant, Preformed Joint Seals and Neoprene Seals. For these materials, special provisions beyond ASTM standards apply for MDOT construction, as specified in the Standard Specifications.

7.6.2 Epoxy

Epoxy may improve the bond between newly-placed and existing concrete, but only if it is applied properly. If the concrete is not cast within a critical period following the application of the agent, the resulting bond is worse than if no epoxy were applied at all. Because it is often difficult to insure that the concrete is cast within this critical

period, it is MDOT's policy to avoid the use of epoxy bonding agent for this purpose (IM #426-B, January, 1991).

In other cases, the requirements for epoxy materials are specified in the Standard Specifications for Construction, section 9. These materials can be used for the following applications:

- Epoxy Binder for Joint Spall Repair. Epoxy binder shall be mixed with dry 2MS masonry sand for the repair of spalls. The type of the epoxy binder to be used depends on the temperature conditions. Type I shall be used for temperatures of 15-40°C (60-104 F), and Type II for 2-15°C (35-60 F). The viscosity should have the proper values as given in section 9 of the Standard Specifications.

- Epoxy Compounds for Anchoring Steel Bars or Bolts in Concrete. Epoxy Mortar should be used for hole clearances greater than 6 mm (0.25"). For smaller holes, Epoxy Grout should be applied. Epoxy Mortar shall be composed of a two-component epoxy binder, and dry fine aggregate 2MS. The temperature requirements are as follows: Type I Epoxy Binder - 20-40°C (68-104 F), Type II Epoxy Binder - 4-20°C (40-68 F). Epoxy Grout shall be composed of a two-component epoxy binder. The temperature requirements are as follows: Type I Epoxy Binder - 20-40°C (68-104 F), Type II Epoxy Binder - 4-20°C (40-68 F).

- Epoxy Resin Adhesive. Acceptable adhesives can be found on the Qualified Products List. Other products must be submitted for testing, and must meet the requirements in section 914.07 of the Standard Specifications, prior to use.

8. QUALITY ASSURANCE/QUALITY CONTROL

8.1 QA/QC Stages of the Project

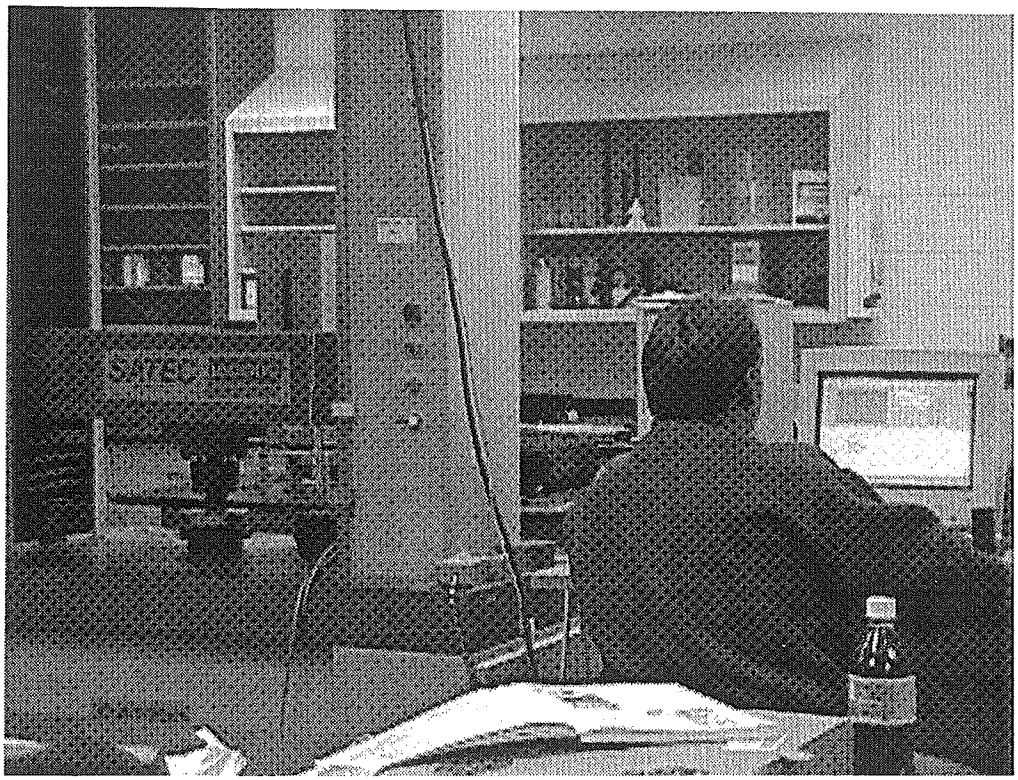
8.2 Pre Grade Inspection

8.3 Grade Inspection, Plans-in-Hand Inspection

8.4 Standards

8.5 Coordination

8.6 Reviews



8. QUALITY ASSURANCE/QUALITY CONTROL

Quality Assurance (QA) is the organized monitoring process designed to insure that the final product (the constructed bridge) meets its specified requirements. These requirements can be in terms of the structure's performance, project completion time, and cost. Quality Control (QC) refers to the steps that individuals can take, such as checking and following standard procedures, to produce a quality product.

8.1 QA/QC Stages of the Project

QA/QC occur throughout the life of a bridge project, which can be, for consideration of QA/QC, broken in seven broad categories:

1. Initial Project Scope
2. Bridge Design
3. Plan Drafting.
4. Project Letting.
5. Construction Materials.
6. Final Acceptance.
7. Post Construction Review.

8.1.1. Initial Project Scope

In the initial stages of the project, the bridge location, structural type, size and geometry are established. Although location is usually pre-determined, the type of structure to use, and its size and geometry, are left to the designer. QA relies upon FHWA guidelines, the AASHTO Code, and MDOT's past experience, both documented in its Design Manuals and Guides and undocumented, to insure that the structure, or its proposed fix if a rehabilitation project, is properly conceived.

Several QC checklists are also used at this stage in the project. The Project Scope Plan Sheet is used to reduce the number of revisions to a project's scope and cost during the design phase, to provide feedback to the Regions to improve future scoping, and to eliminate the tendency to add work during construction. This sheet is included in the plan sheets. To verify project scope for bridge rehabilitation projects, the Engineer uses the Scoping Checklist, which lists items that should be checked, to assure that needed work is not missed. Finally, the overall project concept and scope are evaluated by a standard form.

8.1.2. Bridge Design.

When the structure is analyzed and designed, the engineer typically uses the Bridge Design Program, which curtails human errors. Computer output is spot-checked to verify that the results are reasonable. Span length and ultimate capacity of girders, and shear and forces on

abutments and piers, among other items critical for a particular structure, are among the output checked.

Details not designed by the Bridge Design Program are backed up by calculations, and all design calculations, computer input, and quantity computations are independently checked. These documents are included in the project's permanent record.

8.1.3. Plan Drafting.

As with design, many plan items are drafted by computer automation, which helps to decrease plan preparation time and reduce human error. These computer-drawn plans are also checked. Slab and screed elevations, haunches, and required bulkhead elevations are some items verified. The plans are further checked for geometric conformity and whether they work together as a set. Geometric accuracy is enhanced by referring all dimensions to reference and/or bearing lines, as well as to fixed control points (C.P.) on the construction site. Control points are the intersections of reference and bearing lines with bridge centerline and fascia lines.

A QC tool at this stage is the Checklist for Review of Bridge Plans, which lists in detail items on the plans which should be checked before submission.

To track responsibility and to assure that the checking was done, both the designer and checker initial plans. Typically, two Engineers, a drafting technician, and a Unit Leader check plans independently, and errors are corrected immediately.

8.1.4. Project Letting.

Before the project is let (i.e. a contract is awarded for construction), non-design items, such as utility permits, ROW issues, quantity and cost estimates, among others, are checked for veracity and completion. The preliminary and final ROW submittals are evaluated with the aid of the Preliminary/Final Right of Way Submittal Review form. The final Design Package (the design and construction plans and proposals) is also evaluated.

During Letting, the Engineer records the contractor's questions about the plans and specifications on the Contractor Inquiries sheet. If contractors discover errors or omissions in the plans, all prospective contractors are notified by MDOT so that they can bid on the project accordingly.

8.1.5. Construction Materials.

Material quality is upheld by use of the Qualified Products List, which specifies construction products approved for use by MDOT. Prestressed concrete and steel girder fabrication drawings are reviewed by the Design Division as well as the Construction & Technology Division prior to casting or fabrication of the girders.

In general, all materials must be inspected and approved prior to use. Material quality may be checked in four ways: the supplier may test the material and provide a report of its quality, the supplier may provide a certification of the material's quality, the material may be tested at the job site by the Construction and Technology Division, or the material may be visually inspected at the site by project personnel.

8.1.6. Final Acceptance.

At the end of construction, the final dimensions, slopes, and other geometric characteristics of the structure are checked to verify that they match the design plans and specifications. Deviations are recorded on "as built" plans.

MDOT also monitors the construction process. This responsibility falls to the resident Engineer. For large projects, independent QA consultants, who act as project managers, may be hired.

8.1.7. Post Construction Review.

The process of designing and constructing the entire project is reviewed, to identify what worked well and what needs to be improved. This review is the synthesis of QA successes and areas that need improvement in the project, and provides the 'feedback loop' to improve QA for the next project.

Although significant effort is given to insure that the reliability of QA/QC is high, the success of the entire system depends on the attention of each individual. All QC tasks, although they may seem insignificant, are important for the overall quality of the project.

With this in mind, the engineer must rely upon his or her own efforts to produce quality work, and not depend on the 'safety net' of the QA program to catch personal errors. It is the individual's responsibility to maintain a proper degree of engineering integrity.

8.2 Pre Grade Inspection

For all projects, the Pre-Grade Inspection (GI) meeting is requested by the Unit Leader/project manager through the QA section. It is held to notify utility companies, cities, counties and Region personnel that a

project is in progress and requires their input or review. This occurs when the design project is approximately 35% complete, and the basic geometry of the bridge structure is known and Preliminary Plans are completed. For bridge projects, there should be minimum changes in design scope at this meeting.

8.3 Grade Inspection, Plans-in-Hand Inspection

For bridge projects, the GI meeting is not required unless the project is part of a road project, though the Unit Leader may request it in special circumstances. It occurs when plans are approximately 75% completed. Plans should include the proposed design, construction notes, preliminary grades and drainage, preliminary maintaining traffic, among other information, as described in "General Grade Inspection Requirements." The purpose of the GI is to review the thoughts of the designer, to ask questions and get those at the meeting to think about the design.

8.4 Standards

QC standards have been traditionally governed by codes, such as the AASHTO Code, FHWA guidelines, the Standard Specifications, the Design Manual and Design Guides, and other relevant MDOT manuals.

In addition to those standards given above, QC is now formalized into the checklists, evaluation forms, meetings, inspections, and oversight process discussed at the beginning of section 8.

Although the QA process functions well, sometimes errors in design or a discrepancy will occur on the plans or in the written notes or specifications. In these cases, a hierarchy of information, in descending order of importance, should be followed:

1. Special Provisions
2. Supplementary Specifications
3. Design Plans
4. Plan Notes
5. Standard Specifications

This hierarchy is generally based on how specific are relevant the document is to a particular project.

8.5 Coordination

Failing to establish sufficient coordination among the various participants in a project is one of the most prevalent QA problems. In order for a project to proceed quickly and efficiently, early involvement, and agreement on a design or fix by all participants is essential. This not only applies to MDOT's central Lansing office, but particularly to

utility companies, contractors, city or Region personnel, and the public. By his involvement and encouragement, the engineer should try to further this aim.

8.6 Reviews

All plan sheets submitted for review (study, preliminary, pre-final) are to be checked independently by an Engineer other than the designer. Plan sheets are initialed by both the designer and checker.

The general review process:

1. Scope Verification. The Unit Leader/project manager reviews the scope of work upon project assignment and either approves or requests a scope verification meeting.

2. Pre-GI Meeting. Plans are brought to the Pre-GI meeting, at which other project participants meet for input, review, and approval. This is discussed in section 8.1, above.

3. Final Plan Review. Prior to the submittal of the plans to the Specifications and Estimates section, the Unit Leader distributes the plans to the Region, Lansing Construction, Traffic & Safety, and the Bridge GI Engineer for review.

Reviews are also established through the P/PMS Network (see section 4.8), which monitors project status. In addition to the consideration of milestone events as listed in section 4.8, The Design Division has a Quality Assurance unit that reports the start and finish dates of additional P/PMS project tasks. For bridge projects, these tasks are the following:

- Verify design scope of work and cost.
- Prepare structure Study.
- Prepare Preliminary Plans.
- Develop structure Final Plans and Specifications.
- Hold an Omissions/Errors Check (OEC) meeting.

A Project History and Checklist form is available so the engineer can track the progress of his project. This form enhances QA by helping him or her to keep track of what and when project tasks need to be done, and who should be included in the various meetings needed to complete a project.

For future reference, the plans and proposal that compose the contract documents are stored as part of the permanent record.

9. MAINTENANCE

9.1 Bridge Inspections

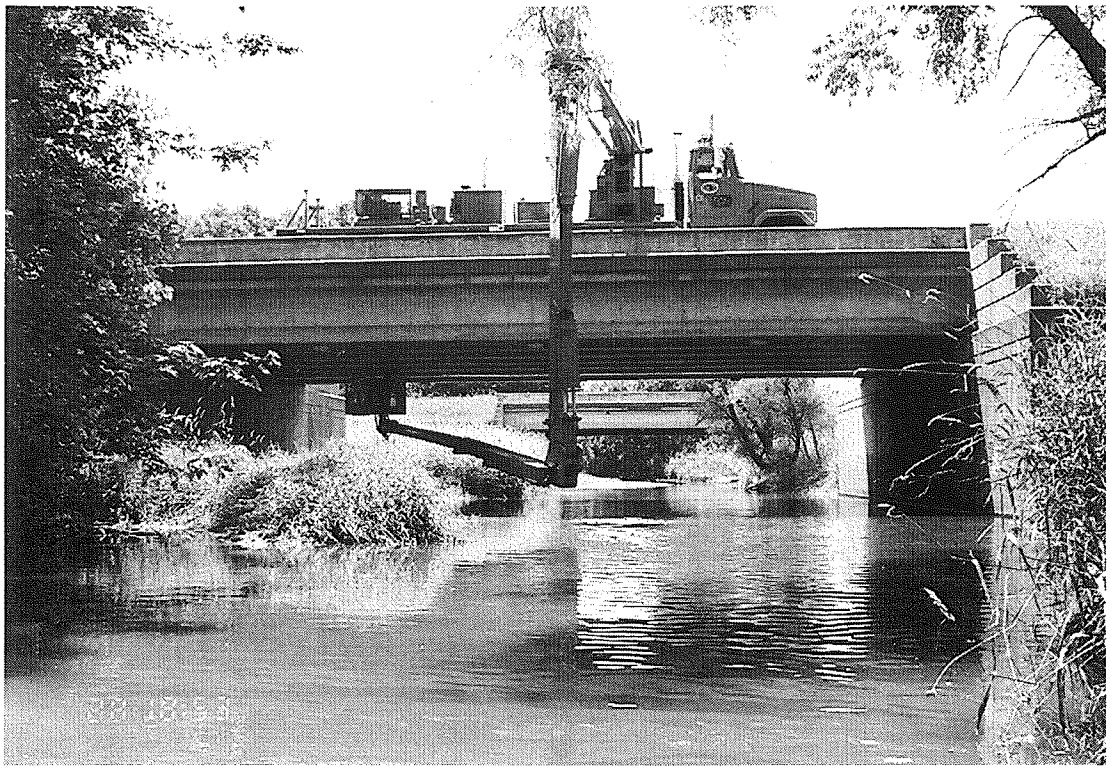
9.2 Condition Ratings

9.3 Evaluation of Existing Bridges

9.4 Maintenance Strategies

9.5 Emergency Bridge Repairs

9.6 Field Testing



9. MAINTENANCE

Based upon current bridge inspection data, approximately 27 percent of the bridges in the United States are structurally deficient and functionally obsolete. In Michigan, 36 percent of the bridges are structurally deficient and functionally obsolete. A bridge is classified as structurally deficient if the condition of the deck, superstructure, or substructure is rated poor or worse. The bridge can also be structurally deficient if its load-carrying capacity is very low. If the inventory rating (see section 10.2.3) of the bridge is less than that given in the table below, it is classified as structurally deficient, as shown in Table 9-1. A bridge can also be classified as structurally deficient if there are frequent traffic delays due to flooding.

Table 9-1 Inventory Rating Limits Based on ADT

ADT	Inventory Rating (metric tons)
0-500	10.8
501-5000	12.6
>5000	16.2

Functional obsolescence is the result of narrow bridge deck widths, inadequate clearances (horizontal or vertical), or unsafe geometrical alignments. A bridge may also be classified as functionally obsolete if the design load-carrying capacity does not adequately service load demands or if frequent flooding occurs. Thus functional obsolescence implies that the structure is not adequately servicing the traffic demands placed upon it by the traveling public.

Michigan is surrounded by the Great Lakes and has a varied climate. During the winter months the southern portion of Michigan is subjected to several freeze-thaw cycles and a varied amount of snowfall, depending upon the proximity to the lakes. Deicing salt, used during winter months to keep the roadways and bridge decks free of ice and snow, has caused corrosion of steel reinforcement in decks and beam ends. Insufficient funds for preventative maintenance and/or rehabilitation of these bridges in the past has resulted in a significant backlog of work. The needs have always exceeded the available funds.

Three options are available to remedy a deficient structure: replace, rehabilitate, or repair. Replacing a bridge is considered to be the last resort in the process of upgrading the existing infrastructure. It is a drastic measure and possibly the costliest. Rehabilitation is the process of upgrading the service or load capacity of a bridge to present standards and requirements. Repair is the process of restoring deteriorated

components of a bridge without upgrading its overall capacity and functional performance.

Bridges are usually found to be structurally deficient based on condition rating, however (section 9.2), before the inventory rating reaches such a low value.

Repairing a bridge will only give it a temporary reprieve by extending its life a few more years. In the long run it might be a costly venture. Of the three alternatives, rehabilitation may be considered a more efficient and viable option, provided that the geometric parameters of the alignment satisfy the current safety, visibility and clearance requirements. A routine site inspection within a comprehensive preventive maintenance schedule could reveal the need for upgrading the condition of a bridge.

Repairs may be instigated by various factors, including:

- scaling or spalling of concrete due to deicing chemicals and/or freeze and thaw
- delamination of concrete due to corrosion of reinforcing steel
- cracking of concrete due to shrinkage and flexural stress or alkali-aggregate reaction
- prestressed cable or anchorage failure due to corrosion at prestressed concrete beam ends

It is imperative that, as early as the design stages of a bridge, a life cycle cost analysis be made and a comprehensive preventive maintenance schedule be established. The selection of construction materials at the preliminary stages of option selection may reduce the service life cost of up-keep and maintenance of a structure. While the initial cost of using high-performance materials may be slightly higher than that of conventional materials, the long-term maintenance cost and effort could be quite beneficial.

9.1 Bridge Inspections

Bridge inspectors are currently centralized, but in the future, inspections will become a Regional responsibility so that bridge-work, maintenance, and inspection can be better coordinated.

There are two reasons for inspections:

- Collection of data for "Pontis," which is utilized by the Bridge Management System to develop the network level bridge rehabilitation strategy.

- For safety, Routine Inspections are mandated by Federal and State law once every two years, or more frequently in special cases. The condition of the bridge is rated on a 0-9 scale (see section 9.2).

There are six types of inspections:

- inventory inspection, to document the condition of the bridge, usually after rehabilitation or construction
- routine inspection, to determine the condition/safety of bridge components
- high load hit or vehicle damage bridge inspection, if a vehicle collides with the bridge
- underwater inspection, to detect the extent of scour damage
- fracture-critical inspections, to detect steel fractures
- special feature inspection, any unique feature on the structure that requires inspection at an increased cycle

An inspection beyond a routine inspection may be called a detailed inspection, which is a close-up, hands-on inspection of elements to detect deficiencies not readily detected during a routine inspection. This inspection will typically require lift equipment to get the inspector close to the elements being inspected. Non-destructive tests are conducted as part of this inspection.

It should be stressed that bridge inspection is very important. If there are doubts as to the safety or condition of the bridge, the engineer should request a more thorough inspection and evaluation.

Guidelines are available that suggest when inspection frequency should be changed. There are also emergency guidelines, which suggest what to do in an emergency situation, such as if a crack is detected in the bottom flange of a girder, or if severe abutment spalling is found.

9.2 Condition Ratings

The bridge condition is evaluated according to the NBIS standard (rated on a scale of 0-9), and by AASHTO guidelines (rated within 1-5 condition states for each identified element) for Pontis data. The three major bridge elements considered for ratings and evaluations are: deck, superstructure and substructure.

The condition of an individual bridge element can be classified according to its rating:

"Poor"	=	condition rating ≤ 4
"Fair"	=	condition rating = 5 or 6
"Good"	=	condition rating ≥ 7

For the purposes of the terminology used in this document, a bridge is classified as poor, fair, or good based on the lowest numerical rating of any of the following major elements:

- deck
- superstructure
- substructure

Routine inspections also identify maintenance and bridge rehabilitation issues. Bridges requiring routine maintenance are identified to the bridge crews whereas bridges requiring major rehabilitation are coordinated with road work and submitted to the Design Division.

9.3 Evaluation of Existing Bridges

There are two primary tasks that the bridge evaluator must complete:

- look for deterioration
- "scoping" of the bridge, which is an inspection to determine what work needs to be done. There is a scoping checklist available that should be consulted.

Bridge rehabilitation and repair costs vary with bridge location, so this is an important consideration when suggesting needed work.

When evaluating existing bridges to determine the inventory rating and operating rating (see section 10.2.3), distribution factors are given in the Michigan Bridge Analysis Guide (Table 1, page 11). For multi-stringer-type bridges, the distribution factors for operating rating are based on a heavy truck in only one lane at a time.

Finite element analyses previously performed at the University of Michigan indicated that the GDF's specified in the AASHTO Code (1996) are too conservative for longer spans and larger girder spacing (Nowak and Hong, 1991). Similar results were obtained by Zokai et al. (1991). Values proposed by Zokai et al. (1991) were adopted as a basis for GDF's in the AASHTO LRFD Code (1994).

Some actual GDFs were determined by field tests performed on five short span bridges (less than 18 m, 60') (Nowak and Kim 1998). Many bridges in Michigan carry low volume roads. However current design and evaluation provisions are based on the assumption that two side-by-side fully loaded vehicles occur simultaneously. This event is unexpected on low volume trunkline and secondary roads. In particular, it is practically unlikely to have two very heavy vehicles simultaneously on the bridge. The actual probability of such an event can be calculated using the

approach developed for the AASHTO LRFD Code (Nowak and Hong 1991; Nowak 1993; Nowak 1995).

The statistical data on heavy vehicles in Michigan is provided in the Michigan Department of Transportation position paper titled "Trucks and Transportation" (1998). There are approximately 108,000 commercial trucks registered in Michigan, with 15,000 capable to carry more than 80,000 pounds (360 kN). The total number of trucks operating in the state is estimated at 300,000. There are about 850 trucks registered to carry 160,000-164,000 pounds (720-740 kN) (less than 1 out of every 350 trucks on the road).

On the major interstate highways 11-axle trucks constitute about 3-5% of all truck traffic. This percentage is much lower for low volume roads (less than 1%). Visual observations on interstate highways showed that about 2-4% of vehicles travel side-by-side (Nowak, Laman and Nassif 1994). These vehicles travel in the same direction using two or three parallel lanes. On low volume roads, with two traffic lanes in opposite directions, the probability of side-by-side occurrence is even smaller (much less than 1%). Furthermore, the probability of having two 11-axle trucks side-by-side on low volume roads, P,

$$P < (0.01)(0.01)(0.01) = 0.000001 = 10^{-6} \qquad (9\text{-}1)$$

where 0.01 = fraction of 11-axle trucks, 0.01 = percentage of side-by-side events, 0.01 = probability the other truck is an 11 axle vehicle. For low volume roads this means that it is practically unlikely to have two 11-axle trucks simultaneously on the bridge. This very low probability can be further reduced by considering a very low likelihood of two fully loaded trucks (as opposed to partly loaded). Therefore, it is recommended to evaluate low volume road bridges using a single heavy vehicle.

For the considered bridges, the girder distribution factors (GDF) for a single truck do not exceed 0.3 (Nowak and Kim 1998). For a single truck, GDF is less than S/4.27 (S/14), for S in meters (feet). Therefore, it is recommended to use:

$$GDF = S/4.27 \quad (S/14) \qquad (9\text{-}2)$$

when evaluating bridges carrying low traffic volume roads (ADTT<1000).

The recommended values of GDF for evaluation of existing bridges are given in Table 9-2. For bridges with low traffic volume (ADTT < 1,000), S/4.27 can be used. For higher traffic volume (ADTT>1000), it is recommended that the GDF formulas specified in AASHTO LRFD Code (1994) be used. However, for short span bridges (span < 15 m, 50'), based on field test results, the AASHTO LRFD Code (1994) formula for one lane is adequate even for two lane bridges. For longer spans (larger than 15 m), there is a need for additional field tests to validate GDF's.

Table 9-2 Recommended GDF for Bridge Evaluation

Span	ADTT < 1,000	ADTT > 1,000
Span < 15 m (50')	S/4.27 (S/14)	AASHTO LRFD, for one lane
Span > 15 m (50')	S/4.27 (S/14)	AASHTO LRFD, for two lanes

This table refers to the 1994 version of the AASHTO LRFD Code.

For evaluating an existing bridge, because the term $K_g/(Lt_s^3)$ in the LRFD Code GDF Formulas (see section 5.2.2 in this report) implies more accuracy than exists, it is recommended that it be taken as 1.0.

9.4 Maintenance Strategies

The Bridge Preventative Maintenance program is a $6 million fund, and there is a $1 million fund for spot painting to prevent corrosion. The counties also help in maintenance; Kent, Wayne, Monroe, etc.

As bridge inspectors identify structure needs (system deficiencies), they first assess whether these should be handled by the State maintenance crews using the maintenance budgets. Examples of work include spot deck patching, guardrail repair, sidewalk repair, joint repair, and sub-structure repair. Usually these projects are minor in scope and can be completed by maintenance forces within a week. The projects identified usually require immediate attention. Greater deficiencies are usually handled by the bridge Preserve program.

The next source of funding is the emergency (MER) fund, although the amount of funds available is based on planning template determinations. Projects that are identified for immediate attention and are either larger in scope or their anticipated completion time exceeds 1 week will utilize MER funding. Examples of work include high load hits, beam end repairs, fire repairs, and scour repairs.

Additional funding, also for emergency work, is a one-time M fund established at $10.8 million, which is to be used to retire problems with critical structures.

Another yearly source of funds is the Highway Preventative Maintenance fund (HPM), Bridge. A template line item is set up each year to address highway preventative maintenance work. Upper management in the Bureau of Highways determines how much of the HPM money will go to roads and bridges. When a target amount is provided for a HPM bridge, Maintenance looks to package projects together on a corridor basis for efficiency. These types of projects are usually joint sealing or epoxy

injection. In addressing corridors, the newer structures are often focused on, but the Department is now attempting to increase the remaining life of an entire corridor.

The final source of funds is the Bridge Preserve Program (capital Federal Aid program). The yearly budget is determined as part of the template development. The Bridge Management System (BMS) establishes a district breakdown of the template amount and recommendations for a strategy mix of work types on a statewide basis as provided by Pontis. The projects are selected using the Call for Projects (CFP) process, or if there is not an official CFP, the projects are re-prioritized in a similar fashion. A large list of projects is created using the existing emergency list, corridor paint candidates, old CFP lists, structures on the 6 and 12 month inspection list, and the list of critical structures. Projects are placed onto this large list if they are not funded by one of the other sources identified. This large list of projects goes through a project selection and prioritization process done in coordination between Maintenance and the Region System Manager, on a Region by Region basis. The final Region lists are submitted to BMS to confirm that they meet the recommended strategies and budget constraints.

Although there are many sources of maintenance funding, only a small percentage (less than 5%) of maintenance funds available to MDOT is used for bridges, as illustrated in Figure 9-1 (MDOT Website, Bureau of Highways, Maintenance Division). Figure 9-2 shows how this bridge maintenance money is utilized.

In 1995 Maintenance produced a list of critical bridges that needed funding. The list started out at fifty structures and since then has grown to a total of 144. Structures from this list have been turned into projects, funded from emergency funds. The current list of critical structures needing work has 14 structures remaining on it.

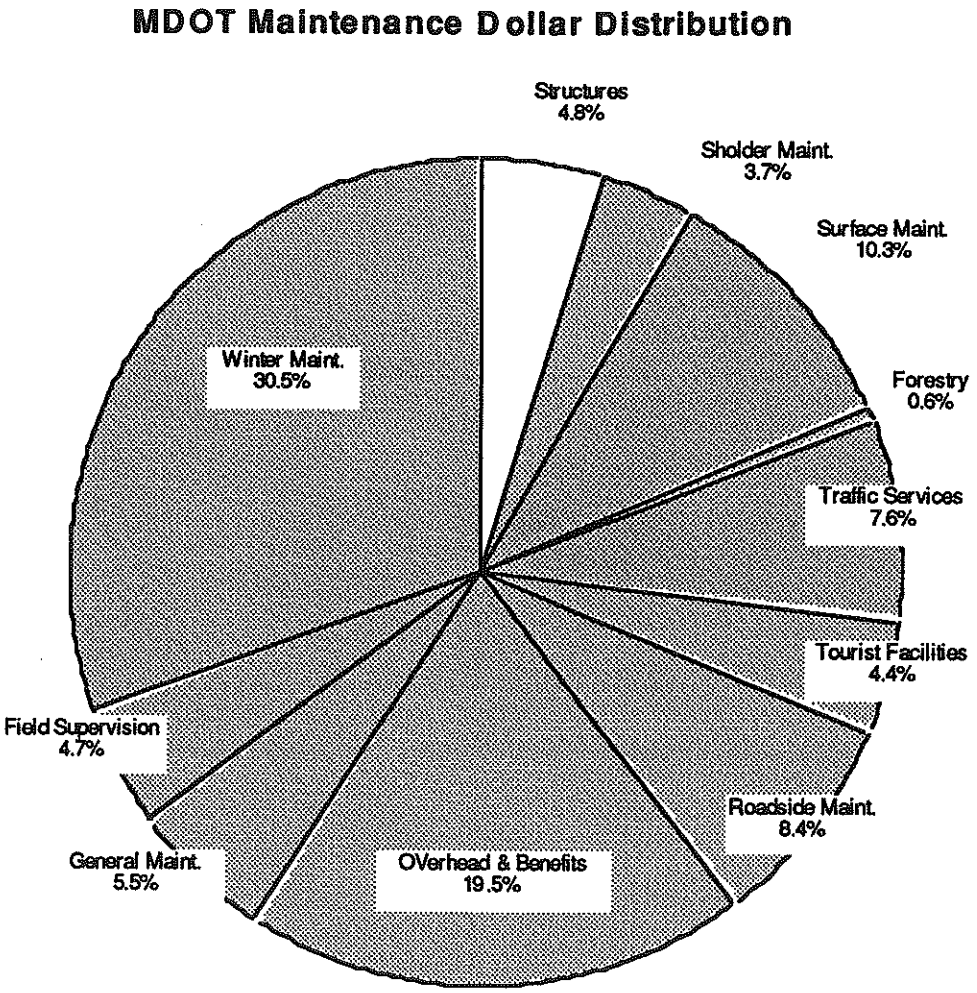


Figure 9-1. Maintenance Dollar Distribution.

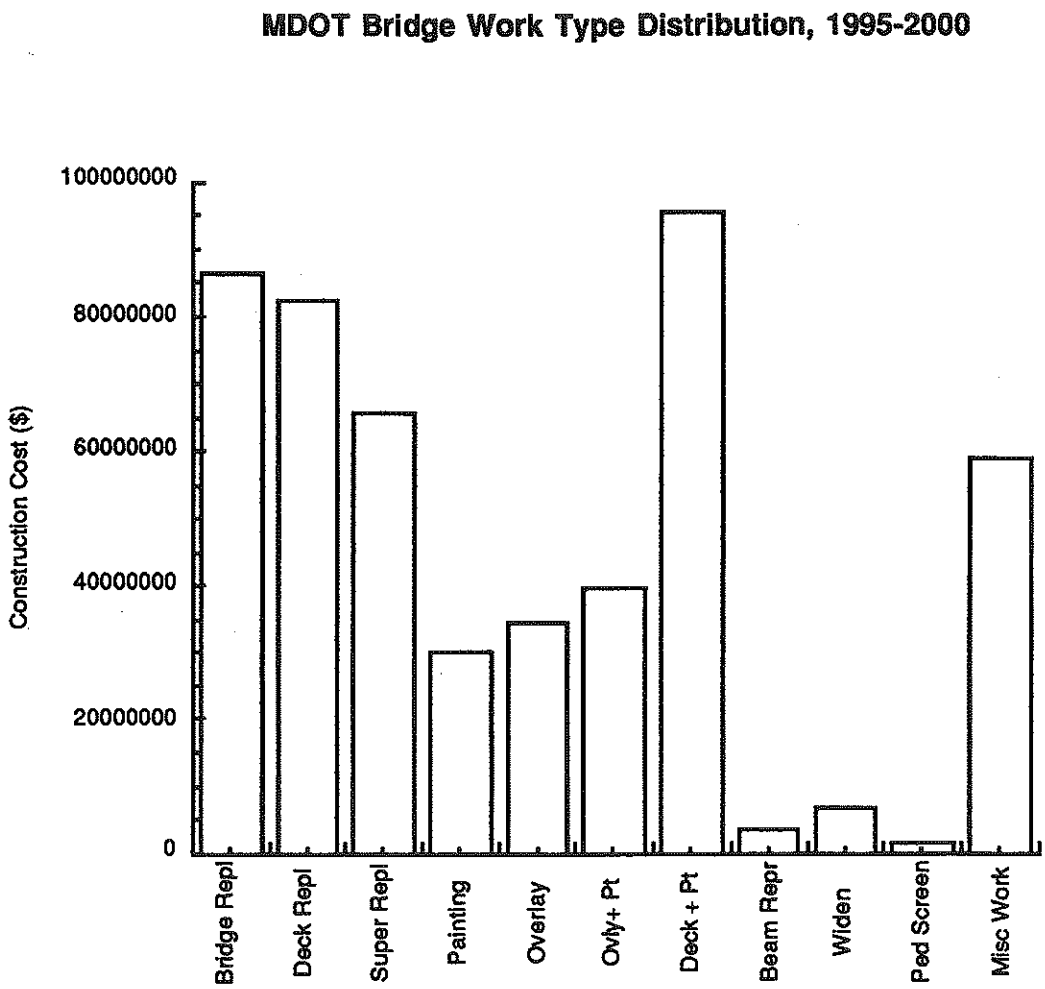


Figure 9-2. Bridge Work Type Distribution.

A few problems with the current maintenance strategy have been identified:

- There needs to be improvements in the QA/QC process of bridge inspection and data collection.

- The use of Pontis output to set the future maintenance strategy. Pontis is not evaluating the most up to date information due to the lag time. This would result in Pontis generating recommendations for investment strategies based on an old database.

- The BMS database is not updated quickly enough. Inspection data collected needs to be merged with the main database with less time lag.

Maintenance is carried out by bridge maintenance crews, which are 3-4 person regional crews that repair concrete, patch decks, etc. For steel repair, there is one centralized crew for welding, straightening girders, etc. Maintenance is also sometimes contracted out, on a limited basis.

Although the use of deicing salts is a significant cause of bridge deterioration, the state has strict requirements to insure road safety in winter weather. Snow must be kept clear of the road surface, and salting effectively achieves this end, the use of which averages to 255,000 kg per two-lane kilometer of road (450 tons per two-lane road mile). In the metro region it may reach 425,000 kg per two-lane kilometer of road (750 tons per two-lane mile). Locations of particular salt concentration (and hence maintenance problems) are areas prone to high accident rates, sharp turns, and steep gradients.

From a maintenance point of view, a bridge is considered "large" if it carries a traffic volume (on the order of 200,000 ADT) such that its closure will result in rerouting a significant number of vehicles. Such bridges should be given special attention before closure. Other bridges that need special consideration are bascule bridges and non-redundant (2-girder) bridges.

Additional bridges that require special attention before rehabilitation or replacement are those in a corridor project, in which many bridges of similar condition are within close proximity of each other. In such cases, a single closure of the relevant area, which would result in all of the bridges being repaired together, may be more appropriate than multiple closures to repair individual structures over a longer period of time.

When scoping a project, the engineer should be aware of the aesthetic considerations of the structures. This is especially true for bridges in corridor projects, in which uniformity of architectural treatment and structural form is desirable.

9.5 Emergency Bridge Repairs

There are two main causes of the need for emergency repairs:

- Damage when a vehicle hits the structure. In this case, the repair is paid for by the vehicle owner.
- Deterioration.

Other common causes of emergency repair needs are scour, fire damage, and dropping heavy steel coils on the bridge deck.

A discussion of emergency repair funding and project identification is presented in section 9.4.

9.6 Field Testing

MDOT hires consultants or uses in-house staff to perform field testing. Some of the field tests that MDOT completes are ultrasonic tests of pins and hangers, and of electroslag welds, which tend to be problem-prone details.

9.6.1 Weigh-in-Motion (WIM) Measurement of Trucks

A weight-in-motion test attempts to gather truck traffic data, which includes axle weight, axle spacing, vehicle speed, multiple truck presence on the bridge, and average daily truck traffic (ADTT). Beneath the deck, the WIM system is invisible to the truck drivers, and so overloaded trucks do not avoid the bridge. Unbiased results can thus be obtained. The system is portable and easily installed to obtain site-specific traffic data. Sensors measure strains in girders, and these data are then used to calculate the truck parameters at the given traffic speed. The Bridge WIM system consists of three basic components: strain transducers, axle detectors (tape switches or infrared sensors), and the data acquisition and processing system. It is fully described in "Development of a Guide for Evaluation of Existing Bridges, Part II" (1998).

Although results depend somewhat on bridge span and girder spacing, field tests have indicated that the actual loads that a bridge will experience over a 75-year design lifetime are from approximately 1.5 to 2 times the AASHTO Code (1996) design loads.

9.6.2 Diagnostic Testing

One type of diagnostic bridge test is a live (truck) load distribution test. The objective of this test is to determine the distribution of live (truck) load to each girder. One or two trucks of known weight are used as the test load, and the resulting strains are collected from all girders. To determine the distribution of load transversely on the bridge, at least one strain value is taken from each girder. An example of the calculation procedure is given in Appendix A. To determine the longitudinal load distribution, strain values at the ends and quarter points of the girders are also necessary. The number and placement of instruments on the bridge may vary according to the test objective, but in general, transducers are placed to determine the distribution of load to the girders transversally and longitudinally, and to find the maximum load effects. Strain transducers are attached to the lower flanges of each girder at midspan, assuming that the bridge is a simple span. Although midspan is not the location of maximum stress, it is sufficiently close for test measurements. For continuous spans, the locations of maximum effect should be estimated analytically, and the transducers should be

placed there. Further detail can be found in "Development of a Guide for Evaluation of Existing Bridges, Part II" (1998).

Field tests have shown that in general, the GDF's specified in the AASHTO Code (1996) are too conservative for longer spans and larger girder spacing (see Appendix A), and in some cases can be unconservative for short span bridges.

9.6.3 Fatigue Load Spectra

Development of a fatigue load model requires the collection of actual dynamic stress time histories for various members and components. Following a collection of time histories, the data must be processed into a usable form. The expected fatigue life of a component can then be calculated using the rainflow method.

The stress measuring system (SMS) is required to collect component strain histories produced by actual traffic loads. Then, the stress cycle histograms can be assembled by the rainflow method of cycle counting and other counting methods. The rainflow method counts the number of cycles, n, in each predetermined stress range, S_i, for a given stress history. The SMS can record up to 4 billion cycles per channel for extended periods in an unattended mode. Strain transducers are attached to all girders at the lower mid-span flanges of a bridge.

The data-acquisition system, installation of equipment, and measurements are described in the report by Nowak et al. (1998). Strain transducers should be attached to the mid-point of each girder. Since the stresses are to be recorded over an extended period of time (a minimum of 1 week), the data acquisition system must be attached to a reliable and secure location on the bridge. Strain histories usually must be collected continuously for periods of at least one week long, although this time can be reduced using the rainflow algorithm. Data should be collected for each bridge girder.

As a means of comparison of fatigue live load, the equivalent stress, s_{eq}, can be calculated for each girder using the following root mean cube (RMC) formula:

$$s_{eq} = \sqrt[3]{p_i * S_i^3} \qquad (9\text{-}1)$$

where S_i = midpoint of the stress interval i and p_i = the relative frequency of cycle counts for interval i. The stress, S_i, is calculated as a product of strain and modulus of elasticity of steel. Stress spectra considerably vary from girder to girder (component-specific). Therefore, the expected fatigue life is different depending on girder location. Exterior girders experience the lowest load spectra.

9.6.4 Dynamic Load Spectra

The objective of dynamic tests is to verify or determine the actual dynamic load. The dynamic load can be a significant component of live load. Not only is it time variant and random in nature, but it depends on the vehicle type, vehicle weight, axle configuration, bridge span length, road roughness, and transverse truck position on the bridge. In a dynamic test, strain transducers are attached to the bridge girders, and stress values are recorded under actual moving traffic loads.

The weigh-in-motion truck measuring system can also be used for dynamic load tests. If gross vehicle weight (GVW) and axle loads are not required then axle detectors are not needed. The procedure for equipment installation is identical to that for the weight-in-motion test. This test can be carried out simultaneously with a weight-in-motion test. Field measurements are taken by the WIM system to determine the actual dynamic load effects and to verify the available analytical models. For each truck passage, the dynamic response can be monitored by recording strain data. The truck weight, speed, axle configuration, and lane occupancy can be determined and recorded from WIM measurements.

Although the dynamic load specified in the AASHTO Code (1996) varies with span length (see section 5.2.4 of this report), field tests have indicated that dynamic load is independent of bridge span, and for heavily loaded vehicles on roads of reasonable quality, typically does not exceed 10% of the static load.

The procedure, equipment, installation and operation are described by Nowak et al. (1998).

9.6.5 Proof Load Testing

Proof load testing is most often used to verify the capacity of a bridge to avoid restricting the traffic that can use it, and the results can help to determine whether to replace or repair a bridge. The proof load test can be used either to find the yield capacity of the structure, or to check its ability to carry a specified live load. Usually, the yield capacity of a bridge is very high and requires exceptionally heavy loads, which make the tests uneconomical and slow. In this case, proof load tests are carried out to verify if the bridge can safely carry the maximum allowable legal load. Before the proof load tests, the target proof load is calculated as described in "Development of a Guide for Evaluation of Existing Bridges, Part II" (1998). The type and placement of load, instrumentation and data acquisition setup would depend on the target proof load level. Most field tests have indicated that bridges have a great amount of reserve capacity beyond that which they are assumed to have in design, and the actual stresses experienced are significantly lower than those expected. Proof load tests usually reveal that even deteriorating structures are capable of carrying loads in excess of their design values

without distress. Example proof load calculations are given in Appendix B.

10. MANAGEMENT

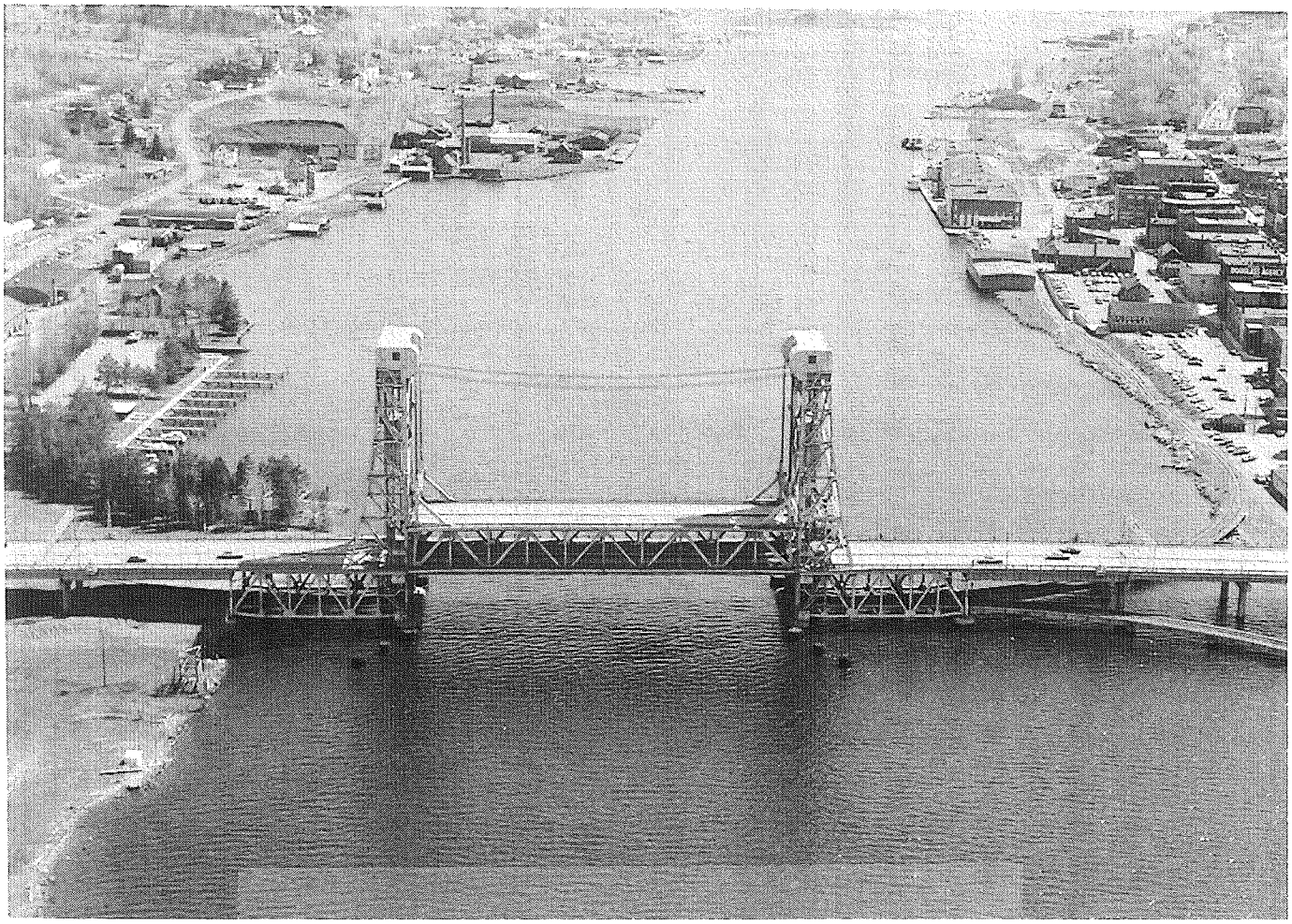
10.1 Concepts, Needs, Costs

10.2 Bridge Management System (BMS)

10.3 Bridge Rehabilitation

10.4 Network Level

10.5 Big Bridges



10. MANAGEMENT

10.1 Concepts, Needs, Costs

MDOT's first step in implementing a system of long range strategic planing and investing for efficient asset management is the plan detailed in "Strategic Investment Plan for Trunkline Bridges," (1998). This plan utilizes the Bridge Condition Forecasting System (BCFS). BCFS is used to predict the future of the bridge network condition. It can analyze the impact of a particular fix strategy, and is described in more detail in section 10.3.2.

The recommended capital investment to successfully implement the proposed network strategies and meet the network condition goals (see section 10.4) is $185,000,000 annually. The recommended funding levels were assessed separately for Maintenance and Preservation/Modernization (see section 10.4.1). Estimates for the inspection and inventory strategy implementation have not yet been determined.

Based on preliminary discussions with the regions, an initial statewide capital investment of $10,000,000 for Capital Scheduled Maintenance (CSM) activities is recommended. This funding is to be managed as part of the Bridge Preserve Program and will be allocated to the regions based on need.

A comprehensive scheduled maintenance plan needs to be developed in each region, under the general guidance of the central office. The maintenance plans will delineate time lines for scheduled work activities and will make recommendations for regional allocations based on need. It is anticipated that an annual statewide investment recommendation will be completed by the end of September, 1998.

An average annual budget of $175,000,000 is recommended for Preservation/Modernization; $171,000,000 for investment in the highway bridge network modeled by the Bridge Condition Forecasting System (see section 10.3.2).

An annual budget of $152,000,000 is recommended for capital investment in the core activities based on the BCFS strategy analysis. This recommendation is based on a mix of CPM, rehabilitation and replacement necessary to reach the network condition goals.

An interim annual budget of $10,000,000 will continue to be allocated for capital investment in Big Bridges until a statewide strategy is developed. A separate investment strategy is required that will prioritize and address statewide Big Bridge needs.

An annual budget of $9,000,000 is recommended for capital investment to retire the existing Special Needs backlog by 2005. This line item within the preservation budget will then be reassessed to determine if continuation of the category and budget is necessary.

10.2 Bridge Management System (BMS)

The bridge management system is an important tool in managing the bridge infrastructure. The input from engineers plays the key role in this process. The overall system performance should be monitored by measuring key indicators on an annual basis, along with coordination with pavement and traffic congestion management systems. This tool also helps to justify funding for bridge programs which compete with other transportation programs for funding allocations.

10.2.1 Bridge Inventory

In order to manage the bridges and other transportation infrastructures efficiently, the Federal government passed the Intermodal Surface Transportation and Efficiency Act (ISTEA) in 1991. This law and additional legislation encouraged each state to develop management systems such as bridge, pavement and congestion management. Prior to passage of ISTEA, the Federal Highway Administration (FHWA) also required each state to perform biannual bridge inspections of all bridges in the state and report the condition data to FHWA. This data resided in the database entitled "National Bridge Inventory" (NBI). This database provided information about condition of bridges as well as the load-carrying capacity of the bridges. The project level decisions, such as repair or rehabilitation options to upgrade the bridges, can be taken by using this database. Reports can be generated to indicate the present state of conditions of decks, superstructures or substructure. However the tools for predicting needs, future conditions and strategic economic analysis were not available in NBI. In order to address these issues, a joint effort was sponsored under the auspices of FHWA to develop a bridge management system called Pontis (Latin for "bridge"). The system is currently supported under the auspices of the American Association of State Highway and Transportation Officials (AASHTO). Forty-five states, including Michigan, are using and participating in joint development and enhancement of Pontis.

The main elements of Pontis are the bridge inspection database, the ability to predict future conditions of bridge components, the fix matrix that represents types of repairs or rehabilitation options with cost data, and the ability to perform multi-year strategic or "what if" analysis based upon the funding levels that can be provided. Pontis is not yet fully developed as a planning and programming tool, however.

10.2.2 Bridge Needs

At the operational level to meet the above requirements, the engineers are using the output of the Pontis system, along with their expertise, to define rehabilitation work needed for bridges that are part of a highway corridor improvement project. The following options are available to the engineers:

- Extract remaining life of the major bridge component, such as a bridge deck. This can be described as a "do nothing" option.
- Fix only the critical areas of the bridge, and postpone major rehabilitation for a few years. In Michigan, use of bituminous overlays is common and used to improve the ride quality of badly spalled bridge decks. The service life of this overlay is assumed to be two years before a deck replacement project is scheduled. Use of partial painting of steel beams, where possible, is used. Only the beam ends under leaky joints and the outside of the fascia beam are coated.
- Use life-cycle cost analysis to support decisions.
- Increase preventative maintenance activities to extend the useful life of bridge components. For example, replacing the leaky joints, waterproofing the concrete components, washing the steel beams of the movable bridges and proper design of the deck drainage system.
- Maximize the number of bridges repaired and/or rehabilitated with allocated funding.

10.2.3 Bridge Rating

Bridge members can have two different ratings, an operating rating and an inventory rating. The inventory rating is a factor of the legal allowable load that a bridge can safely support for an indefinite period of time. The operating rating is a factor of the legal allowable load that a bridge can safely support for the passage of a single vehicle.

The basic formulas for the theoretical rating of a bridge member, as expressed in the AASHTO Manual For Condition Evaluation of Bridges, are as follows :

$$RF = (\frac{1}{L})(\frac{C - 1.3D}{1.3A(1+I)}) \qquad (10\text{-}1)$$

where:

D = dead load effect on the member, calculated from data on the plans and supplemented by field measurements.
L = live load effect on the member.
I = 0.33, the impact factor to be used with the live load effect
A = a coefficient that is equal to 1 for the operating rating and 5/3 for the inventory rating.

C = denotes the capacity of the member to resist the applied load effects.

This is based on MDOT "Development of a Guide for Evaluation of Existing Bridges, Part II" (1998).

10.2.4 Load Testing

In order to extract the remaining life of the bridge, the strategy of load testing has proven successful in a few cases. The deteriorated reinforced concrete bridges are difficult to analyze for their load-carrying capacity. In order to assess the load-carrying capacity of the structure, a proof load test is performed. The test load is larger than the loads predicted by the analysis. The bridge can then be posted for the tested load, using a reasonable factor of safety (Kulkarni 1998). See section 9.6.5 of this report for further information.

10.3 Bridge Rehabilitation

Rehabilitation is the process of upgrading the service or load capacity of a bridge to present standards and requirements. The need for rehabilitation or a bridge or its components should be based upon one or more of the following:

- a deficiency in the load carrying capacity of one or more components, as determined by an evaluation, or the need to strengthen components in order to permit a controlled vehicle to use the bridge
- accident damage which adversely affects the strength, safety, or performance of the bridge or its components
- an unacceptable level of performance of a component or absence of a component where required
- deterioration of components to an unacceptable level
- deficiencies in the hydraulic characteristics at the bridge adversely affecting the bridge, highway, or the surroundings
- any other unacceptable functional deficiencies

Rehabilitation is required when the following deficiencies become apparent:

- Functional short-comings, such as an inadequate traffic load carrying capacity, a limited service capacity (not wide enough), or the standard safety level is not met (need for a median, sidewalks, bike lanes, etc.)
- General deterioration, such as corrosion of reinforcement or steel structural members, or the crumbling of concrete
- Inaccuracies in the original design and detailing
- Material deficiencies, in terms of technology, quality control, etc.

For rehabilitation, an existing bridge is evaluated to determine its actual strength and to predict its remaining life. Criteria for design of a new structure and for evaluation of an existing structure are different. The major differences are due to:

- The reference time period is different for newly designed and existing structures. New bridges are typically designed for a 75 year life time and existing bridges are checked for much shorter time periods (5 to 10 years). The load model depends on the reference time period. Expected maximum moments and shears are smaller for 5 or 10 year periods than for a 75 year life time by about 5 and 3 percent, respectively. However, the load variation is larger for shorter periods.

- Resistance also depends on the reference time period. This is important for evaluating strength loss due to corrosion and fatigue.

- In general, it is less expensive to provide an increased safety level in a newly designed structure than in an existing one. For bridges evaluated for 5 or 10 year periods (interval between thorough inspections), it is assumed that inspections help to reduce the uncertainty about the resistance and load parameters. This change in uncertainty requires an adjustment in the evaluation criteria.

- Non-redundant (single load path) components require a different treatment than redundant (multiple load path) components. In new designs, single load path components should be avoided but such components are often found in existing bridges.

Most methods of rehabilitation are site-specific and require a detailed study of the prevailing conditions at the locality considered. These may include the availability of construction materials, weather and length of construction season, traffic volume, right-of-way availability for traffic detours, site accessibility constraints, and others. However, some general methods of rehabilitating a bridge may include the addition of external prestressing and/or hybrid structural elements to an existing component for upgrading structural capacity. For upgrading service capacity, actual widening of a bridge may be considered feasible.

10.3.1 Life Cycle Analysis - Rehab vs. Replace

Although no specific guidelines exist for the decision to rehabilitate rather than to replace, this decision should be made based on a life-cycle cost basis. The design engineer should look at various combinations of repair strategies to compare with replacement costs.

Replacement may be called for in situations where the bridge:

- is out of date, e.g. a wooden bridge on a busy highway or a narrow truss on a multi-lane road
- has extensive deterioration of its components
- has partial or total damage caused by earthquake, erosion or scour of foundation elements, fire due to accidental collision of a tanker truck or time-related deterioration
- can no longer can conveniently carry traffic due to highway realignment

There is a clear need for rational criteria that establish the need for rehabilitation, the requirements for data collection, and specified loads, load factors, and load combinations to be used in the rehabilitation design based upon the planned service life of the bridge. When a repair or replacement is called for, there are categories of bridge components that are dealt with together as a group. Some of these are: overlay, deck, superstructure, and substructure.

10.3.2 Optimization

In order to most efficiently distribute resources to the various needs of MDOT's bridge network, a resource optimization process is used called the Bridge Condition Forecasting System (BCFS).

Beyond the element level, which is addressed by the use of Pontis, the Bridge Condition Forecasting System (BCFS) was developed to predict future network condition in the context of "good," fair" and "poor." BCFS uses average deterioration rates and average costs, based on historical data and professional judgment. BCFS was used to develop a recommended statewide strategy. The current statewide strategy developed is a mix among CPM/R&R (Capital Preventative Maintenance/Rehabilitation & Replacement, discussed in section 10.4.1) and is 30%, 25%, and 45%, respectively. MDOT acknowledges the need to transition to this strategy from the historical strategy in order to accommodate paradigm shifts and the overall impact to the industry.

BCFS is also to be used in Regional strategy development to address the varying distribution of needs for each Region. Each Region will consider issues such as current network needs, cost and user impact which cause their region to deviate from averages used in the statewide modeling. Individual Regional strategies must aggregate to conform to the statewide strategy.

BCFS is used to model the effect of various levels of bridge funding and various strategies on future bridge conditions. Variables are the bridge funding level and the 'mix of fixes,' or the network-wide combination of preventive maintenance, rehabilitation, and replacement actions. Annual deterioration rates are calculated by averaging actual deterioration rates for MDOT bridges. Bridges rated 4 or less are eligible

for replacement. The model replaces the lowest rated bridges until the replacement budget is exhausted. Bridges rated 4, 5, or 6 are eligible for rehabilitation. The model rehabilitates the lowest rated of these bridges until the rehabilitation budget is exhausted. Replacement actions are assumed to improve bridged to a combined condition rating of 8; and rehabilitation actions improve bridges to a combined condition rating of 6 for the next year. Bridges with a combined condition rating of 5 and 6 are eligible for preventive maintenance, starting with 5's, until the preventative maintenance budget is exhausted ("Strategic Investment Plan for Trunkline Bridges," MDOT, 1998).

10.4 Network Level

Considerations at the network level address the entire system of bridges under MDOT jurisdiction at once in order to most efficiently preserve the bridge network, insure safety and serviceability, and to optimize all available resources. Current specific network goals are to:

- Immediately address the needs of all of the structures of critical concern.
- Improve the overall condition of the freeway bridge network so 95% of the structures on that network are rated good or fair by 2008.
- Improve the overall condition of the non-freeway bridge network so 85% of the structures on that network are rated good or fair by 2008.

Network bridges are sometimes grouped into two categories. The freeway bridge network refers to all bridges that carry freeway traffic or structures over the freeway. This group includes structures within freeway interchanges, pedestrian (P) structures, railroad (X) structures, and any freeway service drives under MDOT jurisdiction. Bridges on the non-freeway bridge network refers to all other trunkline structures under MDOT jurisdiction ("Strategic Investment Plan for Trunkline Bridges," MDOT, 1998).

10.4.1 Strategies and Program Direction

A recently developed, but not yet implemented, bridge network strategy incorporates maintenance and preservation/modernization. It is the following:

1. Maintenance. Schedule maintenance or reactive work that maintains existing serviceability and reduces deterioration rates on "good" structures. Work activities typically would include superstructure washing, flushing drainage systems, minor concrete patching and repairs, spot painting, concrete sealing, and joint repairs. Scheduled maintenance activities prevents "good" structures from becoming "fair" structures. Historically, maintenance was focused on reactive activities. However, failure to consistently perform scheduled

maintenance activities has accelerated bridge deterioration. A new emphasis on conducting a Capital Scheduled Maintenance (CSM) program is recommended while sustaining the necessary reactive activities.

2. Preservation/Modernization. This is programmed work activity that restores or improves element integrity and ensures network safety and serviceability. The Core Activities (CPM/R&R) of preservation/ modernization are:

Capital Preventive Maintenance (CPM). This consists of scheduled work activities that restore element integrity, preventing "fair" structures from becoming "poor" structures. Work activities typically would include joint replacement, pin and hanger replacement, zone and complete painting, scour protection, deck patching, thin overlays, and pedestrian fencing. These work activities have been modeled to equate to a "+1" condition rating improvement for the element(s) addressed. Any fix life realized in a function of the element being restored.

CPM for bridges is not a specific program but a defined level of the preservation program. Specific work items have been identified which address the restoration of element integrity. A streamlined project development process, reduced traffic impact, a condensed bid document package, and special environmental waivers are anticipated characteristics for bridge CPM projects. Strategy development for the Bridge Preserve Program will consider an integration of CPM, rehabilitation and replacement activities. Consistent with road CPM, the main characteristic of bridge CPM work items is to keep fair bridges from becoming poor. The BCFS modeling tool illustrates the impact that these CPM work items have on the bridge network condition levels.

Rehabilitation (R). This consists of programmed work activities that improve element integrity. Work activities typically would include deep overlays, superstructure repair (beam end repairs, bearing rehabilitation, diaphragm repair/replacement), extensive substructure repair, substructure replacement. Any fix life realized is a function of the element being improved. Rehabilitation work activities improve condition ratings to "fair" or "good." Project selection will be considered on a worst-first basis.

Replacement (R). This consists of replacement work activities that improve condition ratings from "poor" to "good." Programmed deck replacement, superstructure replacement, or full structure replacement are considered. Project selection will be considered on a worst-first basis.

The BCFS, discussed in section 10.3.2, is used to optimize resource distribution to these various options.

New Inspection and Data Inventory Strategies are also under development for the network level, which are the following:

Inspection Strategies:

- Review the current frequency guidelines and make recommendations to the Engineering Operations Committee (EOC). The EOC is the principal technical policy making body in the Bureau of Highways on engineering, research, and related matters. The inspection cycle is to be adjusted to four years for good bridges, as allowed by the National Bridge Inspection Standards. A systematic detailed inspection process for poor bridges is to be established.
- Perform inspections on all bridges upon the completion of any work that would impact the current inventory data. Specific inspection procedures and guidelines will be developed.
- Establish a statewide Quality Assurance/Quality Control (QA/QC) plan for bridge inspections managed centrally.
- Develop and provide the necessary tools and training to the inspectors to insure timely and accurate updates to the inventory.
- Develop and provide the tools and training that inspectors will require to accurately and appropriately formulate 'fix' recommendations based on structure history and condition.

Inventory (data) Strategies:

- The inventory needs to include all data items established by Federal and State requirements and any others necessary to implement this plan.
- MDOT must allocate the necessary resources and tools to insure the functionality, accuracy and timeliness of the inventory.
- Establish inventory update procedures for maintenance or permit activities.
- Establish a Statewide QA/QC plan for the inventory data.
- Develop the necessary reporting and monitoring capabilities for the effective use of the data in decision making.

Assessment of the effectiveness of the program will occur at the network and at the program levels.

At the network level, effectiveness will be based on:

- Resultant network condition improvement compared to the previous year's actual program.
- Statewide progress made toward reaching the network condition goals for freeway and non-freeway.

- Regional progress made toward reaching the network condition goals for freeway and non-freeway.
- Network distribution of good/fair/poor.

At the program level, effectiveness will be based on determining:

- If the actual projects let match the proposed strategy planned.
- If not, do the actual projects result in a strategy that maintains direction toward achieving the program goal.
- If the actual network condition improvements match the modeled projected network condition improvement.
- If the projects let reduce the number of structures which require 6 month or 12 month inspections.

This information is based on MDOT "Strategic Investment Plan for Trunkline Bridges, 1998".

10.5 Big Bridges

A Big Bridge is defined by MDOT as a large or unique bridge that is a segment of the bridge network which includes all movable bridges (bascule, vertical lift, and swing), segmental bridges, and bridges with deck areas in excess of 9,300 m^2 (100,000 ft^2). Bridges are also classified as big when they have special management (maintenance, repair) needs that are different from typical bridges on the trunkline. MDOT's Big Bridge Committee specifically addresses the needs of these bridges. As of April, 1998, MDOT has identified 52 Big Bridges, 13 of which are movable. The current (as of 1998) movable bridges in Michigan are listed in Table 10-1. The Big Bridge list, however, is not finalized.

Another category of bridges that falls outside of the typical management plan are Special Needs Bridges. These are bridges which have been found to be in need of rehabilitation to correct structural deficiencies discovered in the initial detailed inspection of the structure. A list of these bridges is established as the network's initial detailed inspection cycle is completed ("Strategic Investment Plan for Trunkline Bridges, MDOT, 1998").

Table 10-1 Moveable Bridges in Michigan

MDOT ID#	Identifying Feature
B01-09032	M-13 & M-94 over Saginaw River
B01-09042	M-25 over Saginaw River
B05-11013	I-94 BL over St Joseph River
B01-11053	M-63 over St Joseph River
B01-15012	US-31 over Island Lake Outlet
B03-16081	US-23 over Cheboygan River
B01-31012	US-41 over Portage Lake
B01-51011	US-31 over Manistee River
B12-66013	M-64 over Ontonagon River
B02-70014	US-31 over Grand River
B01-77032	I-94BL over Pine River
B02-77052	M-29 over Black River
B04-82071	Old US-25 over Rouge River

11. RESEARCH

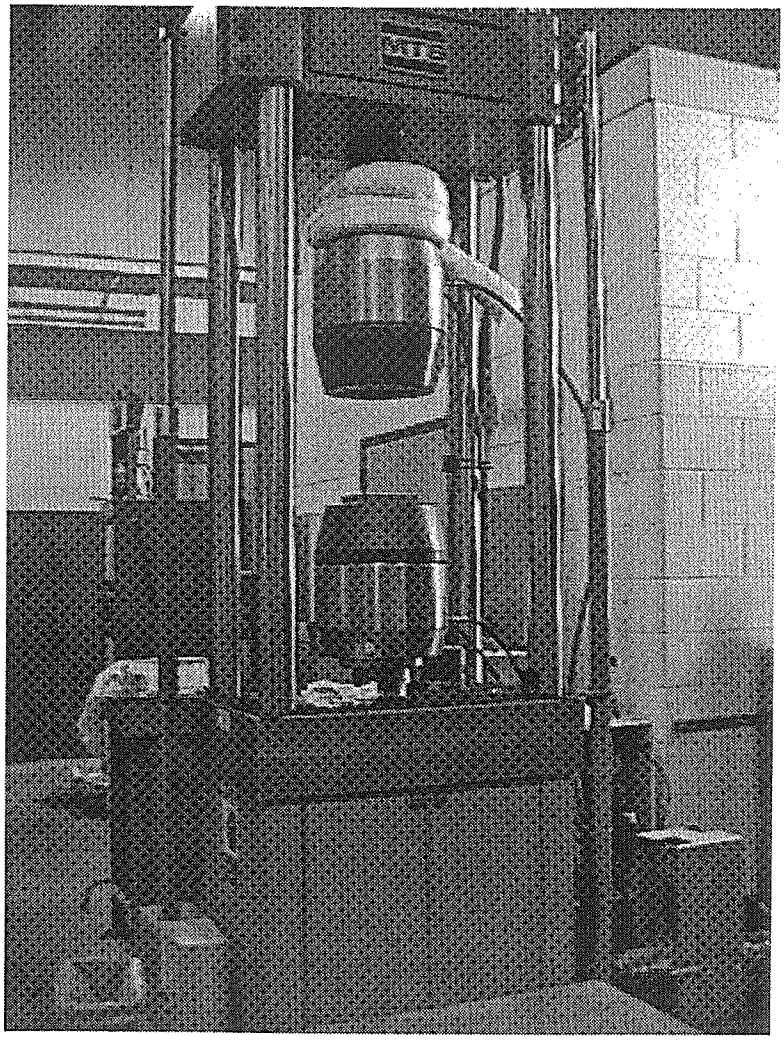
11.1 Major Research at MDOT 1960-97

11.2 Current and Future Research

11.3 National Research Programs - NSF, NCHRP, SP&R

11.4 Implementation of Research Findings - AASHTO, FHWA, MDOT

11.5 Research Pay-Offs



11. RESEARCH

11.1 Major Research at MDOT 1960-97

MDOT keeps a permanent record of research projects. They are microfilmed for long-term storage approximately 1 year after the projects are completed.

A project log file is available that gives a short description of research projects, including the date started and the investigator in charge. This file was not kept up to date, however, and the last entry ends in January, 1996.

Some of the major areas that MDOT has investigated are the following:

- deicing and snow removal techniques and products, 1936-1951
- joint sealers, 1936-1959
- concrete durability studies, 1939-1945
- concrete pavement design, 1939-1959
- reflectorized traffic marking materials and methods, 1947-1980
- specific product evaluations, such as cements, prefabricated retaining walls, paints, concrete patches, and many others, with an emphasis on joints and joint sealers, 1936-present
- site-specific noise, vibration, and air-pollution studies, 1972-1995.
- A588 steel and reinforcing bar corrosion rates, especially in 1978
- concrete deck overlay products and techniques, especially at the beginning and end of the 1980's
- Preliminary Site Investigations (PSI's), to evaluate parcel right-of-ways, ground contamination, or underground storage tank (UST) removals, especially in 1992

11.2 Current and Future Research

Approximately 0.5% of MDOT's budget is dedicated to research. Funds dedicated to bridge research vary yearly, but for 1999 this is up slightly, to approximately 8% of the total research budget, or about $550,000.

Current research projects can be found on a periodically updated list titled "Active Project Listing By Project Leaders."

In the structural research unit, some of the current research projects are the following:

- the effects of corrosion on A588 steel
- the investigation of specific bridge performance and proof-load testing

- the application of carbon fiber to reinforce existing bridges
- the presence of structural damage, such as fatigue damage and concrete cracking

In the future, MDOT plans to investigate some of the following areas:

- composites and their applications, such as prestressing strands, reinforcing bars, and carbon fiber strips, as applied to both beams and columns
- other alternate structural materials, such as aluminum, fiberglass, plastics, and high performance (HP) concrete
- methods of determining the remaining life of existing decks
- rapid construction methods, and other ways to decrease the negative impact of construction on the public
- the post-tension splicing of prestressed girders
- alternate deicers
- the possibility of design-build contracts, warranties, and specifying performance parameters from contractors

11.3 National Research Programs - NSF, NCHRP, SP&R

11.3.1 National Science Foundation (NSF):

The National Science Foundation is an independent US government agency responsible for promoting science and engineering through programs that invest over $3.3 billion per year in almost 20,000 research and education projects in science and engineering. It funds research and education in science and engineering through grants, contracts, and cooperative agreements to more than 2,000 colleges, universities, and other research and/or education institutions in all parts of the United States. The Foundation accounts for about 20 percent of federal support to academic institutions for basic research.

The NSF organizational structure reflects academic organization, with Divisions for the various disciplines and fields of science and engineering and science education. NSF is helped by advisors from the scientific and engineering community and from industry who serve on formal review panels or review proposals by mail. This advisory system, which focuses on both program direction and specific proposals, involves more than 59,000 scientists and engineers a year.

Research proposals are reviewed in accordance with the merit review criteria approved by the National Science Board. The criteria are designed to be useful and relevant across NSF's many different programs; however, NSF employs special criteria as required to highlight the specific objectives of certain programs and activities. NSF program officers who are experts in a certain field or area use reviewer input to make award

recommendations. For more information on the merit review criteria, see Chapter III of the NSF Grant Proposal Guide. Awardees are wholly responsible for doing their research and preparing the results for publication; NSF does not assume responsibility for such findings or their interpretation. NSF welcomes proposals on behalf of all qualified scientists, engineers, and science educators.

11.3.2 National Cooperative Highway Research Program (NCHRP):

Administered by the Transportation Research Board (TRB) and sponsored by the member departments (i.e., individual state departments of transportation) of the American Association of State Highway and Transportation Officials (AASHTO), in cooperation with the Federal Highway Administration (FHWA), the National Cooperative Highway Research Program (NCHRP) was created in 1962 as a means to conduct research in acute problem areas that affect highway planning, design, construction, operation, and maintenance nationwide.

The state departments of transportation are the sole sponsors of the NCHRP. Support is voluntary and funds are drawn from the states' Federal-Aid Highway apportionment of State Planning and Research (SPR) funds. Furthermore, the funds can be spent only for the administration of problems approved on ballot by at least two-thirds of the states. Each state's allocation amounts to 5 and 1/2 percent of its SPR apportionment and is set forth in supplementary tables issued with each year's Federal-Aid Highway apportionments.

Research problems are obtained through the AASHTO Standing Committee on Research, which solicits problems from four authorized sources: (1) the chief administrative officers of the member highway and transportation departments, (2) the chairs of AASHTO's committees and subcommittees, (3) AASHTO's Board of Directors, and (4) the Federal Highway Administrator.

The Secretary (i.e. the Director of the Cooperative Research Programs) determines which completed or ongoing projects should receive additional funding for further work. and which new problem submittals should be programmed. An Announcement of Research Projects is prepared each year in April.

TRB solicits research proposals from private and public research organizations that can demonstrate capability and experience in the problem area to be researched. These organizations include universities, nonprofit institutions, consulting and commercial firms, and individual consultants. Guidance for the preparation of proposals is included in the NCHRP brochure titled, Information and Instructions for Preparing Proposals.

The technical panels review the proposals, recommend contract awards, monitor research in progress, provide technical guidance, and review reports for acceptability and for accomplishment of the agency's research plan. Research findings are published in the NCHRP Reports series and the NCHRP Synthesis of Highway Practice series.

11.3.3 NCHRP Publications:

- NCHRP Reports
- NCHRP Synthesis of Highway Practice
- NCHRP Research Results Digests
- NCHRP Legal Research Digests

Full details on the program's work since inception in 1962 can be found in NCHRP Summary of Progress Through 1988 and subsequent NCHRP Summary of Progress reports beyond 1988.

MDOT contributes panel members and writes problem statements for NCHRP, but does not have sufficient manpower to conduct research for NCHRP. MDOT does make use of NCHRP reports, however.

The Transportation Research Board is a unit of the National Research Council, which serves the National Academy of Sciences and the National Academy of Engineering. The Board's purposes are to stimulate research concerning the nature and performance of transportation systems, to disseminate the information produced by the research, and to encourage the application of appropriate research findings. The Board devotes attention to all factors pertinent to the understanding, design, and function of systems for the safe and efficient movement of people and goods, including:

- Planning, design, construction, operation, safety, and maintenance of transportation facilities and their components
- Economics, financing, and administration of transportation facilities and services
- Interaction of transportation systems with one another and with the physical, economic, and social environment that they are designed to serve

The activities of the Transportation Research Board are organized under five divisions:

- Technical Activities
- Studies and Information Services
- Cooperative Research Programs
- Special Programs

- Administration and Finance

The Board's program is carried out by more than 400 committees, task forces, and panels composed of nearly 4,000 volunteer members, including researchers and practitioners in a wide variety of disciplines from the public and private sectors and academia. The program is supported by state transportation and highway departments, the modal administrations of the US Department of Transportation, and other organizations and individuals interested in the development of transportation.

11.3.4 State Planning & Research (SPR):

Two percent of Michigan's federal highway funds must be expended on planning and research, via the SPR program, as mandated by federal law. The funding provided by the federal government represents 80% of the total SPR budget; the remaining 20% are provided by local funds. In 1997, the government provided approximately $3.3 million, and there is an expected funding increase in the future.

There are two parts to SPR: (1) planning, and (2) research, development and technology transfer.

MDOT staff are responsible for the following planning activities under SPR: development of statewide, regional, and urban plans; transportation needs studies; transportation improvement plans; traffic surveys; speed studies; and transportation-related social, economic, and environmental studies. Universities and consultants are hired if additional specialized skills are required.

A minimum of 25% of the SPR budget must be spent for research, development, and technology transfer studies. The studies are prioritized by the SPR Policy Committee and are conducted by department staff, universities, other agencies, and consultants, as needed. Research is done to increase knowledge concerning improvements in methods, materials, and equipment used for planning, developing, constructing, maintaining, and administering surface transportation facilities and processes.

MDOT's policy statement for transportation research, development, and technology transfer is: "transportation research and development shall be conducted to increase knowledge concerning improvements in methods, materials, and equipment used for planning, developing, constructing, maintaining, and administering all surface modes of transportation facilities and processes. This research shall be coordinated among the various bureaus within the department, state universities, and other agencies." The process of fund allocation to research, development, and technology transfer is the following:

- Categories of research needs (focus areas) are identified by the State Planning and Research Policy Committee.
- Available funds are identified by the SPR manager.
- The SPR Policy Committee prioritizes research focus areas.
- Research proposals are accepted from applicants. The Bureaus of Highways, Transportation Planning, and Urban and Public Transportation each have guidelines for obtaining, screening, and prioritizing proposed research projects.
- The State Planning and Research Policy Committee reviews research proposals and based on priority focus areas and available funds, selects those to be included in the Annual SPR Work Program (AWP).

Implementation of research findings is the responsibility of the Engineer of Research and the administering bureaus, and is processed through the SPR Policy Committee.

MDOT long range research focus areas are the following (Research Procedures: State Planning and Research Program (SPR)):

- construction
- maintenance
- environmental
- pavements
- structures
  - bridge inspection/evaluation techniques
  - bridge painting
  - deck cracking-design influence
  - effects of freight loading
  - rapid repair/replacement methods
  - rehabilitation-estimating
- transportation materials
- privatization
- traffic and safety operations
- IVHS
- multi-modal
- planning
- management systems

11.4 Implementation of Research Findings - AASHTO, FHWA, MDOT

A technical advisory group reviews the research that MDOT carries out. They determine whether the research findings should be implemented, and if so, how they are to be implemented. The group includes members from divisions that the research will effect. Ideally a member from the

design, construction, and maintenance divisions are in the group, as well as representatives from the Regions.

Important findings are sometimes brought to the attention of the federal government and other states. For example, MDOT would alert organizations outside of the department if research uncovered a construction detail prone to failure. MDOT personnel sometimes attend seminars sponsored by other DOT's to present or gather new research findings.

11.5 Research Pay-Offs

As discussed above, since the implementation of research findings is difficult, it is similarly difficult to determine the precise benefits of research. Whenever possible, a cost-benefit analysis is carried out for each project. Because of the inherent difficulties of determining a firm cost/benefit relationship for the majority of research projects, there is no formal review dedicated to a cost/benefit analysis.

This does not imply that the benefits from research remain unmeasured, as in most cases, experience serves as the guide for evaluation, in addition to the judgment of a technical advisory group. There are many recent examples in which research has led to policy changes at MDOT. Some of these are the following:

- *Deck overlays.* Due to performance reasons, MDOT now specifies micro-silica modified concrete as the material of choice for overlays. This has overtaken latex modified concrete as the previous standard overlay material.

- *Expansion Joints.* Because research has shown that they deteriorate quickly, MDOT has eliminated the use of neoprene compression seals. For small movement bridge joints, the Jeene neoprene inflatable seal or pourable sealants are used. Strip seals are used for deformation requirements between 2 and 5 inches (50-130 mm), and modular joint systems are used for movements greater than 5 inches (130 mm).

- *Night-Time Casting.* To prevent shrinkage cracks, MDOT now requires night casting of bridge decks, which lessens temperature fluctuations. This requirement stands unless the ambient air temperature falls below 60 degrees F.

- *Steel.* A-588 steel is manufactured to avoid the need for painting, and to halt corrosion damage at an acceptable level. MDOT found that this steel does corrode badly in the Detroit area, however, and now requires that A-588 steel be painted, as standard structural steel, if used.

- *Diaphragm Connection Design.* To prevent fatigue cracks in diaphragm connections, usually caused by differential deflection of the beams, the connection plates are now welded to the tension flange of the beam. Previously, this plate was not fastened to the beam flange, which resulted in the cracks.

- *Isotropic Bridge Decks.* It was found that a non-standard concrete deck design, in which the steel is greatly reduced and placed identically both longitudinally and transversely in the deck, has performed well. MDOT will use this deck design with more frequency in the future.

- *Continuous Bridge Designs.* The use of continuous girders is not only more structurally efficient, but it was found that such a design eliminates the need for deck joints, which greatly reduces bridge deterioration.

- *Prestressed Concrete I-Beam Repair.* MDOT is currently developing new details for repairing the ends of PC I-beams. Research has indicated that most PC I-beam deterioration problems occur at the beam ends, because of the high chlorides present from leaking joints.

- *Cantilever Sign Supports.* The anchor bolts on cantilever signage have been redesigned to resist fatigue at the support. Only recent research has identified the correct loading.

- *Reinforcement Steel.* MDOT now requires that all reinforcement in concrete decks be coated with epoxy, which was found, if the coating remains undamaged during construction, to reduce corrosion.

- *Life-cycle cost analysis.* Although there are no official research projects investigating life-cycle costing, experience has led MDOT to increasingly design structures based on life-cycle costs (see section 4.7) rather than initial cost, which is more economical in the long run.

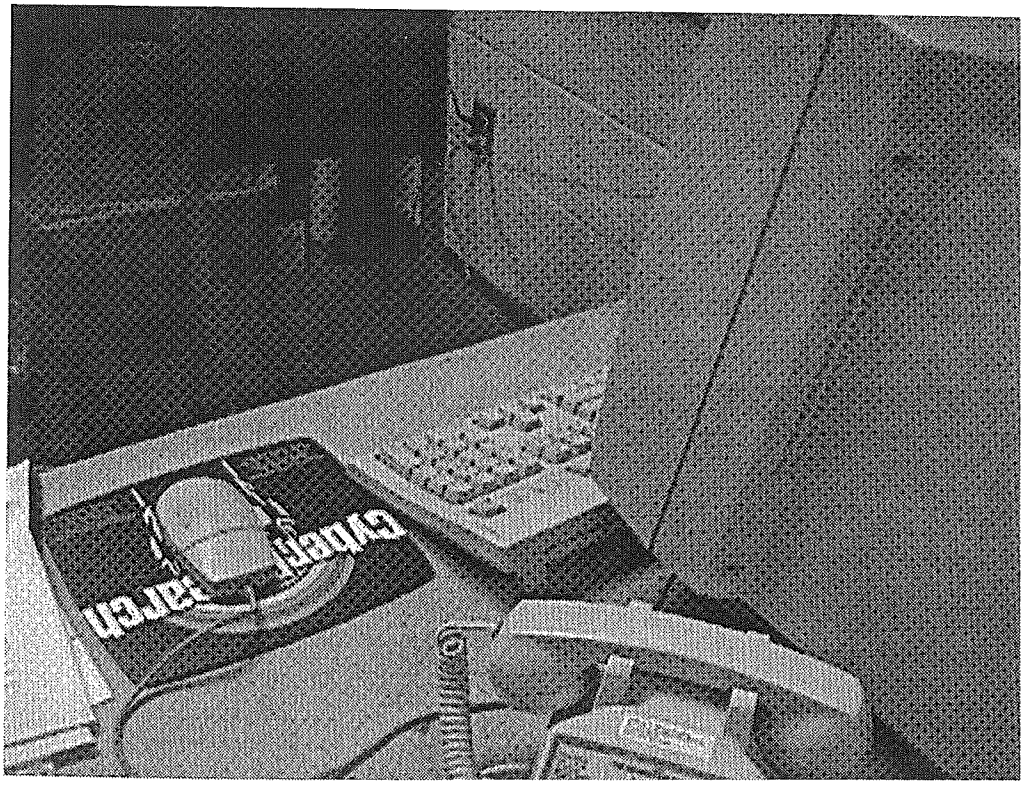
- *Coating.* MDOT now specifies a 3-coat painting system for steel surfaces; a first coat of zinc-rich primer, a second coat of epoxy, and a protective urethane coat, a system that was found to perform better than previous coating techniques.

12. AUTOMATION

12.1 Development of automation at MDOT

12.2 Future Automation

12.3 National Trends



12. AUTOMATION

12.1 Development of automation at MDOT

To increase efficiency, MDOT developed computer programs to automate the design and drafting processes.

The first MDOT design program was written in 1956 by D. Bullen, and designed simple span beams. Additional programs were developed over time and used as needed. For example, a subroutine that determined stud spacing was developed in 1957; continuous girder and cantilever beam design (the standard steel design of the 1960's) were added in 1961 and 1962; prestressed beam design was developed in 1963, and abutment analysis and fatigue checks were added in 1965. In 1969, these programs were combined into the Bridge Design Program. Since then, the Program was updated as new design methods and needs were encountered. Some of the important design additions were: vertical piles, 1970; elastomeric bearings, 1972; abutments, batter piles, and load factors, 1975; piers, 1976; curtain walls, 1977; steel box girders, 1978 (rarely used); counterfort abutments, 1982; fixed abutments, 1984; cost estimates, 1987; LRFD, 1992; and metric, 1993. A complete and detailed history of the Program's development is in its Documentation.

As noted in section 5.2, nearly all of MDOT's in-house bridge design is done by this program. Other structural analysis and design programs are used by MDOT in rare instances, and are discussed in section 5.2.

12.2 Future Automation

There are three general areas where MDOT automation is changing.

The first is a change in hardware. In the past, MDOT accessed programs on terminals from a central mainframe computer. Increasingly, MDOT is now relying on the PC for its automation needs. This is particularly true for bridge analysis, design, and the production of construction documents. In some cases, it is now possible for working drawings to be produced automatically by the computer, once a structure is designed.

The second is a change in software that accompanies the hardware change. Emphasizing the use of the PC, the Design Division has recently changed its PC operating system to a graphical user interface, networked environment (Windows NT). This has mandated a change in software, as some previously used design programs are no longer compatible with the new system. One example is the anticipated switch from MicasPlus to GTSTRUDL analysis software.

There is also a desire at MDOT to begin to use different design tools. Instead of relying on large in-house programs or commercial software, it is possible for the engineer to develop his or her own automated

procedures as needed for specific tasks. Many simple, high-level programming languages, such as those contained in a spreadsheet-type of application, are particularly suited for automated design by following code guidelines. Programs written in such applications are simple to understand and can be quickly changed to meet new design situations or code changes, and may be especially useful when in-house programs, such as the Bridge Design Program, are being modified to incorporate needed changes. The engineer must apply his or her judgment as to the efficiency of developing and using an application-based design tool as opposed to a large, previously-developed program.

The third area of change is how information is accessed. Engineers are encouraged to utilize the resources available on the internet, which makes it possible to access a wide range of bridge engineering related data, including commercial and free programs that can be quickly downloaded, and immediate information on manufacturer's specifications for products.

Some important internet web sites are listed below:

Departments of Transportation:

US DOT:	http://www.dot.gov/
MDOT:	http://www.mdot.state.mi.us/
All state DOT's:	http://osdbuweb.dot.gov/programs/states.html/

Bridge Engineering Related Organizations:

AASHTO:	http://www.aashto.org/
FHA:	http://www.fhwa.dot.gov/
NSF:	http://www.nsf.gov/
TRB:	http://www.nas.edu/trb/
ASCE:	http://www.asce.org/

General Links to Bridge Engineering sources:

http://www.ce.gatech.edu/WWW-CE/home.html
http://www.best.com/~solvers/bridge.html

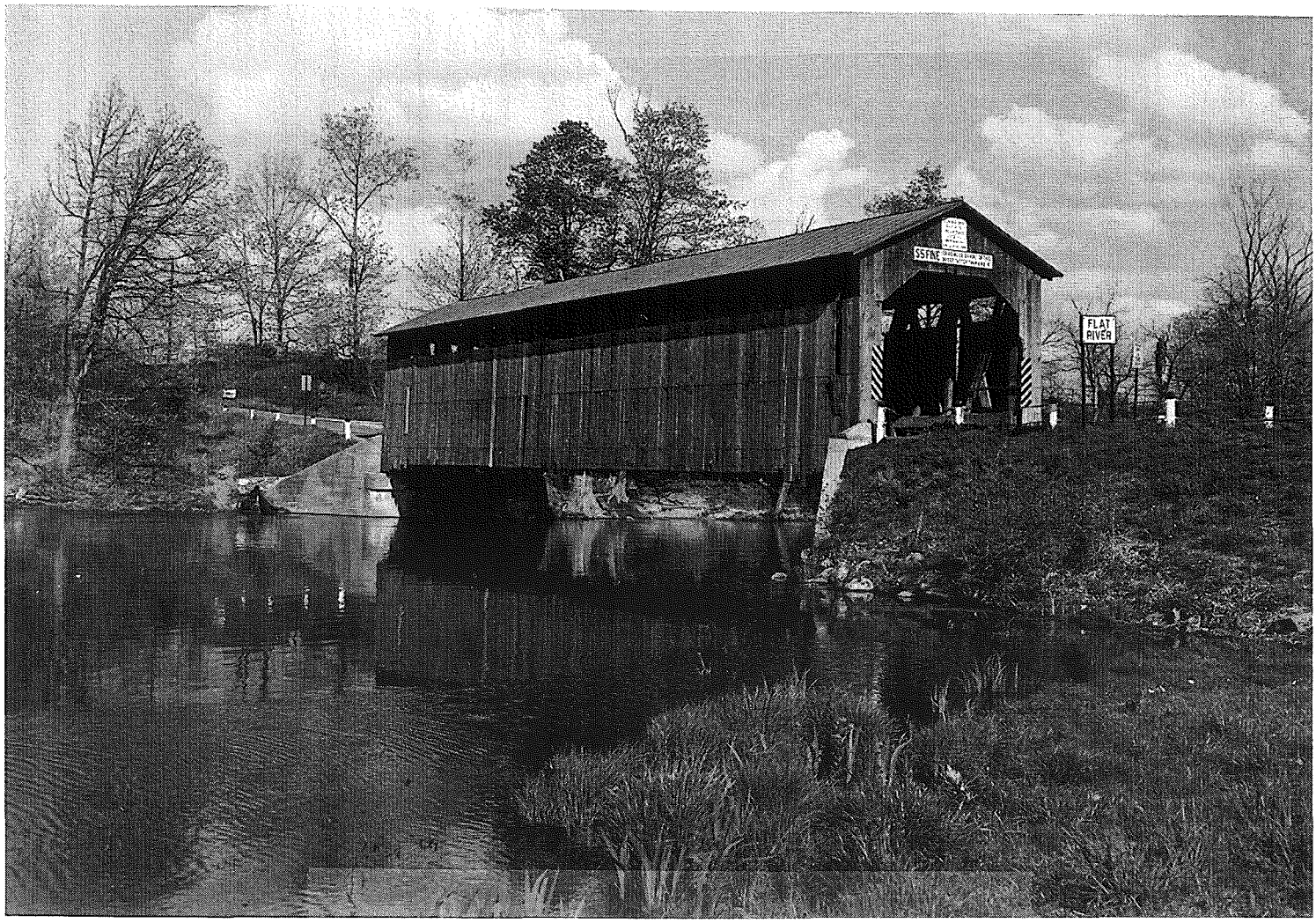
The last site listed has an extensive list of useful links to bridge engineering sites and resources, including: upcoming events; government agencies; research institutions; associations; companies; publications; software; and management systems that are related to bridge engineering.

12.3 National Trends

The following are the opinions of the MDOT staff related to national automation trends.

- Compared to most DOT's and consultants' bridge design and plan drafting methods, MDOT is far ahead of others in the area of automation.
- MDOT has followed current trends, but at the same time MDOT has always developed its own automation according to its unique needs and using its own specifications.
- It is expected that the future trend for MDOT in this area, in terms of hardware, software, and design problems/situations and plan production that can be addressed by automation, is still to use PC's running NT Workstation, Microstation, and "in-house" enhanced programs. If MDOT is willing to invest in the advancement of its automation programs, there is no design problem that could not be addressed by automation.
- The significant advantages with the move toward more automation are quicker plan completions, fewer human errors, and ultimately less cost in preparing a project.
- MDOT has joined cooperative efforts with AASHTO to develop, implement and maintain software related to bridge analysis, bridge rating and management systems, as well as software packages related to highway design, surveys and cost-estimating systems for letting.

13. HISTORICAL BRIDGES IN MICHIGAN



13. HISTORICAL BRIDGES IN MICHIGAN

The Bureau of History (BOH) in Michigan, under the Department of State, administers the historic bridge program under the auspices of the State Historic Preservation Office. It is the State Historic Preservation Officer (SHPO) who determines the treatment of historic bridges in Michigan. To be classified as a historic bridge, the structure must meet certain standards of significance. Although there are no firm rules that identify a historic bridge, some relevant factors are: age of the structure, who designed it, who built it, the architectural and structural style, and any unique features. It is usually difficult to place a bridge in an historical context, however, because of a lack of information regarding who designed and built it, and the general history of the structure.

If the bridge is designated as historic, it is eligible to be placed on the National Register of Historic Places, and it then falls under the protection of two primary pieces of federal legislation: the National Historic Preservation Act and the Department of Transportation Act. The former requires that the transportation agency (MDOT) proposing to carry out a project affecting the historic bridge lead to the least destructive and practical option. The latter act requires that if MDOT proposes to damage the historic significance of the bridge, the Department must show that there is no "prudent and feasible alternative."

Even with these laws in place, historic bridges are being demolished because of excessive deterioration or because they are too narrow or weak to be useful. Of 140 structures listed in the historic bridge inventory in 1986, more than half have been destroyed or are scheduled to be replaced by 2000. There were approximately 100 historic bridges in Michigan as of 1993 (Historic Highway Bridges of Michigan. Charles Hyde, Wayne State U Press, Detroit, 1993).

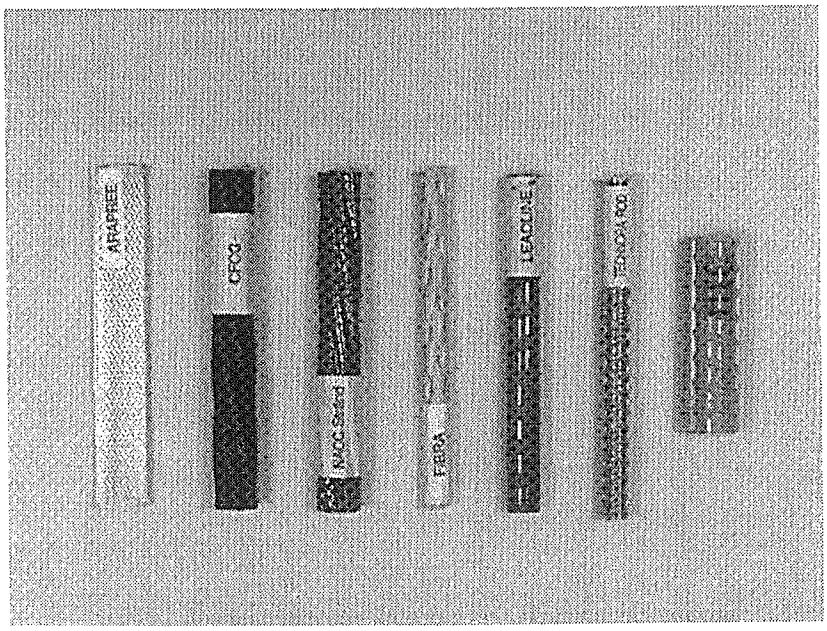
To protect historic bridges, a procedure was developed by the Bureau of History and MDOT. This plan involves considering a list of alternative treatments, the most appropriate from a preservation standpoint considered first. These treatments are as follows:

- *Do nothing.* The bridge will be maintained and kept serviceable. This option is usually not viable on a trunkline, but is often possible on low volume traffic roads if the bridge is in good condition.
- *Build a new bridge adjacent to the old bridge.* This will relieve the old bridge of vehicular traffic. This is often not practical, as there are many constraints on this scheme. There must be enough land adjacent to bridge, the roadway must be realigned, and a new function must be found for the old bridge, such as pedestrian or bicycle use.
- *Rehabilitate without affecting the historic integrity of the bridge.* In this option, the bridge is brought up to modern standards. This option is

also difficult because repair often requires components to be replaced, which damages historic significance.

- *Reuse on a new site.* Some bridges, like truss bridges, can be moved. This is rarely done, as it is often not economically feasible, both for the move and for the new owner, who then must maintain the bridge.
- *Record before demolition.* If no other option is possible, a historian prepares documentation of the bridge, such as pictures and a written history of the structure, and it is demolished.

14. FUTURE BRIDGES IN MICHIGAN



14. FUTURE BRIDGES IN MICHIGAN

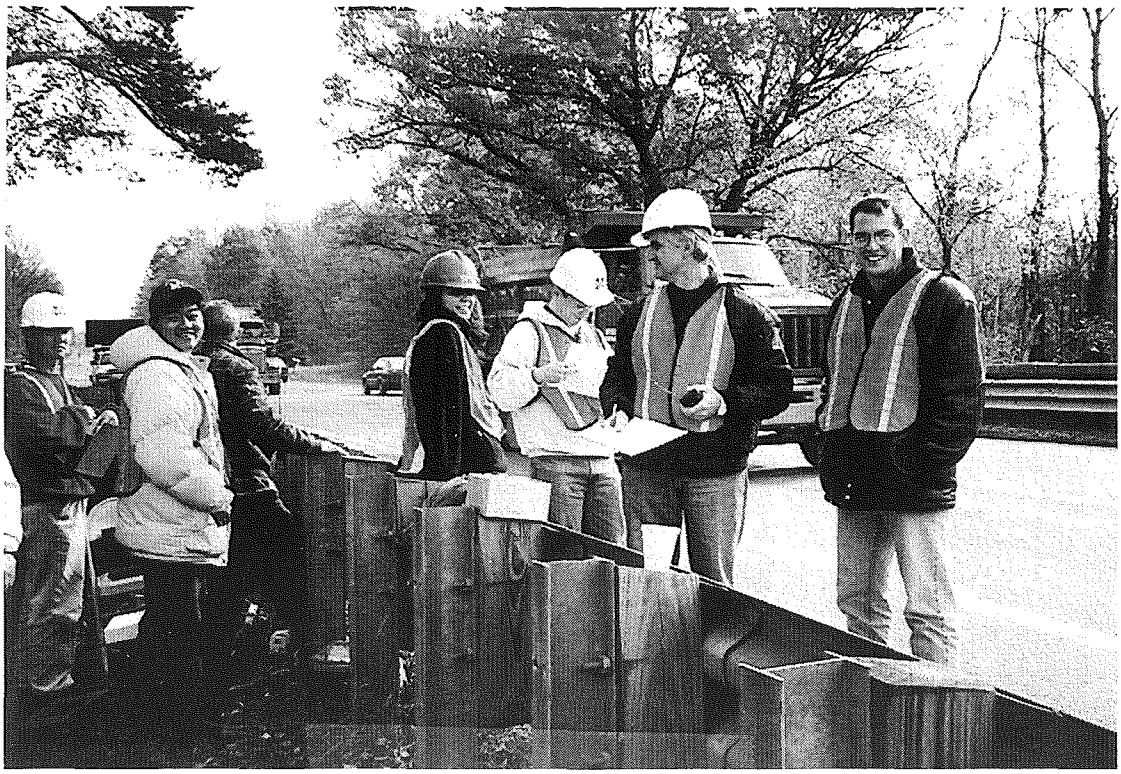
The majority of bridge construction in Michigan is the replacement of old bridges rather than the expansion of the trunkline infrastructure. The majority of these bridges, in the present as well as in the future, will be based on conventional, proven technology. Due both to a safe conservatism and a resistance to change, MDOT is slow to implement new technologies. Even so, there is an anticipation by MDOT to change some aspects of bridge construction in the future.

The primary consideration is the use of new materials. This includes not only high-performance steel and concrete, but the expanded use of new composites. Carbon fiber, in the form of reinforcing bars (although perhaps unlikely, due to the material's poor ductility), externally applied strips that can strengthen existing concrete girders, as well as fibers that are used as a mix additive, are being considered. Stainless steel is another reinforcement bar material possibility. It is also conceivable that an entire bridge could be built from non-rusting materials, such as aluminum or carbon fiber reinforced plastics (CFRP), although the high cost of these materials, as well as a lack of sufficient data on their long-term performance, prevents their immediate use.

Another desired area of improvement is the longevity of decks. MDOT has traditionally used the typical concrete deck, as described in section 5.4.1. Because of maintenance problems, different deck types, such as steel, or some of the other exotic materials described above, may be used in the future. An additional advantage to these modular deck components is that they are more easily replaced than concrete.

Finally, there is a continuing consideration of new structural systems, although the resulting future forms are difficult to anticipate. One recent example that MDOT has adopted is constructing a long continuous girder of several pre-tensioned, pre-stressed beams by post-tensioned links. Another is the consideration of a deck design without internal reinforcing, and of an isotropic deck with substantially less steel. More non-conventional systems are of course possible and not unlikely.

15. HUMAN RESOURCES



15. HUMAN RESOURCES

For any employee working in any occupation, there are of course certain skills and a depth and breadth of knowledge that must be held to successfully complete the required tasks.

It is not required nor expected at MDOT that a junior engineer have the complete knowledge or skills to independently analyze and design an entire bridge structure. It is important, however, that the engineer is aware of the skills that are needed for this task, and how over time to acquire them through job-related activities. The engineer must realize his or her limitations and weaknesses, and where to find information and help when needed.

All engineers, of course, must have a solid background in analysis and design; i.e. the skills and knowledge acquired from a formal education. These are the skills that provide the basis to complete all required tasks, by the use of critical thinking and general problem solving ability.

An additional important area is a general knowledge of construction methods and the current state of construction practice, particularly how this relates to the design of bridge structures. A thorough understanding of construction standards will prevent the mistakes of designing or specifying costly, difficult to construct, or unbuildable structures and details. The best way to obtain this knowledge is to acquire experience in the field; to be present at the job site to observe how things are actually constructed. This kind of 'hands-on' experience, not only in the field but in the design office, by observing how experienced engineers design structures, is invaluable.

The engineer should also become aware of the inherent problems when using automation. Since many design procedures at MDOT are computerized, the engineer may become divorced from the actual process of analysis and design, relying on the infamous 'black box' to complete work. The engineer should fully understand this problem, becoming aware, at least in general, of how an analysis or design program works, and what assumptions and limitations the programmer used in its development. This knowledge is critical for three reasons:

- to avoid misuse or misapplication of the program to situations for which it is not valid,
- to be able to correctly interpret the program's output, and to have the ability to judge its correctness and not unconditionally accept it,
- to maintain the skills needed to confront special situations where these programs cannot be used.

The engineer must also develop an understanding of cost versus performance and the trade-offs involved. The best structural solution

may not always be the best overall solution, once other important considerations, such as cost, are considered. The realization that MDOT has a limited budget, and that when funds are used in one place, they are unavailable for use in another, is essential. This is not to say that the cheapest solution is the most desirable either; an informal cost-benefit analysis, which includes a consideration of the life-cycle cost of the considered solutions, should always be done by the engineer.

Perhaps the most important skill required of the engineer, at MDOT or elsewhere, is engineering judgment. The ability to understand when a specific procedure is applicable to a certain situation, the awareness of what solutions seem reasonable, the realization that all methods of analysis and design are mere models of reality with many assumptions and limitations, and the ability to adapt and expand skills and knowledge to solve new problems, are all part of engineering judgment. These skills can only be acquired by experience. The engineer should be open to this experience, as it is MDOT's aim to provide it.

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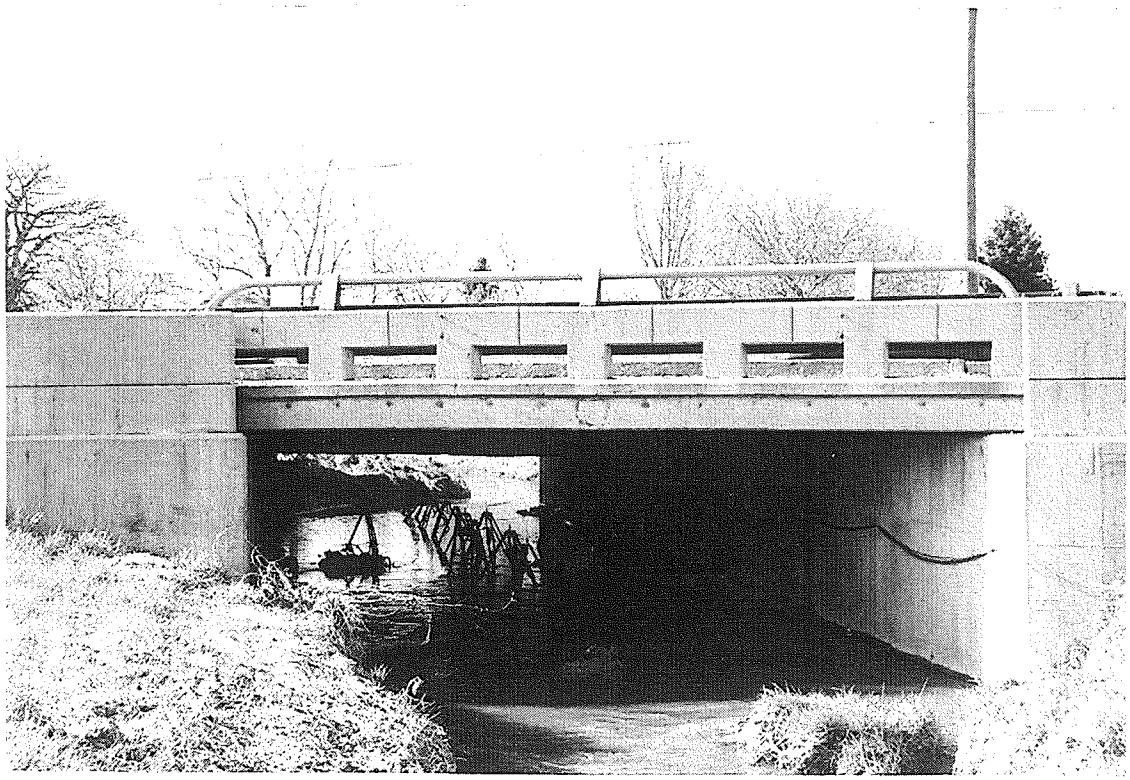

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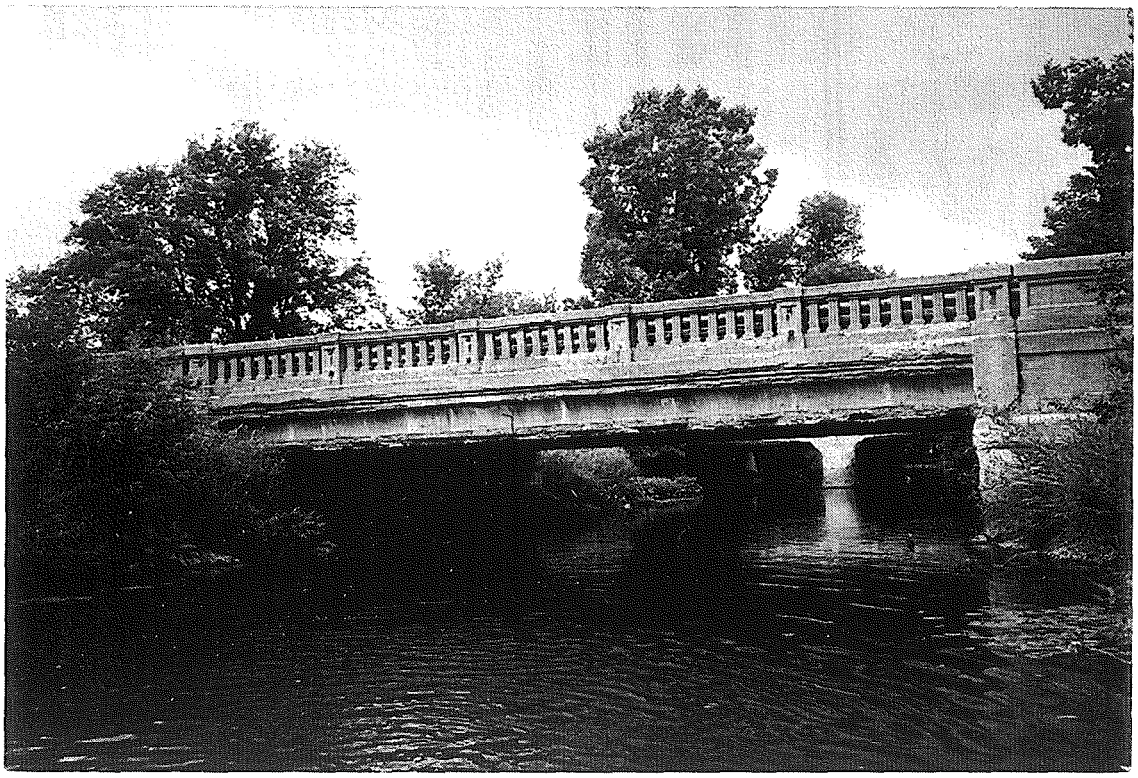
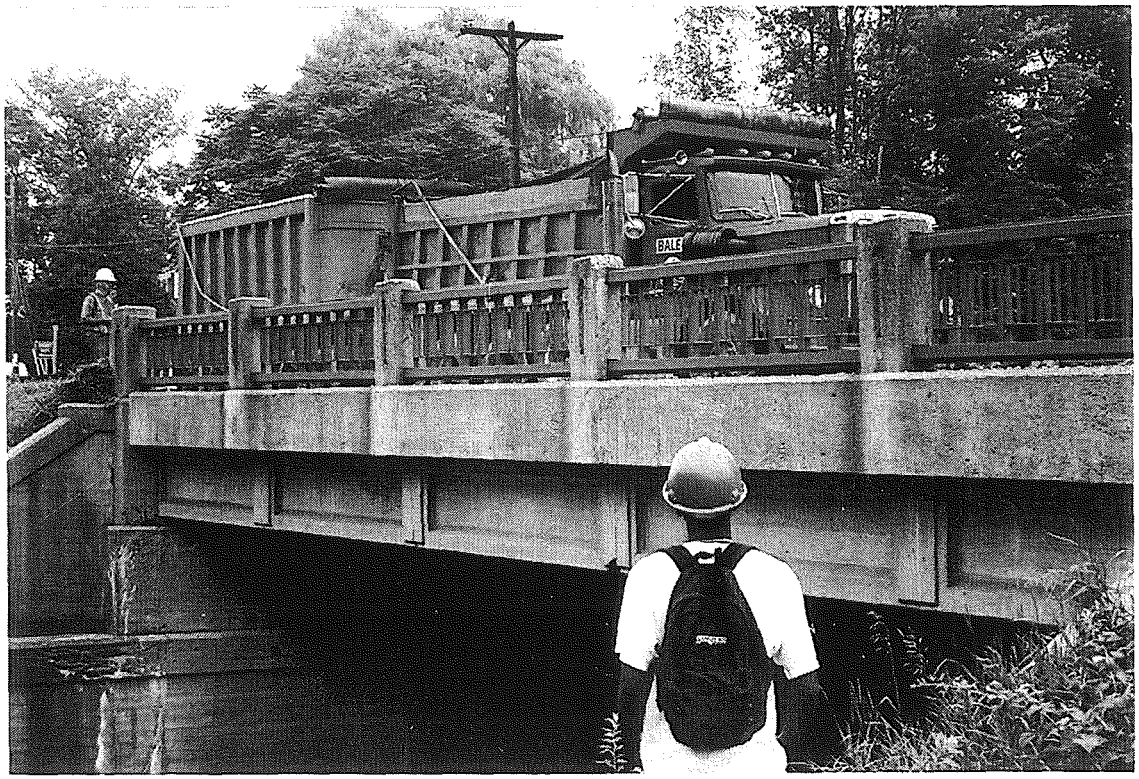




17. GLOSSARY

AASHTO. American Association of State and Highway Transportation Officials. An organization that supports the development of transportation systems, one branch of which is highway transportation. It publishes design specifications and guides, including the AASHTO Bridge Design Specifications, that are widely adopted by government agencies.

Abutment. Bridge structural element that rests against the embankments and supports the ends of the superstructure.

ACI. American Concrete Institute. An organization that supports the use of concrete. It sponsors research and publishes design specifications that are referred to by AASHTO.

ADT. The Average Daily Traffic that crosses a particular measuring point; often meaning the traffic that crosses a bridge. It includes all vehicles on the highway.

ADTT. Average Daily Truck Traffic. Similar to ADT, but it includes truck traffic only. Because of the much greater weight of trucks, it is usually a more significant indicator of load effect on a bridge than ADT.

AISC. American Institute of Steel Construction. An organization that supports the use of steel. It sponsors research and publishes design specifications that are referred to by AASHTO.

AREA. American Railway Engineering Association. An organization that publishes specifications that govern the design of railway bridges.

ASD. Allowable Stress Design. A design method which achieves safety by specifying that the effect of the loads should produce stresses that are a fraction of the yield stresses (about 50%). It is used to design deck slabs, elastomeric bearing pads, bolted connections, footings and piles, and prestressed concrete beams, among other items.

ASM. Allowable Stress Method. See ASD.

ASTM. American Society for Testing and Materials. An organization that develops widely recognized quality standards and tests for materials, products, systems and services.

AWS. American Welding Society. An organization devoted to promoting welding and related processes. It sets welding standards referred to by MDOT.

BCFS. Bridge Condition Forecasting System. BCFS analyzes the impact of a particular fix strategy to optimize bridge funding. It does this by

modeling the effect of various levels of funding on the future of the bridge network condition.

BDS. Bridge Design System. See Bridge Design Program.

Bid Proposal. The plans and documents needed to let a project. They are the documents that contractors use to prepare bids for the project.

Big Bridge. A large or unique bridge which includes all movable bridges, segmental bridges, and bridges with deck areas in excess of 9,300 m^2 (100,000 ft^2). Bridges are also classified as big when they have special management (maintenance, repair) needs.

BMS. Bridge Management System. It is used to help optimize bridge funding. By using data from Pontis, BMS establishes a district breakdown of bridge funding and recommendations for a strategy mix of work types.

Bond Breaker. A material used to prevent concrete from adhering to prestressing tendons, a previous section of concrete, or other components.

Box Beam. A prestressed concrete beam that has a hollow, rectangular section. It is often used when a shallow beam depth is needed. As compared to an I-beam, the box section has superior torsional properties.

Bridge Design Guides. A series of details, charts, and other design aids compiled by MDOT that can be used by the bridge engineer to complete a project.

Bridge Design Manual. A manual detailing the practice and standards of bridge design at MDOT.

Bridge Design Program. A program written and periodically updated by MDOT staff that is used by the engineer to design most highway bridges.

Camber. The construction of a beam in a slightly arched state so that when service loads are applied and the beam deflects, the total deflection will be minimized.

Charpy V-Notch Test. A test used for measuring the fracture toughness of steel by fracturing it with a pendulum swung from a specified height.

CFP. Call For Projects. A process by which particular bridges are identified and selected for funding, once the network budget is established by BMS.

Cofferdam. A water-tight enclosure used to permit the construction of water-bound bridge substructures in the dry. It is often made of sheet piling.

Compact Section. A steel section that has a sufficiently sturdy shape so that it can develop a fully plastic stress distribution before buckling. Most girders used in bridge construction are compact. Non-compact sections cannot be stressed to a completely plastic stress distribution without buckling locally.

Composite Action. Also composite beam/girder. When a girder and a portion of the deck that it supports act together as a single "T" section with a moment of inertia larger than that of the girder alone. Shear connectors are usually used to insure composite action. All modern highway girder bridges are built using composite action.

Condition Rating. A rating scale from 0 to 9 used to identify the structural integrity of a bridge and/or a bridge component, 9 meaning perfect condition and 0 meaning failed or out of service.

Construction Manual. A guide that details the practice and standards of bridge construction at MDOT.

Contract Plans. These are the final drawings which are used by the contractor to bid and construct a project.

Coping. Cutting the flanges of a steel beam so that it can more readily be connected to another beam or column.

Corridor Project. The simultaneous rehabilitation, repair, or replacement of a number of bridges that have similar needs and are in a somewhat close proximity to each other.

Cover Plate. A steel plate welded to the lower (tension) flange in a composite steel beam to increase its moment of inertia.

CPM. Capital Preventative Maintenance. A core activity of the preservation/modernization wing of the bridge network strategy. It is a scheduled work activity that restores element integrity, preventing structures rated "fair" from becoming "poor."

Critical Bridge Program. A program established to repair or replace inadequate bridges in Michigan, funded from the State and from the federal government.

CSM. Capital Scheduled Maintenance. Part of the maintenance wing of the bridge network strategy. It is periodic maintenance work that prevents structures rated "good" from becoming "fair."

Dead Load (D). The weight of all components of the bridge structure, appurtenances and all utilities permanently attached to the structure.

Design Lane. A longitudinal strip 3.6m (12') wide that the bridge roadway is artificially divided into for design purposes. One design truck is considered to occupy one design lane on the bridge.

Design Truck. An idealized load representing a real truck. It is one portion of the live load that a bridge is designed to carry. See MS18 (HS-20) and MS23 (HS-25).

Diagnostic Test. A field test used to gather information about a bridge structure. Most often this is a load distribution test, which determines how load is transversely distributed to the various bridge girders.

Diaphragm. A secondary structural member that links adjacent girders together, often either in the form of a deep beam or cross-bracing. It is to assist in the transfer of lateral forces due to wind, to prevent girder buckling in compression areas, to maintain structural stability during construction, and to assist in distributing vertical loads more evenly throughout the structure.

DNR. The Department of Natural Resources. A construction permit must be obtained from the DNR prior to bridge construction. Through regulation, the DNR attempts to limit the environmental damage that construction may cause.

Ductility. The ability of a material to withstand deformation before failure under tensile stresses. In steel members, it is defined specifically as the amount of permanent strain up to the point of fracture.

Dynamic Load. See Impact Load.

Expand. See New Routes.

Falsework. A temporary structural system, such as shoring, that supports a structure in the construction phase until it can safely stand on its own. It is most often used with concrete construction.

Fatigue Load. Periodic stress variations or stress reversals, usually caused by bridge traffic, that can cause metal members to fail at stresses below their normal design values.

FEM. The Finite Element Method. A method of structural analysis in which a structure is idealized by divided it into small elements of various properties. It is based on a matrix formulation of the stiffness method. Most commercial structural analysis programs use FEM.

FHWA. Federal Highway Administration. A government agency that administers a number of highway transportation activities including standards development and technology enhancement. The FHWA facilitates the strategic development and maintenance of State and local transportation systems. It also administers the Federal-aid Highway Program, which provides federal financial and technical assistance to the states to improve the National Highway System.

Final Plans. The set of plans needed to construct a project. They include all details necessary to build the structure, material quantities required, and the specifications needed in the Bid Proposal.

Finite Difference Method. A method of structural analysis, not commonly used, that is practically different from FEM only in the choice of degrees of freedom and location of nodes. It is most suited to problems in which there is a single homogeneous medium with simple boundary shapes.

Finite Strip Method. A method of structural analysis based on FEM, that discretizes a bridge into small elements in the shape of longitudinal strips that span the length of the structure. It often represents loads as a harmonic series, and is limited to simple shapes and boundary conditions, however.

Fix Life. The expected period of time until further work is required on a structure to keep it in an acceptable condition.

Folded Plate Method. A method of structural analysis that idealizes a structure as a number of smaller plate elements, similar in execution to the finite strip method, but suited for more complex bridge cross-sections.

Fracture Toughness. A material's resistance to the propagation of a crack. Steel has a relatively high fracture toughness and can thus be subjected to large deformations without cracking.

Functionally Obsolete. A bridge is functionally obsolete if it is not adequately servicing traffic demands. This may be the result of inadequate clearances, unsafe geometrical alignments, if the design load-carrying capacity does not adequately service load demands, or if frequent flooding occurs.

GDF. Girder Distribution Factor. A factor that distributes the moment or shear generated by the design truck transversely to the bridge girders. It is the fraction of the truck weight (1/2 of the truck weight in the 1996 AASHTO Code, and the whole truck weight in AASHTO LRFD) that is applied to a girder for design. The GDF can be found by simple formulas.

GI. Grade Inspection. A site inspection to verify scope of proposed work.

Grillage Analogy. A method of structural analysis in which a bridge is idealized as a grid of simple elements. It is accurate for determining load distribution to the girders, but less so when determining the load effect in the deck.

GVW. Gross Vehicle Weight. The total weight of a vehicle crossing a bridge.

Haunch. A shallow concrete element cast with the deck, which sits between the top flange of a girder and the lower surface of the deck. It is used to increase the moment of inertia of the composite girder, as well as to allow for beam-top elevation changes.

Harmonic Analysis. A method of structural analysis which represents loads as the superposition of sine waves. It often minimizes computing time, but is limited to simple structural shapes and boundary conditions. Also called series or Fourier Analysis.

HP. High Performance. This usually refers to an increased strength, ductility, or other important performance measure of a typical civil engineering material. The exact definition depends on the material considered.

HPM. Highway Preventative Maintenance Fund. An annual funding source for bridge maintenance.

Hybrid Member. A built-up steel member made from components of different yield stresses.

I-beam. An open-section prestressed concrete beam with a web and top and bottom flanges. AASHTO types I-IV, the Wisconsin and Michigan girders are I-beams.

IC. Increase Capacity. A funding category of highway-related expenditures that adds traffic lanes to an existing road or bridge.

IM. Informational Memorandum. In the Design Division, the IM is often used to update the Bridge Design Manual and the Design Guides.

Impact Load (I). The load due to vehicle dynamics on the bridge. In reality it is a complex function of vehicle weight and suspension, road surface, and bridge structure. The AASHTO Code simplifies this effect as a fraction of the design truck live load.

Improve. See IC.

Inventory Rating. A factor of the legal allowable load that a bridge can safely support for an indefinite period of time.

ISTEA. Intermodal Surface Transportation and Efficiency Act. Passed in 1991 by the federal government, this law required each state to develop management systems such as bridge, pavement and congestion management.

Lane Load. When either MS18 (HS-20)or MS23 (HS-25) 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 on 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.

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

LFD. Load Factor Design. A design method in which 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). Safety in the design is achieved with these factors.

Live Load. In the AASHTO Codes, live load is specified as a Design Truck and a Lane Load. In the Standard Code, both are considered separately; in the LRFD Code, both are considered simultaneously.

LRFD. Load and Resistance Factor Design. LRFD has the same format as LFD (see LFD). In LRFD, however, the procedure leading to the calculation of load and resistance factors is different. LRFD factors are based on structural reliability analysis.

MPO. Metropolitan Planning Organization. For planning purposes, each region within the state with a population greater than 50,000 is clustered into a MPO. Each MPO develops project and expenditure plans that coordinate with STIP.

MS18 (HS-20). The basic design live load as specified in the AASHTO code, section 3.6.1.2.2 (called HS-20 in the AASHTO code). MS18 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). The design live load in Michigan that is 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.

NBI. National Bridge Inventory. A database that provides information about the condition of bridges as well as their load-carrying capacity. Project level decisions, such as repair or rehabilitation options to upgrade the bridges, can be made by using this database.

NCHRP. National Cooperative Highway Research Program. A program that provides means to conduct research in acute problem areas that affect highway planning, design, construction, operation, and maintenance nationwide. The state departments of transportation are the sole sponsors of the NCHRP.

New Routes. An MDOT funding category in which money is used to add additional roads and bridges to the transportation system.

NHS. National Highway System. Created by NHWA, the NHS eliminated the distinction between interstate and non-interstate routes which pertained to Federal Aid requirements. All former interstate routes are on the NHS.

NSF. National Science Foundation. The NSF is an independent US government agency responsible for promoting science and engineering. It funds research and education in science and engineering through grants, contracts, and cooperative agreements to colleges, universities, and other research and education institutions in all parts of the US.

Operating Rating. A factor of the legal allowable load that a bridge can safely support for the passage of a single vehicle.

Overlay. Often used in bridge deck repairs, the overlay is a concrete mix, sometimes with special admixtures (such as latex), that is usually poured over the top layer of reinforcement once the old deck surface is removed.

P&H. Pin and Hanger. A steel girder splice detail that is prone to maintenance problems. They are no longer used at MDOT in new construction.

P/PMS. Program/Project Management System. At MDOT, P/PMS is a two-level network that describes a critical path of tasks that must be completed to finish a design project.

PC. Prestressed Concrete. In bridge construction, PC usually refers to a concrete beam in which steel tendons are inserted and tensioned to a high level, compressing the concrete. This compression increases the flexural capacity (and thus potential span and load-carrying capacity) of the beam.

PCI. Precast/Prestressed Concrete Institute. An organization that supports the use of precast and prestressed concrete. It sponsors research and publishes design guides, such as the PCI Design Handbook.

Plate Girder. A steel beam that has a cross-section which is made of several smaller pieces joined together. Also called "built-up" girder.

Plate girders are often used when the standard W-shapes available are not adequate in flexural capacity for the span considered.

PM. Preventive Maintenance. Refers to preservation of the existing transportation system by scheduled work activities that restore element integrity, preventing "fair" structures from becoming "poor" structures.

Pontis. Literally, "bridge" in Latin. Pontis is a bridge management system developed by FHWA and supported by AASHTO. Forty-five states, including Michigan, are using and participating in joint development and enhancement of Pontis. The main elements of Pontis are the bridge inspection database, the ability to predict future conditions of bridge components, the fix matrix that represents types of repairs or rehabilitation options with cost data, and the ability to perform a multi-year strategic or "what if" analysis based upon the funding levels that can be provided.

Preliminary Plans. These are the second set of bridge construction plans prepared by the Design Unit, after the Study and with more detail. They are distributed for 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 is included in the Preliminary Plans, as must a proposed concept for maintaining traffic through the construction zone.

Preserve. Programmed work activity that restores or improves element integrity and ensures network safety and serviceability. Preserve work prevents bridges rated fair from becoming poor.

Proof Load Test. A field test in which a bridge is subjected to heavy loads in a controlled way, most often used to verify the capacity of the structure. This information can be used to determine the traffic load that can safely use the bridge (most often resulting in lifting or avoiding traffic restrictions that were determined by analytical means), and can also help to determine whether to replace or repair a bridge.

RC. Reinforced Concrete.

Region. MDOT has divided the state of Michigan into seven Regions, geographical divisions which are used by MDOT for administrative purposes. MDOT is currently being reorganized (as of 1998), as the department's nine district offices are being restructured into the Regional offices. The duties of these new offices will follow those of the former district offices, with additional planning and programming responsibilities.

Rehabilitation. This consists of programmed work activities that improve element integrity. Work activities typically would include deep overlays, superstructure repair, extensive substructure repair, or substructure replacement. Rehabilitation work activities improve condition ratings to fair or good. Project selection is considered on a worst-first basis.

Repair. Repair is the process of restoring deteriorated components of a bridge without upgrading its overall capacity or functional performance. Repairing a bridge will only give it a temporary reprieve by extending its life a few more years.

Replacement. This consists of replacement work activities that improve condition ratings from poor to good. Programmed deck replacement, superstructure replacement, or full structure replacement are considered. Project selection is considered on a worst-first basis.

Rolled Beam. Most commonly refers to a wide-flange (W) steel section, as opposed to a plate girder. Rolling refers to the section manufacturing process, by which in a heated state, the steel is run through rollers which shape it appropriately (as opposed to cold-formed sections). Sections other than W-sections are also hot-rolled, however; shapes designated S, C, L, WT, ST, and pipes, structural tubing, bars and plates are also hot-rolled.

R&R. Rehabilitation and Replacement. See each.

ROW. Right-of-way. The land area that a transportation agency controls through some recorded instrument (usually a Deed). Sometimes a road is in Statutory ROW, meaning that it was set aside by a previous Law. In Michigan, an early subdividing law that established Sections also sometimes dedicated 33' (10 m) to each side of the Section line for a public road; this 66' (20 m) width along the road is the right-of-way.

Scoping. The process of investigating a bridge to ascertain what work is needed to be done, or to verify the scope of a project.

Scour. The result of erosive action of flowing water, which excavates and carries away material from the bed and banks of streams. This can undermine foundations, causing bridge collapse. Loose granular soils are most susceptible. Scour is particularly dangerous during flooding conditions.

Shear Developer. A device used to insure Composite Action between a girder and slab, by allowing shear transfer between the two members. For steel girders, shear studs are often used, which are nail-shaped devices welded to the top of the girders before the concrete deck is cast. For PC girders, rebar that was cast into the girder during its manufacture

and projects from the top of the girder, sometimes functions as shear developers.

Special Needs Bridges. A category of bridge that falls outside of the typical management plan. These are bridges which have been found to be in need of rehabilitation to correct structural deficiencies discovered in the initial detailed inspection of the structure.

SPR. State Planning & Research. A federally mandated program that requires funding for transportation planning and research activities by the states. Two percent of Michigan's federal highway funds must be expended on planning and research, via the SPR program, as mandated by federal law. There are two parts to SPR: (1) planning, and (2) research, development and technology transfer. MDOT staff are responsible for the following planning activities under SPR: development of statewide, regional, and urban plans; transportation needs studies; transportation improvement plans; traffic surveys; speed studies; and transportation-related social, economic, and environmental studies.

Standard Specifications. In this document, refers to the 1996 version of the Standard Specifications for Construction (not the AASHTO Standard Specifications for Highway Bridges, the AASHTO Code), published by MDOT. The Standard Specifications describe to what standards construction is to be done and how payment is made.

STIP. Statewide Transportation Improvement Program. During the annual planning process, local authorities help to develop the STIP at the MPO level. STIP's are composed of the TIP's from all MPO's and all non-MPO areas of the state.

Structurally Deficient. A bridge is classified as structurally deficient if the condition of the deck, superstructure, or substructure is rated poor or worse. The bridge can also be structurally deficient if its load-carrying capacity is very low or if there are frequent delays due to flooding.

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.

Subfooting Concrete. A non-structural concrete base which is sometimes placed to provide a working surface on which footing forms can be erected.

Substructure. The structural portion of a bridge which is below the bearings but above the foundation; the abutments and piers.

Superstructure. The structural portion of a bridge which is supported by the bearings; the girders and deck comprise the superstructure on a typical highway bridge.

TIP. Transportation Improvement Program. A strategy developed by a MPO for its transportation funding expenditure.

TRB. Transportation Research Board. An organization that supports transportation. It sponsors research and facilitates communication among transportation professionals.

Tremie seal. Concrete used to provide lateral support to a cofferdam and to resist hydrostatic pressure from below when the cofferdam is dewatered.

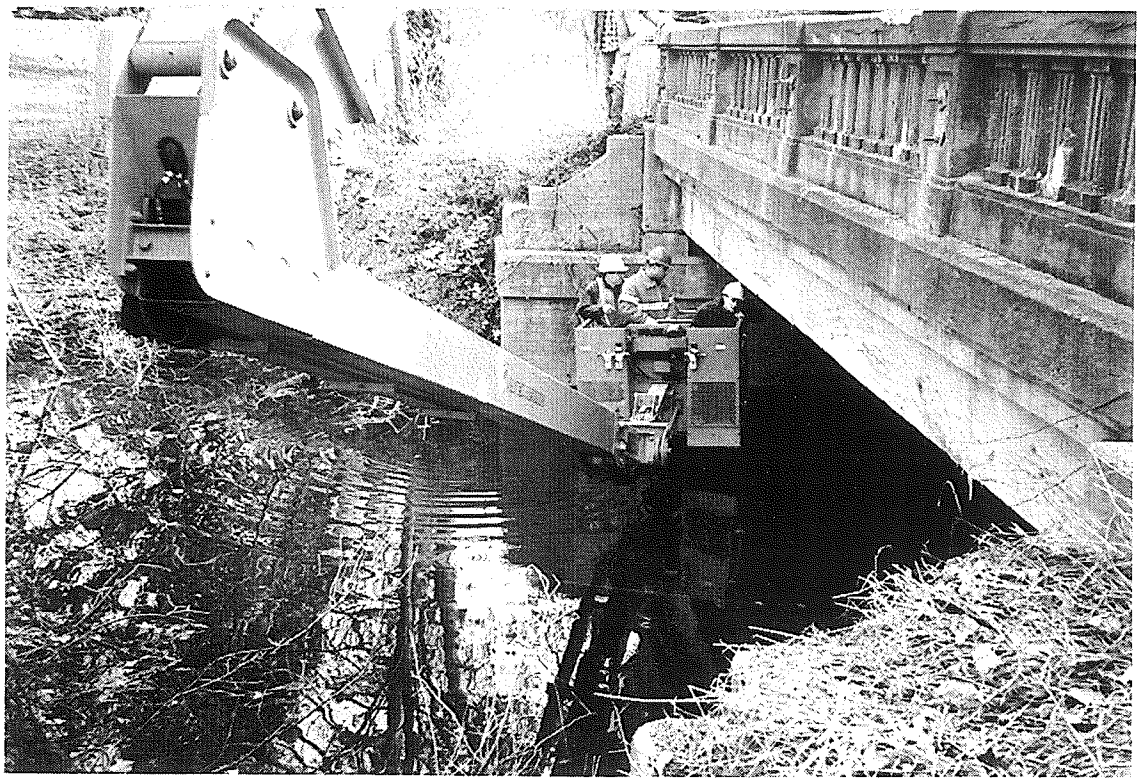
Trunkline. MDOT's US, I, and M routes across the state.

TSC. Transportation Service Center. An administrative office within a Region. There are approximately 25 TSC's, and the specific responsibilities of each are to be established by its governing Region.

WIM. Weigh-In-Motion. A field test that gathers truck traffic data crossing a particular bridge such as axle weight, axle spacing, vehicle speed, multiple truck presence, and ADTT.

Yield Line Method. A method of structural analysis which is based on finding a collapse mechanism that requires the least energy. Often used to analyze concrete plate elements, such as decks.

APPENDICES



Appendix A: Girder Distribution Factor

The following example illustrates how the actual girder distribution factor (GDF) on a particular bridge can be obtained from a live load distribution test.

The example bridge is an actual structure located on M-45 over Bass River west of Grand Rapids, Michigan. It has ten steel girders spaced at 1.42 m. The total span length is 11.7 m. The cross-section of this bridge is shown in Figure A-1.

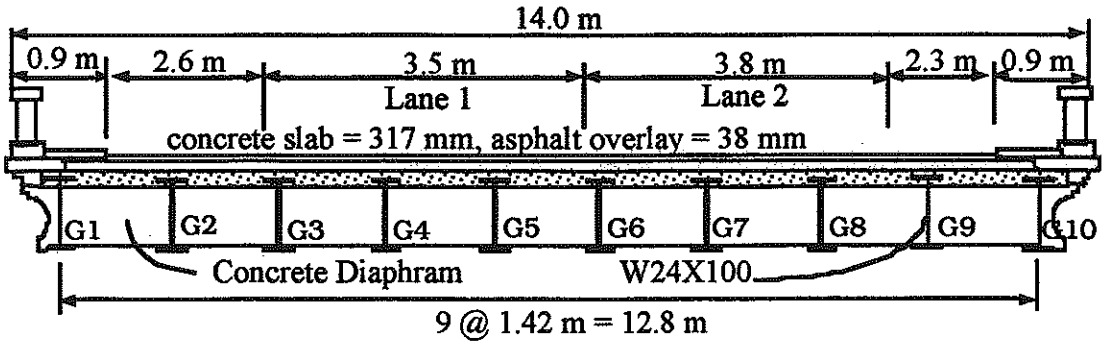


Fig. A-1. Bridge Cross-section

The bridge was loaded with 2 three-unit 11-axle trucks side by side. The resulting strain values at midspan for each girder, recorded from strain transducers, were:

Girder No.	1	2	3	4	5	6	7	8	9	10
Strain (με)	4.7	20.5	50.5	64	88	79	83	50	32	12.7

The GDF for the *i*th girder, GDF_i, can be computed as follows:

$$GDF_i = \frac{M_i}{\sum_{j=1}^{k} M_j} = \frac{ES_i\varepsilon_i}{\sum_{j=1}^{k} ES_j\varepsilon_j} = \frac{\frac{S_i}{S_\ell}\varepsilon_i}{\sum_{j=1}^{k} \frac{S_j}{S_\ell}\varepsilon_j} = \frac{\varepsilon_i w_i}{\sum_{j=1}^{k} \varepsilon_j w_j} \qquad \text{(A-1)}$$

where M_i = moment; E = modulus of elasticity; S_i = section modulus; S_ℓ = typical interior section modulus; ε_i = maximum bottom-flange static strain; w_i = ratio of the section modulus of the *i*th girder to that of a typical interior girder; and k = number of girders. i indicates the number of girder.

Because exterior girders are often stiffer due to curbs and barrier walls, the weight factors, w_i, for exterior girders are slightly greater than one. In this example, however, the weight factors, w_i, are assumed to be 1.0.

Assuming the weight factors for all girders are 1 (i.e. all girders have the same stiffness):

$$GDF_i = \frac{\varepsilon_i w_i}{\sum_{j=1}^{k} \varepsilon_j w_j} = \frac{\varepsilon_i}{= 4.7 + 20.5 + 50.5 + 64 + 88 + 79 + 83 + 50 + 32 + 12.7} = \frac{\varepsilon_i}{484.4}$$

$GDF_1 = 4.7/484.4 = 0.0097$	$GDF_{2+} = 20.5/484.4 = 0.0423$
$GDF_3 = 50.5/484.4 = 0.1043$	$GDF_4 = 64.0/484.4 = 0.1321$
$GDF_5 = 88.0/484.4 = 0.1817$	$GDF_6 = 79.0/484.4 = 0.1631$
$GDF_7 = 83.0/484.4 = 0.1713$	$GDF_8 = 50.0/484.4 = 0.1032$
$GDF_9 = 32.0/484.4 = 0.0661$	$GDF_{10} = 12.7/484.4 = 0.02622$

Therefore, the maximum girder distribution factor occurs at girder number 5 and the value is 0.1817.

A distribution factor graph from an actual test carried out in 1997 is given in Fig. A-2 (from an 11-girder, 16.8m long bridge on M-34 over the south branch of Raisin River in Adrian, MI). The bridge was loaded in both lanes with the maximum legal truck load. Clearly, the results indicate that the bridge girders experienced stress values significantly lower than what would be expected analytically (i.e. from stresses calculated by following code procedures). The results are typical.

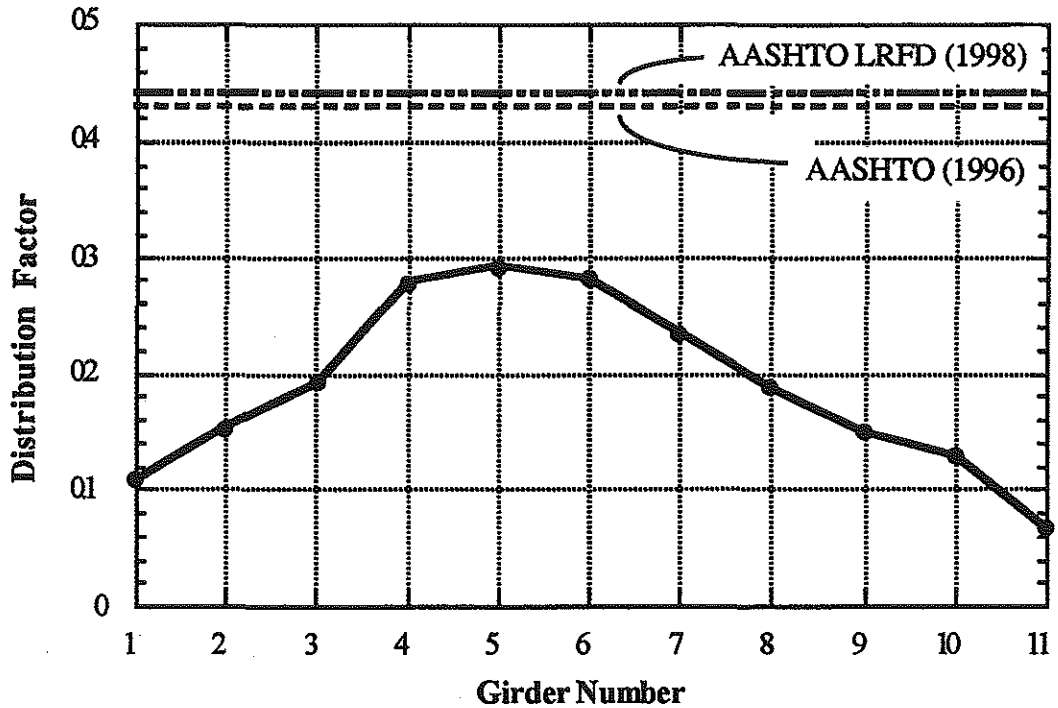


Fig. A-2. Maximum GDF's compared with Analytical (code) Results.

Appendix B: Proof Load

The procedure for conducting a proof load is the following:

1. Determine target proof load.
2. Conduct proof load test.
3. Compute operating rating.

1. Determine Target Proof Load.

Determination of the needed proof load level is fully described in "Bridge Rating Through Load Testing" by A.G. Lichtenstein (NCHRP, 1993), which is summarized here.

The maximum allowable legal load is multiplied by a factor X_p, which represents the live load factor needed to bring bridge to an operating rating of 1.0. X_p has a base value of 1.4, and further adjustments are as follows:

- Increase X_p by 15% for one lane structures or for other spans in which the single land loading augmented by an additional 15% would govern.
- Increase X_p by 10% for spans with fracture critical details. A similar increase in X_p shall be considered for structures without redundant load paths.
- Increase X_p by 10% if inspections are to be performed less often than 2-year frequency.
- Reduce X_p by 5% of the structure is ratable and there are no hidden details, and if the calculated rating factor exceeds 1.0.
- Additional factors including traffic intensity and bridge condition may also be incorporated in the selection of the live load factor X_p.

The target live load factor X_{pa} is X_p adjusted by the applicable factors given above. The target proof load L_t is then:

$$L_t = X_{pa}(1+I)L_r \qquad \text{(B-1)}$$

where:

$1.3 \leq X_{pa} \leq 2.2$
Lr = live load due to the rating (test) vehicle
I = impact factor

2. Conduct the Proof Load Test.

See section 9.6.5 for a description of this test. The test is stopped if signs of structural distress appear during load application.

3. Compute Operating Rating.

At conclusion of the proof load test, the operating rating is calculated as follows:

$$OP = K_o L_p / X_{pa} \qquad \text{(B-2)}$$

where:

OP = operating level capacity
L_p = actual maximum proof load applied to bridge
X_{pa} = target live load factor
K_o = 1.0 if target load is reached, = 0.88 if a distress level is reached prior to reaching the target load

The operating rating factor (ORF) is then:

$$ORF = OP / L_r(1+I) \qquad \text{(B-3)}$$

where:

L_r = maximum allowable legal load.

If ORF >1, then the bridge is considered safe for the legal load.

Example:

A two lane, 12m (40') span bridge is to be tested. For this span, the maximum moment resulting from the maximum legal load is produced by a 11-axle, 2-unit 77ton truck, and is 922kN-m (678 k-ft) (see Table 2-1, section 2.3 of this report).

1. *Determine target proof load level.*

In this example, $X_{pa} = X_p = 1.4$, and the AASHTO LRFD impact factor of 0.33 is used.

$L_t = 1.4(1+ 0.33)(922) = 1717$ kN-m (1263 k-ft).

2. *Conduct the proof load test.*

A heavy test vehicle is obtained. Prior to the proof load test, simple calculations are made (statics) to determine the needed position of the vehicle on the bridge that will produce a moment which is approximately equal the target level, L_t.

A proof load test is preformed. During the test, the vehicle is placed on the bridge in a position that would theoretically produce a moment of 1750 kN-m (statics). There were no signs of structural distress on the bridge.

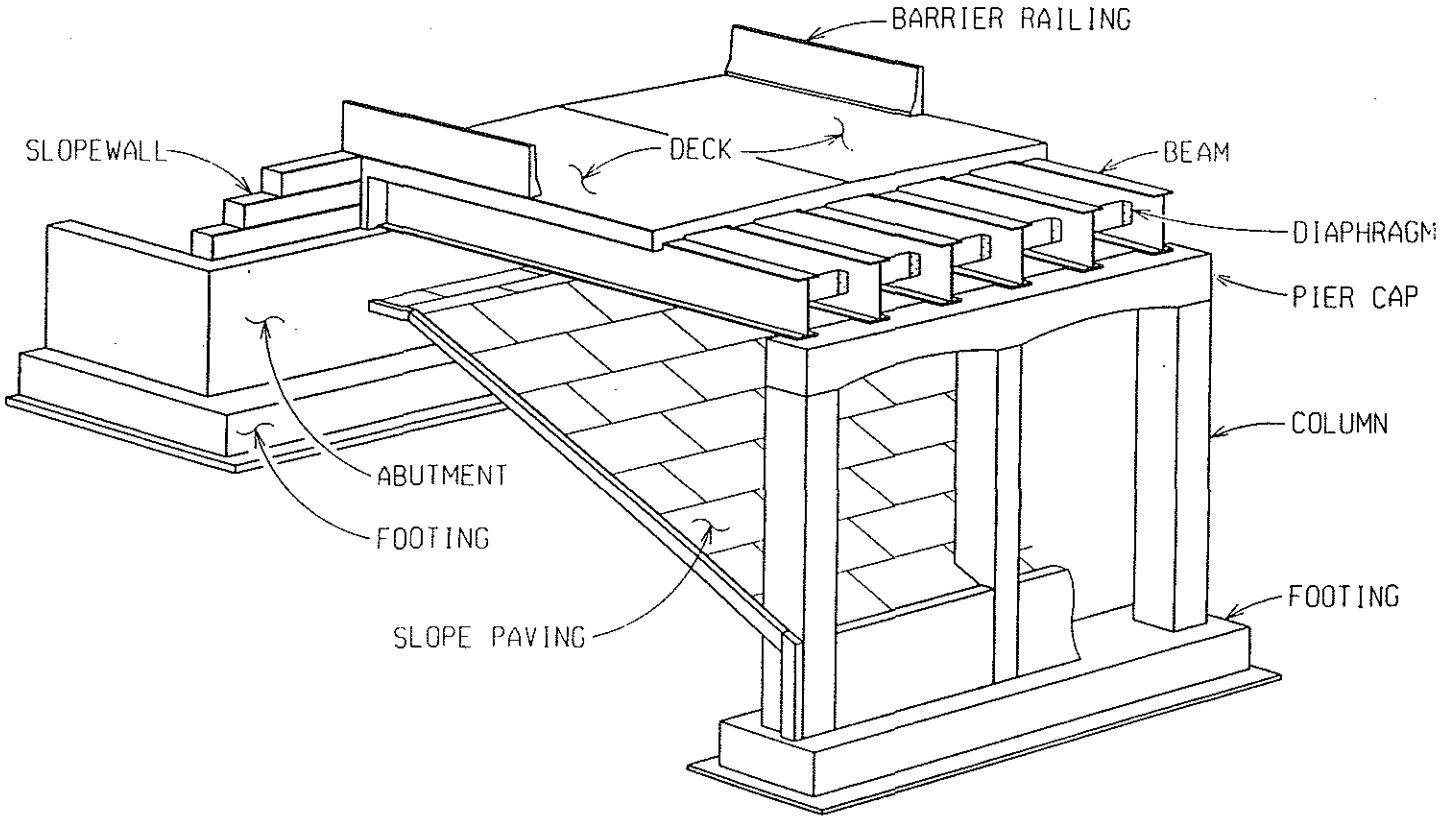
3. *Calculate operating rating.*

OP = 1.0(1750)/1.4 = 1250 kN-m (919 k-ft)

ORF = 1250/(922)(1+.33) = 1.02 > 1

The bridge is therefore safe for the legal load.

Appendix C: Typical Bridge Configuration



TYPICAL BRIDGE CONFIGURATION

MAJOR ELEMENTS

Appendix D: English/SI Unit Conversions

Length

1 inch	=	25.4	millimeters
1 foot		0.305	meters
1 mile		1.61	kilometers

Area

1 square inch	=	645	square millimeters
1 square foot		0.093	square meters
1 square mile		2.59	square kilometers

Volume

1 cubic inch	=	16,387	cubic millimeters
1 cubic foot		0.0284	cubic meters
1 cubic yard		0.765	cubic meters

Force & Mass

1 pound	=	0.454	kilograms
1 kip		4.45	kiloNewtons
1 ton (short)		0.907	metric tons

Stress & Pressure

1 psf (lb./ft^2)	=	0.0479	kiloPascals (kN/m^2)
1 psi (lb./in^2)		6.9	Pascals (N/m^2)
1 ksi (kip/in^2)		6.9	megaPascals (kN/mm^2)

Moment & Torque

1 lb-in	=	1.088e-4	kiloNewton-meters
1 lb-ft		1.36e-3	
1 kip-in		0.113	
1 kip-ft		1.36	

Unit Weight & Density

1 pci (lb./in^3)	=	27.7	g/cm^3
1 pcf (lb./ft^3)		16	kg/m^3

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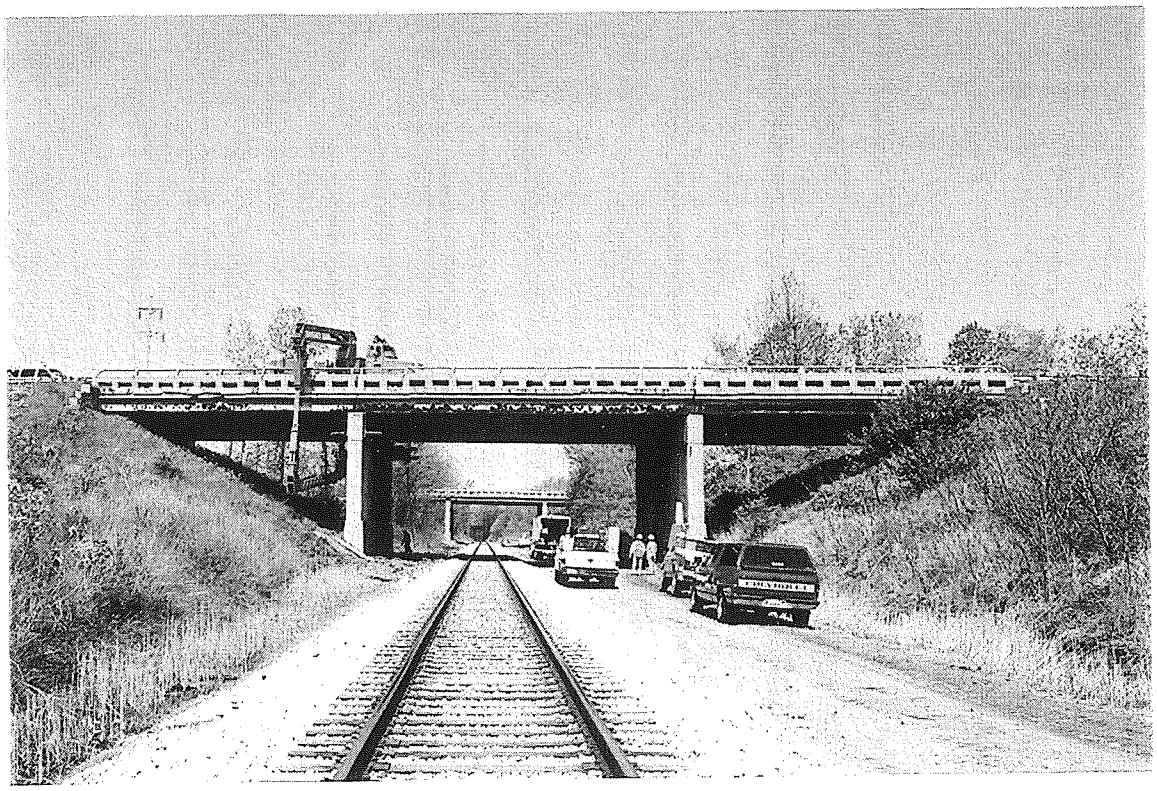
Come Out Of The Blue
Give her a shot at the prize.



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