INTRODUCTION

Finland has 78,000 km of public roads with over 13,000 bridges, which are maintained and repaired by the Finnish National Road Administration, Finnra. Bridge repair is demanding work that differs in many ways from new bridge construction. Therefore, Finnra Bridge Engineering has compiled a Finnish Bridge Repair Manual (SILKO). This manual contains more than 150 directives describing bridge repair methods, as well as materials and equipment used in repair work.

International connections and cooperative projects are increasing. To serve this activity, Finnra has translated the most important bridge repair directives into English and Russian. The 35 translated directives in this folder are grouped as follows:

Part 1 (red) General guidelines, which generally describe mechanisms that cause damage, as well as repair methods and materials.

Part 2 (blue) Repair instructions, which form the main part of the Finnish Bridge Repair Manual. They describe damages and repair.

Part 3 (green) Product file, which contains brand names of materials approved by Finnra. Approval is based on tests conducted by the Technical Research Centre of Finland.

Part 4 (gray) Job equipment file, which presents tools that have been proven in bridge repair.

The Finnish Bridge Repair Manual is an effective aid for designers, builders, contractors and material suppliers involved in bridge repair work. The directives may also be applied to other outdoor concrete structures.

The Finnish Bridge Repair Manual is also well suited for personnel training. It helps employees understand the mechanisms that cause damage, describes how damage may be prevented, and explains how effective, modern repair methods are implemented.

For more information on technical questions related to the implementation of these directives, please contact Finnra Bridge Engineering at the following address:

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Bridge Engineering
P.O.Box 33
FIN-00521 HELSINKI
FINLAND
Tel. +358 204 44 150
Fax +358 204 44 2395

Finnish Bridge Repair Manuals are available at the above address.

Helsinki, February 1997
Finnra
Bridge Engineering

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Bridge repair directives, the SILKO directives, are compiled within the framework of Finnra's SILKO project.

The goals of the SILKO project are:
- to develop repair construction
- to improve the durability of structures
- to influence bridge construction and maintenance

The SILKO project's primary areas of influence in bridge repair are:
- Specification of quality goals and quality requirements.
- Guiding repair work so that it complies with European standards SFS-EN 1504-1...10.
- Taking Finnra's environmental protection goals into consideration.
- Ensuring work safety at bridge construction sites.
- Approving materials used in bridge construction and repair, and conducting relevant testing.
- Experimental repair work and compilation of repair directives based on practice, so that repair work done according to the directives will be completed with sufficient reliability.

The SILKO project is closely linked to the bridge management system (BMS). Information about repair work is entered into a bridge register, and the success of repair work is monitored on the basis of information obtained from the bridge inspection system.

Training is an important part of the SILKO project. Training sessions present:
- recommended repair methods
- approved repair materials
- experiences with experimental repair work.

Figure 1. Ordinary construction methods are usually used in repair work, but they must be adapted to the special requirements of the repair work being done.

Figure 2. Many special materials are used in repair work. The instructions for using the materials must be followed strictly.
2 USING THE FINNISH BRIDGE REPAIR MANUAL

The Finnish Bridge Repair Manual has been compiled primarily for bridge repair work. The directives dealing with bridge structures have been compiled for use in bridge construction, also. The directives are also used for the repair of construction errors made on site. The directives can also be applied in other construction activity.

The Finnish Bridge Repair Manual is used in the phases of repair work (figure 3) as follows:

1. Damages are determined during general inspections, which are conducted under the bridge management system’s (BMS) bridge inspection programme. Damages are classified according to the damage classification presented in tables 2-19 of the Bridge Inspection Handbook /2/. The repair methods of the damage classification comply with the repair directives in the Finnish Bridge Repair Manual (folder 2: Job-specific quality requirements). The need of repair is determined in section 2 of each repair directive on the basis of the damage classification of the Bridge Inspection Handbook.

2. The main principle of repair construction is to eliminate the cause of damage. The cause of damage and other contributing factors are determined during a special bridge inspection conducted according to the Bridge Inspection Guidelines /3/. Information contained in the Finnish Bridge Repair Manual’s General Guidelines (folder 1: General quality requirements) concerning factors that stress bridge structures, as well as construction materials and their damage mechanisms, are needed in the special inspection.

3. Selection of a solution in principle, by comparing alternatives during general planning, is the most important phase of repair construction. A solution in principle is selected on the basis of the Finnish Bridge Repair Manual’s General Guidelines and European standards /4/. Each solution in principle may be implemented using several repair methods, which are presented in the European standards /1/ and /4/, among others.

4. Specification of quality requirements and quality assurance procedures are the most important issues during the planning phase. They are specified according to the directives in folders 1 and 2. It is not enough to simply refer to the Finnish Bridge Repair Manual. The designer should familiarise him or herself with the manual and select the instructions and information that are applicable in each case. Information concerning repair work is compiled into a repair plan work description and job-specific quality requirements. For a job completed separately, a surface structure, surface treatment, injection or other similar plan and relevant quality standards are compiled. A safety manual, which is the responsibility of the client, is also always needed. It is compiled according to

5. In a contract bidding competition, the Finnish Bridge Repair Manual is included either as an appendix to a repair plan. In minor special jobs, the manual is used alone as quality requirements as is. Lists of contractors, research institutes and consultants needed for quality assurance, and tools that are suitable for bridge repair work are presented in the Finnish Bridge Repair Manual's job equipment file (folder 4).

6. During the contracting phase, the Finnish Bridge Repair Manual is used as the basis for compiling a technical work plan or a quality plan, or a combination of the two. Environmental protection and work safety measures are implemented according to the manual and the laws, statutes and regulations listed therein. The Finnish Bridge Repair Manual is used in worker guidance and job assignment, and as a general source of background information that provides guidelines and alternative solutions. The manual functions as a bridge repair handbook.

In bridge maintenance, the Finnish Bridge Repair Manual is used as a guide in minor repair work and in estimating the need for repair.

The Finnish Bridge Repair Manual is also used as educational material during training.

The Finnish Bridge Repair Manual serves two different purposes:

1. The manual is part of a bridge repair plan. The plan presents the following in more detail:
   - job-specific quality requirements
   - quality assurance measures
   - a possible alternative, which is used
   - other issues that need to be taken into consideration in the repair work, such as a warning about a commonly occurring error.

   These types of bridge repair directives include instructions dealing with demanding, extensive repairs, such as renewing an edge beam or repairing by ejection, coating a concrete surface, injecting cracks with epoxy, and repainting a railing or other steel structure.

2. The manual is used as is for minor repair work included in bridge maintenance. Issues that should be taken into consideration when using the manual are presented in a technical work plan or a quality plan, or a combination of the two. The possibility of using the Finnish Bridge Repair Manual in this manner is presented in the beginning of the section dealing with quality require-
The Finnish Bridge Repair Manual and individual bridge repair directives are sold by the Finnish Road Administration’s publication sales.

Contact information:

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The order numbers of the Finnish Bridge Repair Manual are (figures 7 and 8):

<table>
<thead>
<tr>
<th>Folder without directives</th>
<th>Folder directives</th>
</tr>
</thead>
<tbody>
<tr>
<td>TIEH 2232220</td>
<td>TIEH 2230095</td>
</tr>
<tr>
<td>TIEH 223221</td>
<td>TIEH 2230096</td>
</tr>
<tr>
<td>TIEH 223222</td>
<td>TIEH 2230097</td>
</tr>
<tr>
<td>TIEH 223223</td>
<td>TIEH 2230098</td>
</tr>
</tbody>
</table>

**Figure 7.** The common order number of the directives of each folder is marked on the lower left edge of the cover page of each directive.

**Figure 8.** The folder order number (without directives) is marked on the cover of each folder.
To order a specific directive, the SILKO number (e.g., SILKO 3.252) of that directive, which appears in the heading of the directive, is needed (figure 9).

The manual can be updated by means of a continuous subscription, in which case new directives are sent to the subscriber as they are completed, or by ordering individual directives separately from the Finnish Road Administration, Bridge Engineering.

The Finnish Road Administration, Bridge Engineering, will be glad to reply to inquiries and to accept comments concerning the directives. Contact information:

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e-mail jouko.lamsa@tiehallinto.fi
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tel. +358 (0)204 22 2351
e-mail raili.barlund@tiehallinto.fi

4 REFERENCE PUBLICATIONS


/4/ Products and systems for the protection and repair of concrete structures - Definitions, requirements, quality control and evaluation of conformity. EN 1504-2...6
1 COMPILATION OF THE FINNISH BRIDGE REPAIR DIRECTIVES (SILKO)

Most of the bridges in Finland are administered by Finnra, the Finnish railways and the larger cities. For this reason, the State Railways and the city of Helsinki also co-operate with Finnra in the SILKO project. The Radiation Protection Centre, which represents a special field, also participates in the SILKO project. This illustrates the broader significance of the project. These participants also pay for part of the expense of the SILKO research.

Work groups compile the Finnish bridge repair directives based on outlines prepared by a special consultant in the field. The five work groups are responsible for the following areas:
- concrete work group; concrete structures and their protection
- steel work group; steel structures and their surface treatment
- surface structure work group; waterproofing and paving
- bridge site work group; bridge-related structures and equipment (bridge site finishing work)
- general work group; stone and wood structures, drainage systems, joint structures, and other furnishings and equipment.

Each work group is chaired by a representative from Bridge Engineering. The instructions are approved for use by a ten-member SILKO committee. The committee and the groups include members from the following interest groups:
- State Technical Research Centre
- State Railways
- the city of Helsinki
- the districts
- material manufacturers
- contractors

The SILKO project includes experts from 25 different fields. In this way, issues affecting repair work are taken into consideration as extensively as possible in the compilation of the directives. Members of the work groups also participate in work groups that compile euronorms, so the SILKO project has direct contacts with research and development work being carried out elsewhere in Europe.

Repair material and tool agents attend work group meetings and present new products and work methods. The committee visits production facilities in the field and makes educational trips abroad. The work groups also visit repair job sites.

The Finnish Bridge Repair Manual is continuously being compiled and revised. This is necessary, because repair materials and methods are constantly being developed. A few directives were still incomplete in 2002.

Selection of the correct repair material is essential to successful repair work. Therefore, the SILKO project also includes repair material research conducted the State Technical Research Centre (VTT) since the beginning of the 1970s.

Repair materials and methods are tested not only in laboratories, but also at district repair job sites.
The Finnish Bridge Repair Manual is divided into four folders (figure 3):
1. General quality requirements
   (General guidelines)
2. Job-specific quality requirements
   (Repair instructions)
3. Product file
4. Job equipment file

The main part of the manual is the repair instructions folder, which is supplemented by the other folders. The general guidelines provide background information and the other files contain detailed information about products and equipment.

The contents of the folders are divided into the following parts:
- concrete structures
- steel structures
- wood structures
- stone structures
- drainage systems
- joint structures
- deck surface structures
- bridge-related structures.

Figure 3. Finnish Bridge Repair Manual folders.
The purpose of the general guidelines (folder 1) is to provide background information needed in bridge repair work in the topic areas of the Finnish Bridge Repair Manual.

Since some of the topic areas differ considerably from the rest, the contents of the guidelines also vary. The general guidelines generally cover:
- damage and causes
- theories of repair
- terms and definitions
- planning repair work
- preparing for repair work
- methods used in repair work
- repair materials
- work safety
- environmental protection
- general quality requirements
- quality assurance

In principle, the general guidelines present theoretical information and information common to several repair instructions in the topic area. This information is not repeated in the repair instructions. The repair instructions include references to the general guidelines whenever the two should be used together. The general guidelines are supplemented by relevant
- rules and regulations
- vocational and training material
- course material
- magazine articles.

The general guidelines must be familiar before the other repair instructions can be used. In order to have a better grasp of details and to keep important background information in mind, it is recommendable to review the general guidelines periodically.

<table>
<thead>
<tr>
<th>GENERAL GUIDELINES</th>
<th>CONCRETE STRUCTURES</th>
<th>STEEL STRUCTURES</th>
<th>WOOD STRUCTURES</th>
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<tbody>
<tr>
<td>1.101 The purpose and use of the Finnish Bridge Repair Manual</td>
<td>1.201 Concrete as a bridge repair material</td>
<td>1.301 Metals as bridge repair materials</td>
<td>1.401 Wood as a bridge repair material</td>
</tr>
<tr>
<td>1.102 Contents</td>
<td>1.202 Polymers as bridge repair materials</td>
<td>1.351 Surface treatment</td>
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<tr>
<td>1.111 Work safety</td>
<td>1.203 Removal and pre-treatment methods</td>
<td>1.352 Degree of corrosion R10-R12 tables</td>
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<tr>
<td>1.112 Environmental protection</td>
<td>1.231 Patching concrete</td>
<td>1.353 Degree of corrosion R13 tables</td>
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<td></td>
<td>1.232 Guniting</td>
<td>1.354 Degree of corrosion R14 tables</td>
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<tr>
<td></td>
<td>1.233 Injection of concrete structures</td>
<td>1.355 Degree of corrosion R15 tables</td>
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</tr>
<tr>
<td></td>
<td>1.251 Shielding concrete</td>
<td>1.356 Specifying the repair of surface treatment</td>
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</tr>
<tr>
<td></td>
<td>1.271 Underwater repair work</td>
<td>1.357 Specifying the repair of steel pipes</td>
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</table>

<table>
<thead>
<tr>
<th>STONE STRUCTURES</th>
<th>DRAINAGE STRUCTURES</th>
<th>JOINT STRUCTURES</th>
<th>DECK SURFACE STRUCTURES</th>
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<tr>
<td>1.501 Natural stone as a facing material</td>
<td>1.601 Bridge and bridge site drainage</td>
<td>1.701 Expansion and contraction joints</td>
<td>1.801 Waterproofing 1.802 Pavements</td>
<td>1.901 Bridge site finishing</td>
</tr>
</tbody>
</table>
The repair instructions (folder 2) are an important aid in repair work. They are the most important part of the Finnish Bridge Repair Manual, and they are supplemented by the other parts. The general guidelines provide background information, and detailed information is found in the product and job equipment files.

The repair instructions present job-specific quality requirements and quality assurance measures in wide columns of text. Directives are presented in narrow columns of text. Planning instructions are only given for rather small repairs that are usually done in conjunction with maintenance work.

The repair instructions contain the following parts:
- damage
- need for repair
- quality requirements
- work phase requirements
- quality assurance
- supplementary instructions

Appendix: instructive information
- work phases
- directive resource information

The applicable area of the instructions is limited, if necessary, on the cover page. The type of damage, its cause, the effects of the surrounding conditions, and the characteristics of the damage are explained. If necessary, consequential damage is explained. The degree of damage requiring repair is specified as concisely as possible. If necessary, instructions for observing and examining the damage and references to suitable source material are given to provide help in determining the extent of the damage. Alternative methods of repair are presented.

The text that explains the repair work organises the work according to an operational chart, as well as job-specific quality requirements and work phase requirements:
- preparing the repair work
- preparing the object being repaired
- handling repair materials
- doing the repair work
- taking into consideration the surrounding conditions
- finishing and post-repair work.

<table>
<thead>
<tr>
<th>CONCRETE STRUCTURES</th>
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<th>STONE STRUCTURES</th>
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<tbody>
<tr>
<td>2.211 Renewing an edge beam</td>
<td>2.311 Renewing a railing</td>
<td>2.411 Renewing a wooden deck</td>
<td>2.511 Facing concrete with stone</td>
</tr>
<tr>
<td>2.221 Reinforcing the superstructure with steel plates</td>
<td>2.321 Reinforcing the superstructure with steel plates</td>
<td>2.421 Reinforcing a wooden deck with steel plates</td>
<td>2.521 Fastening stones with steel rods</td>
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<tr>
<td>2.231 Patching without forms</td>
<td>2.331 Restoring the base of a railing post</td>
<td>2.431 Injecting cracks with epoxy</td>
<td>2.531 Injecting a structure</td>
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<tr>
<td>2.232 Patching with forms</td>
<td>2.332 Restoring the upper flange of a steel beam</td>
<td>2.451 Protecting a glued laminated beam</td>
<td>2.532 Jointing a structure</td>
</tr>
<tr>
<td>2.233 Repairing by injection</td>
<td>2.351 Touch-up painting a railing</td>
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<td>2.551 Cleaning stone surfaces</td>
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<tr>
<td>2.234 Repairing by guniting</td>
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<td>2.236 Injecting cracks with epoxy</td>
<td>2.353 Maintenance of a bearing</td>
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<td>2.237 Grouting with cement</td>
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<td>2.239 Repairing a crack by capillary absorption</td>
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<td>2.240 Restoring a waterproofing substrate</td>
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<td>2.251 Chemical cleaning of a concrete surface</td>
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<td>2.252 Impregnating a concrete surface</td>
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<td>2.253 Coating a concrete surface</td>
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<tr>
<td>2.261 Fixing anchoring bars</td>
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<tr>
<td>2.262 Repairing reinforcement bars</td>
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<td></td>
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<tr>
<td>2.271 Underwater repair work</td>
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</tbody>
</table>
Product names are not given in the repair instructions, only commonly used or separately defined generic names. Most of the instructions contain proven work methods or materials, as well as alternate work methods or materials. Traditional terminology of the field is used.

The repair procedure is shown as an operational chart, which
- gives an illustrative picture of the various stages of the repair work
- shows the layout of the text and the main work phases
- provides a base for work planning and a logical work arrangement.

Furthermore, the required amount of workers, tools and generic materials, job site and work safety arrangements, and estimated work output are given.

The last two digits of a directive’s SILKO number indicate the nature of the repair work as follows:
11-19 Repair of structures and facing
21-29 Reinforcement of structures
31-49 Restoration of structures
51-59 Protecting structures
61-69 Concrete reinforcement bars
71-79 Underwater repair work
91-99 Other structures.

<table>
<thead>
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<tr>
<td>2.611 Installing a drain pipe in the superstructure</td>
<td>2.711 Sealing an edge beam expansion joint with caulking</td>
<td>2.811 Renewing waterproofing</td>
<td>2.911 Stone rip-rap facing</td>
</tr>
<tr>
<td>2.612 Making a drain hole at the base of a railing post</td>
<td>2.712 Sealing an edge beam expansion joint with a joint element</td>
<td>2.812 Renewing waterproofing</td>
<td>2.912 Stone revetment</td>
</tr>
<tr>
<td>2.613 Making an edge drain</td>
<td>2.713 Installing an expansion joint device</td>
<td>2.813 Renewing waterproofing</td>
<td>2.913 Concrete revetment</td>
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<tr>
<td>2.614 Making a cross drain</td>
<td>2.731 Sealing an edge beam expansion joint</td>
<td>2.814 Renewing asphalt pavement</td>
<td>2.914 Concrete block facing</td>
</tr>
<tr>
<td>2.615 Making an expansion joint and bearing seat</td>
<td>2.732 Sealing a joint between an edge beam and pavement</td>
<td>2.815 Paving a wooden deck</td>
<td>2.915 Peat facing</td>
</tr>
<tr>
<td>water drain</td>
<td>2.733 Sealing joints between superstructure elements</td>
<td>2.831 Patching waterproofing</td>
<td>2.917 Gravel facing</td>
</tr>
<tr>
<td>2.631 Extending a drain pipe</td>
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<td>2.832 Sealing a crack in pavement</td>
<td>2.916 Natural stone revetment</td>
</tr>
<tr>
<td>2.632 Extending a downpipe</td>
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<td>2.919 Gabion baskets</td>
</tr>
<tr>
<td>2.651 Installing surface water drains</td>
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<td>2.931 Planting trees and bushes</td>
</tr>
<tr>
<td>2.652 Installing a slope drainage pipe</td>
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<td>2.991 Slope stabilizers</td>
</tr>
<tr>
<td>2.653 Installing a slope gutter</td>
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</table>
5 PRODUCT FILE

Repair materials approved by the Finnish Road Administration, Bridge Engineering, are presented in the product file (folder 3) of the Finnish Bridge Repair Manual. Approval is based on tests conducted by the State Technical Research Centre (VIT). The test programmes are available from VTT Building and Transport.

The following repair materials, among others, are subjected to testing:
- concrete patching materials
- poured and gunited concrete
- concrete protection materials
- injected materials and impregnants
- concrete surface cleaning materials
- coating systems for steel surfaces
- waterproofing sheet membranes and liquid applied membranes
- thin-layer pavements

The study reports are translated into English. Approved repair materials are also tested at bridge repair work sites. Periodic inspections are conducted to monitor the results of the experiments.

<table>
<thead>
<tr>
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<td>3.352 Surface treatment materials</td>
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</tr>
<tr>
<td>3.235 Injection plastics and sealing compounds</td>
<td>3.353 Bearing lubricants and cleaning agents</td>
<td></td>
<td>(see 3.251)</td>
</tr>
<tr>
<td>3.251 Graffit resistant materials and surface cleaning chemicals</td>
<td>3.354 Metal spraying materials</td>
<td></td>
<td>3.572 Underwater patching materials</td>
</tr>
<tr>
<td>3.252 Impregnants and sealants</td>
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<td>(see 3.271)</td>
</tr>
<tr>
<td>3.253 Surface coating materials</td>
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<tr>
<td>3.271 Underwater patching materials</td>
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</tbody>
</table>

The product file contains the brand names, manufacturers and suppliers of approved repair materials. The file also contains the following information on the materials:
- the area of application and possible limitations of use
- transportation and storage instructions.

The owner of the folder may supplement the information as needed with product descriptions and safety bulletins.

The product file is a supplement to the general guidelines and repair instructions (folders 1 and 2). The general guidelines refer to materials by their commonly used or separately defined generic names, which form the headings of the table of contents of the product file. The quality requirements of repair materials are presented in the general guidelines.

The product file is numbered in the same manner as explained at the end of the text dealing with the repair instructions.

<table>
<thead>
<tr>
<th>DRAINAGE SYSTEMS</th>
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<tbody>
<tr>
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<td>3.711 Expansion joint devices</td>
<td>3.811 Sheet membrane waterproofing structures</td>
<td>3.912 Concrete products</td>
</tr>
<tr>
<td>3.651 Bridge site drainage devices</td>
<td>3.712 Asphalt plug joints</td>
<td>3.814 Mastic asphalt and edge beam sealants</td>
<td>3.913 Landscaping products</td>
</tr>
<tr>
<td></td>
<td>3.731 Sealing compounds</td>
<td>3.815 Liquid applied membranes</td>
<td>3.914 Slope reinforcement products</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.821 Thin-layer pavements</td>
<td>3.915 Stone cribs and stone beds</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.831 Pavement patching compounds</td>
<td>3.931 Seedling suppliers</td>
</tr>
</tbody>
</table>
The job equipment file (folder 4) supplements the general guidelines and repair instructions (folders 1 and 2) in the same manner as the product file.

The job equipment file contains lists of:
- contractors approved by Finnra Bridge Engineering
- material testing laboratories and consultants that conduct special inspections and perform quality assurance work
- tools that have been proven in bridge repair work
- formwork and other structures that have been developed in conjunction with bridge repair work.

An electronic version of the job equipment file is being compiled. It is located on the Finnish Road Administration's information page at www.tiehallinto.fi.

The job equipment file is numbered as follows:
- 01-09 contractors, manufacturers, material testing laboratories and consultants approved by Finnra
- 11-49 repair equipment
- 51-59 protection equipment
- 61-69 measuring equipment
- 91-99 passenger lifts, scaffolding, protective roofs and covers, and related accessories.

### CONCRETE STRUCTURES

| 4.201 Bridge repair contractors |
| 4.202 Construction machinery renters |
| 4.204 Material testing laboratories and consultants |
| 4.211 Concrete equipment |
| 4.231 Cutting and dismantling equipment |
| 4.232 Injection equipment |
| 4.281 Measuring equipment |
| 4.291 Passenger lifts |

### STEEL STRUCTURES

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1. GENERAL

1.1 Corrosion and prevention

Corrosion results from reactions between metal and the environment. In construction, these reactions are usually electrochemical. The natural phenomenon corrosion releases excess energy bound to a metal during various metallurgical processes. As this energy is released, steel is gradually converted into iron compounds, or rust.

Surface treatment of steel structures protects the metal from corrosion.

In the presence of water, a steel surface contains potential differences, causing corrosion cells to form. The potential differences are caused by the quality of the steel or impurities in the steel surface. A small electric current develops when the surface of the steel is moist. This starts the corrosion process. The electronegative part of the steel, called the anode, begins to deteriorate.

The electrochemical corrosion process proceeds as follows (figure 1):

1) at the anode, iron (Fe) is converted to positive iron ions (Fe²⁺) and electrons (e⁻) (anode or oxidization reaction). Then the electrons migrate to the cathode and the iron ions are dissolved in water, an electrolyte,

2) at the cathode, the electrons combine with oxygen (O₂) and water molecules (H₂O) to form negative hydroxyl ions (OH⁻) (cathode or reduction reaction),

3) the iron ions and hydroxyl ions react in water to form iron hydroxide (Fe(OH)₃),

4) the iron hydroxide reacts with water and oxygen, and the resulting product of corrosion is brown rust (Fe₂O₃ · n H₂O).

Figure 1. Schematic diagram of a local cell and an electrochemical reaction in a water-filled pore on a steel surface (microscopic diagram).

Corrosion requires the presence of three electrochemical conditions:

1) sufficient moisture,
2) non-continuous regions on the surface of the metal (anode and cathode regions) and
3) the corrosion reactions are able to take place simultaneously at the cathode and anode regions.

The metal will not corrode if even one of these conditions is eliminated. The last two conditions always exist unless special measures are taken. Therefore, unless steel is protected in some way from corrosion, even a trace of moisture on the surface of the steel will cause it to corrode.

In an anode reaction, released negative electrons (e⁻) migrate along a conductor (metal) to the cathode, where they react. Electric current, a positive electric charge, travels from the cathode to the anode.
Corrosion will stop if this electric circuit can be broken. To stop the corrosion current, structural methods and maintenance procedures may be used as follows:

1) by controlling the electrolyte; by cleaning road sanding residue, slush and water from the surfaces, or by preventing them from reaching the surfaces. Closed spaces are dried using ventilation (figure 2).

2) by stopping or retarding anode and/or cathode reactions; by coating steel surfaces correctly and by keeping the coating in good condition (figure 3),

3) by isolating connecting surfaces of structural parts made of different metals from each other using rubber, plastic or paint (figures 4 and 5),

4) by eliminating or neutralizing the potential difference between the anode and cathode; by selecting the correct materials when renewing damaged structural parts, and by coating the surface to match the appearance of the old structures.

The success of corrosion prevention is affected by the shape of a steel structure. In repairing bridges, it is often noted that insufficient emphasis was placed on this aspect during the designing stage. It is not possible to make essential changes in steel structures when a bridge is being repaired. However, it should be determined what may be done to improve the conditions. In designing the shape of a structure, aspects such as measures that prevent accumulation of water and impurities like salt, should be taken into account. This involves making drain holes, ventilation holes, splash barriers, as well as correctly shaped structures.

Anti-corrosive painting is used to prevent the formation of corrosion cells or retard the corrosion process. The anti-corrosive effect of a painting system is based on the following factors:

- isolation; the film of paint prevents oxygen, water and chemicals from reaching the surface of the metal and increases the resistance to corrosion current in the electrolyte
- passivation; corrosion reactions in the cathode and/or anode regions are prevented by means of the active corrosion prevention pigments in the paint film
- cathodic protection; the primer paint contains enough zinc or similar material for the pigment particles to be in conductive contact with the base and each other. This makes the steel cathodic.

Hot dip galvanizing, sprayed zinc or aluminum coating may be used as an alternative method or together with painting to protect bridge structures from corrosion. The zinc in the coating gives cathodic protection to the steel.
1. Terminology and definitions

Surface treatment in bridge repair can be divided into the following main phases: planning, preliminary treatment, coating (figure 6).

Terminology and definitions are grouped under preliminary treatment, coating and measurements.

**Preliminary treatment** refers to the cleaning of a metal surface, and other preparations for the application of a metallic or other coating.

Terminology and definitions related to preliminary treatment and corrosion of metal surfaces are:

- **alkali wash**, a cleaning method in which the surfaces are washed with an alkaline detergent solution
- **corrosion**, deterioration of a material caused by chemical reactions with the environment
- **corrosion prevention**, to protect a structure from corrosion by using metal alloys, environmental control, structural solutions or coating
- **degree of rusting of an unpainted surface**, the condition of an unpainted surface before rust removal. The condition is defined using color photographs and expressed using a letter code (A, B, C or D)
- **degree of rusting of a painted surface**, a condition defined by using color photographs and expressed using a code (Ri 0 ... RI 5)
- **flame cleaning**, to clean a surface using an oxyacetylene flame
- **pickling**, a chemical preliminary treatment of metal in which acid is used to remove rust, oxides and other impurities that inhibit paint adhesion
- **preparation grade**, is defined by comparing the surface to colour photographs after wire brushing or grit blasting
- **scraping**, a rust removal method in which rust is manually removed using a metal scraper
- **grit blasting**, to clean a surface by blasting it with steel shot or quartz sand
- **stress class**, classifies environmental conditions based on the amount of corrosion stress they place on steel and cast iron surfaces
- **wire brushing**, a surface cleaning method in which rust is removed by manual or mechanical brushing.

Coating refers to the covering of a base material with another material. Terminology and definitions related to coating are:

- **chalking**, partial deterioration of the binding agents in paint, usually caused by weather. A loose, smudging layer of pigment remains on the surface of the paint
- **component**, an ingredient of paint
- **dry film**, a dry film of paint
- **dry to repaint**, a state of dryness of a film of paint in which the painted surface withstands application of another coat of paint without wrinkling or loosening
- **dry to use**, a state of dryness of a film of paint in which the part can be taken into use without damaging the film of paint
- **dust dry**, a state of dryness of a film of paint in which glass shot placed on the surface may be brushed away without leaving a trace
- **hot dip galvanizing**, to coat a part by immersing it in molten zinc
- **maintenance painting**, to patch or repaint a previously galvanized or painted surface that has been in use
- **paint combination**, a film of paint of specific thickness, formed by one or more specified layers of paint
- **painting**, to apply paint using a brush, roller, sprayer or immersion
- **painting system**, consists of a base, preliminary treatment and a film of paint formed by paints that are used to protect the base
- **pigment**, a fine-grained powder that is not dissolved by binding agents, used for corrosion protection or colouring
- **pot life of paint**, the time within which two-component paints should be used after they are mixed
- **putty**, an elastic material with a binding agent of oil, epoxy, silicon, etc., used to fill holes, dents or seams
- **repainting**, to remove previously applied paint from a surface and coat it with new paint
- **solvent**, a volatile liquid used to dissolve the binding agent in paint and make it spreadable
- **sprayed zinc coating**, to spray small particles of molten zinc onto a cleaned steel surface
- **temporary protection**, a coating intended to prevent corrosion for a short or long time. The surface of the protected part is left in its original condition, or it may be restored to its original condition, for example, by removing the protective material
- **thinner**, a volatile liquid that may be added to paint to thin it
- **touch-up painting**, to paint damaged places of a painted surface using a suitable paint combination
- **wet film**, a film of paint immediately after it has been applied, before the solvent has evaporated from the film

Terminology and definitions related to measurements are:

- **measurement area**, an area of a service surface subject to a specified number of individual measurements
- **measurement point**, a point in a measurement area subject to an individual measurement
- **nominal film thickness**, thickness of a film specified in a standard or a painting specification
- **service surface**, a part of a surface that is essential to the appearance or use of the part
1.3 Professional skill and form of work

The difficult environmental conditions of bridge structures require the use of high-quality coatings. This requires professional skill and a sense of responsibility from both supervisors and workers. With the exception of minor touch-up painting, maintenance painting of bridge structures should be supervised by a master painter experienced in the field. The painter should have at least two years of experience in the field.

Unless a district has personnel specialized in painting, contracting is a natural form of work, because surface treatment of steel structures is demanding professional work. The painting contract should be supervised by a master painter, technician or building technician. The supervisor should have sufficient basic knowledge of surface treatment. He/she should also keep in contact with the paint manufacturer's agent or other experts.

It is recommendable to include the surface treatment of the steel structures of several bridges in a single contract. In order to allow implementation of serial work and facilitate supervision, the sites should be selected from within a limited area.

A request for bids should clearly specify the following items:
- a plan and alternatives
- the scope of the contract
- changes in the price of the contract
- terms of payment
- responsibilities (work safety, environmental protection, etc.)
- guarantee period and guarantee insurance

The contract documents are compiled and the requests for bids are prepared according to the general procedure used at Finnra.
1.4 Work safety

1.4.1 Health hazards

Health hazards are mainly caused by:
- solvent vapours that enter the system through the respiratory passages
- pigments and binding agents that enter the system as paint mist and dust
- the effects of materials on the skin.

Tolerance of chemicals varies among different workers. Therefore, potentially harmful materials should be handled carefully. Skin contact should be avoided, as well as unnecessary breathing of solvent vapours and paint mist. The employer must be sure that each worker is suitable for the work he/she is doing.

The employer is responsible for the materials that are used, and obligated to make sure containers of harmful materials used at the job site are labeled correctly. The workers also must be given relevant information and instructions. If the use of a material requires special safety measures, the workers must be informed of this before work is started.

Materials used in the surface treatment of bridges may be combustible, harmful and irritating (figure 7).

![Warning labels](image)

**Figure 7. Warning labels**

Furthermore, paint products are classified according to the solvent they contain into four work safety classes called LT classes:
- LT class 0 latex paints and oil paints
- LT class 1 alkyd paints
- LT class 2 wood preservatives
- LT class 3 solvent-thinned conversion paints, baking enamels, vinyl paints, chlorinated rubber paints and cellulose paints.

LT 0 is the safest and LT 3 is the most harmful class.
Working conditions should be arranged so that the workers are not hindered by the use of personal shields. However, this is not always possible, and therefore personal shields are needed (figure 9). Instructions on the use of personal respiratory shields in bridge painting are in the following table.

Table 1. Use of respiratory shields in bridge painting (the letters refer to figure 9).

<table>
<thead>
<tr>
<th>Work phase in maintenance painting</th>
<th>Type of work</th>
<th>Harmful material code</th>
<th>Work safety class of solvent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>wire brushing</td>
<td>d</td>
<td>LT 0 LT 1 LT 2 LT 3</td>
</tr>
<tr>
<td>Preliminary treatment</td>
<td>grit blasting</td>
<td>s</td>
<td></td>
</tr>
<tr>
<td>Touch-up painting</td>
<td>brush painting</td>
<td>a</td>
<td></td>
</tr>
<tr>
<td></td>
<td>spray painting</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Repainting</td>
<td>brush painting</td>
<td>a</td>
<td>a a a a</td>
</tr>
<tr>
<td></td>
<td>spray painting</td>
<td>f</td>
<td>a a f f</td>
</tr>
<tr>
<td>Touch-up painting and repainting</td>
<td>brush painting</td>
<td>f</td>
<td>f f f f</td>
</tr>
<tr>
<td>in a closed space</td>
<td>spray painting</td>
<td>f</td>
<td></td>
</tr>
</tbody>
</table>

Figure 9. Active carbon dust filter (a), dust filter (d), fresh air hood (f) and sandblaster's helmet (s)

Preliminary treatment is definitely the riskiest phase of maintenance painting. In order to avoid accidents, the supervisor(s) should make sure the workers have respiratory shields and the following personal shields:

- wire brushing and grinding; protective glasses, protective suit and leather gloves
- grit blasting; hearing protectors, coveralls and long-sleeved leather gloves

It should also be noted that the natural sand used in sand blasting contains crystalline silicon dioxide in free form. This dusty material, quartz, is known to cause silicosis.

Protective glasses should be used to avoid getting paint in the eyes when spray painting, and protective gloves should be worn to avoid unnecessary skin contact.
1.42 Fire prevention

Most surface treatment materials are combustible liquids, which are classified into three classes:

- **Class I** Combustible liquid with a flash point below 21°C
- **Class II** Combustible liquid with a flash point between 21°C and 55°C
- **Class III** Combustible liquid with a flash point between 55°C and 100°C.

Paints usually belong in class II. Paints or thinners in class I are not allowed in bridge repair work.

Smoking and fires are not allowed where painting is being done. Welding, burning and cutting, and any work that causes sparks is forbidden. Before spraying is started, the following must be checked:

- the paint pump is grounded to the metal of the part being painted.
- the spraying pistol and pump are grounded to each other.

The equipment must also be grounded while it is being rinsed with solvent.

1.5 Environmental protection

Materials used in anti-corrosive painting and waste material created in the preliminary treatment of painted surfaces may be hazardous to the environment. Environmental hazards should be estimated, especially when selecting a rust or paint removal method. Sand and dust that spread into the surroundings during grit blasting often are a major environmental hazard. In particular, it should be remembered that red lead was used as a primer until the late 1970's. Old paints contain dangerous lead and chrome pigments, which must not be allowed to contaminate freshwater lakes and rivers.

Environmental hazards may be created in the various phases of surface treatment in the following ways:

- when surface treatment materials, especially solvents, are transported or stored
- from waste material, dust and noise created during preliminary treatment from paint splashes and mist and emissions during the coating phase.

Leftover paint and unused solvents are hazardous waste, which must be disposed of correctly. Small amounts of paint may be disposed of by first allowing the solvent to evaporate, and then bringing the waste material to the dump. Larger quantities are stored in a central storage depot in the district. They are brought to a hazardous waste disposal plant in suitable batches. Cleaning, solvent and paint residues must not be allowed to contaminate the freshwater system, nor must they be left at the job site to spoil the scenery.

The appearance of a bridge should coincide with its scenic value. Surfaces near a part that will be painted should be protected to prevent their appearance from being spoiled by splashes. The colour of the surface paint should be selected with expertise, so the colour of the bridge will blend in with the surroundings. Often it is necessary to consult with a landscaping expert sufficiently in advance.
2. SURFACE TREATMENT MATERIALS

2.1 Chemical primers

Surface treatment of new and removable bridge structures may be enhanced using chemical primers, which form a phosphate, chrome or oxide layer on the metal surface. This layer improves paint adhesion to a painted surface and prevents rusting underneath the film of paint.

Chemical preliminary treatment methods include:
- washprimer treatment
- phosphating
- chromating

These preliminary treatment methods are usually used to coat sheet metal, and they are rarely used in bridge repair. The paint manufacturer should be contacted before the surface is painted.

Rust converting materials may be used as primers for temporary protection and minor touch-up painting. These materials should not be used where the road is salted. These materials usually are phosphoric acid-based, and they may be harmful to concrete surfaces. If a surface has been treated with a rust converting material, the suitability of any final anti-corrosive coating should be verified.

2.2 Paints

Paints are available in liquid or powdered form. They form a uniform, intact film when applied on a surface. Paints that are used to protect steel and other metals are called anti-corrosive paints.

A film of paint consists of binding agents and pigments.

A film that does not contain pigments is called a lacquer film. A paint film also includes other materials that affect the film or characteristics of the paint.

The binding agent is the most important component of paint. It glues particles of pigment to each other, forming a film that adheres to the base. The following characteristics of a paint film are affected by the binding agent:
- adhesion
- cohesion
- chemical characteristics.

The binding agent also defines paint characteristics such as the drying method and the paint type (table 2).

Table 2. Types of paint used in bridge painting, named according to the binding agent and classified according to the drying method

<table>
<thead>
<tr>
<th>Binding agent</th>
<th>Physically drying</th>
<th>Chemically drying</th>
<th>Two-component paints</th>
</tr>
</thead>
<tbody>
<tr>
<td>- chlorinated rubber - vinyl - bitumen</td>
<td>- alkyd - urethane alkyd</td>
<td>- epoxy - epoxy tar - resin-modified epoxy - polyurethane - zinc silicate</td>
<td>- epoxy - epoxy tar</td>
</tr>
</tbody>
</table>
There are three main types of pigments. Anti-corrosive pigments retard or prevent rusting of the steel beneath the film of paint. Colour pigments give the film of paint a tone of colour, make the film opaque and protect the binding agent. Pigments that seal the film are sometimes used. Pigments protect the film of paint from the degrading effect of the sun's ultraviolet rays and the weather.

Paint solvents dissolve solid binding agents and reduce the viscosity of liquid binding agents. A solvent containing a dissolved binding agent is called a lacquer. Although solvents evaporate after the paint has been applied, they have an important effect on the formation and durability of the film of paint.

A thinner is a volatile liquid added to paint to thin it. The composition of the thinner may be different from that of the solvent in the paint.

A coating of paint will last for about 15 years if the type of paint and paint combination are selected correctly for prevailing environmental conditions, and the painting work is done according to specifications. The life of the coating is affected by the total thickness of the film of coating (figure 10).

2.21 Alkyd paints

Alkyd paints used in bridge painting are dried by the oxygen in the air, after the solvent has evaporated from the film. The lowest temperature for painting is +5°C. The surface should be dry. This should be checked using a dew point measurement. The relative humidity of the air should be below 80%. The paint is usually applied on a grit blasted surface (Sa 2). Touch-up paint may be applied on a wire brushed surface (St 2).

The paint combination consists of the following:
- alkyd primer coat, which usually contains active anti-corrosive pigments
- alkyd upper coat, which contains pigments according to the desired durability and appearance.

Alkyd paints have excellent weather resistance and moderate wear resistance. They do not withstand basic materials or immersion.

2.22 Chlorinated rubber and vinyl paints

Chlorinated rubber and vinyl paints are physically drying solvent paints that form a film of paint without a chemical reaction, after the solvent has evaporated from the film. A dry film of paint may be redissolved by a solvent and softened by heat. The lowest temperature for painting is 0°C. The surface should be dry. The relative humidity of the air should be below 80%. The paint requires a grit blasted metal surface (Sa 2.5).

The paint combination in bridge painting consists of the following:
- primer coat (epoxy or zinc silicate) pigmented with zinc powder
- chlorinated rubber or vinyl coat that adheres to a zinc surface
- chlorinated rubber or vinyl upper coat.

Chlorinated rubber and vinyl paints have good weather resistance. They withstand water-based chemicals, such as salt and acids, well. They withstand basic materials moderately, but their solvent and oil resistance is limited.
2.23 Epoxy and polyurethane paints

Epoxy and polyurethane paints are two-component, chemically hardening reactive paints that are supplied in two containers. The components of the paint are mixed together in a specified ratio immediately before painting. After they are mixed, the mixture has a limited pot life. The lowest temperature for painting is +10°C. The surface should be dry. The relative humidity of the air should be below 80%.

The paint requires a grit blasted metal surface (Sa 2.5).

The paint combination in bridge painting consists of the following:
- zinc epoxy primer coat or epoxy coat pigmented with inert pigments
- epoxy coat that also adheres to a zinc surface
- epoxy or polyurethane upper coat.

Epoxy paints have excellent resistance to mechanical wear and chemicals, but outdoors the surface gets dirty quickly.

The binding agent in epoxy tar paints is a mixture of epoxy and coal-tar pitch. Thick films of these paints are used in underwater and underground sites, and in moist places.

The binding agent in resin-modified epoxy paints is a mixture of epoxy and chemical resistant resin. Resin-modified epoxy paints may be used as the surface material of metal surfaces subject to chemical or other exceptional stresses. Solvent-free or low-solvent epoxy paints, which are applied in one 300-500 μm coat, are made from liquid epoxy resins. The coatings well withstand immersion and mechanical wear, such as the wearing effect of ice on the bottom of ferries and vessels.

Polyurethane paints are upper coats for two-component combinations. They retain their shine and are weather resistant.

2.24 Zinc silicate paints

A silicate is used as a binding agent in zinc silicate paints. Ethyl silicate is the most commonly used binding agent. Moisture in the air causes ethyl zinc silicate paint to dry chemically after the solvent has evaporated.

The lowest temperature for painting is 0°C. The surface should be dry. The relative humidity of the air should be at least 50%. If the relative humidity is not sufficiently high, the surfaces should be wetted according to the manufacturer's instructions.

The paint requires a grit blasted metal surface (Sa 2.5).

Zinc silicate paint is used alone in special sites or as the primer of a chlorinated rubber combination in bridge painting.

Zinc silicate paint functions like galvanizing. The paints withstands mechanical stress and solvents well.

2.25 Temporary anti-corrosive materials

Temporary anti-corrosive materials may be used in bridge repair work. These materials form an oily or waxy surface on the structure after the solvent has evaporated.

These materials protect against corrosion for 2 - 5 years, which should be taken into account when selecting a material.

The manufacturer's instructions should be followed closely in surface treatment work, and job-specific instructions should be compiled. Experience has shown that all temporary anti-corrosive materials do not withstand salt or mechanical wear.

2.3 Metallic coatings

Zinc is the most commonly used metallic coating material in bridge structures. A zinc coating may be applied by means of hot dip galvanizing, where the part is immersed in molten zinc, or spraying, where molten zinc is sprayed on the surface using compressed air. The methods are explained in detail in sections 4.4 and 4.5. Layer thicknesses corresponding to those obtained using hot dip galvanizing may also be obtained with mechanical zinc coating. This method is especially suited for coating small parts, such as fasteners. Zinc electroplating produces such a thin layer of zinc that this method should not be used on bridge structures.

A zinc coating protects steel from corrosion in two ways:
1) by forming a sealing layer that prevents moisture and oxygen from reaching the surface of the metal
2) by providing a cathodic shield for scratches and dents.

Therefore, small scratches do not require repair, because the potential difference between the steel and the coating at the damaged place forms a cell, corroding the coating. The corrosion products precipitate on the exposed metal surface, protecting it. Corrosion does not advance underneath the zinc coating, as may happen with a paint coating (figure 12).
Zinc coating

An electric pair develops. The zinc corrodes around the damaged place. The corrosion products settle on the surface of the metal and protect it. The steel is also protected because it is cathodic with respect to the zinc coating.

Steel begins to rust when the paint coating is damaged. The rust penetrates underneath the layer of paint and loosens the paint. Corrosion continues until the damage is repaired.

Figure 12. Corrosion does not advance underneath a zinc coating

A sprayed zinc surface is usually sealed with paint wherever the road is salted. Bridge structures may also be coated with aluminum or a mixture of aluminum and zinc. The coating is usually applied by spraying. The surface does not necessarily need to be sealed with paint, as the aluminum oxidizes quickly, and the corrosion products clog the pores.

The protective effect of zinc and aluminum and their compounds is based on the relative positions of the structural metal and the coating metal in the electrochemical voltage series (figure 13). Zinc and aluminum are more electronegative than steel.

Zinc corrodes at a rate of 1 - 10 μm per year, depending on environmental conditions. The method of galvanizing also affects the life span of the coating (figures 14 and 15). In Finland, the rate of corrosion of zinc is generally low, because the corrosion products quickly form a protective film on the surface of the zinc, preventing further corrosion. Moisture and carbon dioxide in outdoor air convert zinc oxide into basic zinc carbonate. This layer is impenetrable and well adhered. Because this layer is nearly insoluble in water, it protects a zinc coating well, especially in an environment that has little sulphur contaminants.

Figure 13. Voltage series of structural metals.

The rate of corrosion of the zinc coating should be monitored using bridge-specific measurements. Usually, the old zinc is removed from removable parts, and they are hot dip galvanized again. Otherwise, the surface is painted or sprayed with zinc before the thickness of the zinc layer decreases below 20 μm.
3. PLANNING SURFACE TREATMENT

3.1 Basic surface treatment information

3.1.1 General

A detailed surface treatment plan should be compiled well in advance before maintenance painting of a bridge is started. For the plan, information is needed on the original coating and environmental conditions, as well as an estimate of the condition class of the coating.

Information on the original coating may be found in the following documents:
- contract documents in the district archives
- possibly, a painting file kept by the roadmaster
- a certificate of qualification compiled when the bridge was built.

Often, however, reliable information on the original coating is not available. If touch-up painting is in question, cellulose thinner testing or test painting should be done to attempt to determine the coating combination. When the cellulose thinner has been allowed to affect the surface of the paint for 10 min, the type of paint may be determined by means of the following changes that may take place on the surface of the paint:
- cellulose thinner has no effect on epoxy and urethane paints
- cellulose thinner will loosen or soften alkyd paints
- cellulose thinner will dissolve chlorinated rubber or vinyl paints.

If possible, the age of the coating should also be determined, as well as the types of paint that were customarily used at the time the bridge was painted. The structures may contain many types of paint that were applied in conjunction with maintenance procedures performed at different times. Therefore, the coating should be studied to the bare metal surface, and the method used to clean the surface should also be determined.

Grit blasting was not used to clean a surface for painting until after the middle of the 1960's. Bridges that were built earlier may have roll scale under the coats of paint, making adhesion unreliable. Roll scale should be removed using grit blasting before the bridge is repainted. Touch-up painting of these bridges is not recommended as a form of maintenance painting. Any welding seams should be ground smooth, if necessary, and carefully coated.

3.1.2 Touch-up painting

Maintenance painting instructions should be applied to touch-up painting. Usually, the original type of paint is used, unless it should be changed because of inferior durability of the original paint, environmental conditions or other reasons. The paint combination should also be suitable for the achieved preparation grade.

If the structural parts are removable, it is also possible to use galvanizing. If necessary, hot dip galvanized surfaces are painted immediately after galvanizing to match the colour of the adjacent surfaces.

Oily and waxy temporary anti-corrosive materials also may be used in bridge repair. These are suitably used in places that are difficult to clean and treat otherwise. However, all of these surfaces do not withstand mechanical stress, salt and sunlight. A separate work specification on the use of coatings should always be compiled.

3.1.3 Repainting

Bridge repair painting systems or coating combinations are used in repainting. The following types of paint are used, depending on the cleanness of the surface and painting conditions:
- epoxy or polyurethane paint combinations may be used if the preparation grade is Sa 2.5 and painting conditions are good
- a chlorinated rubber paint combination is used if the preparation grade is Sa 2.5, but painting conditions are poor
- an alkyd paint combination is used if the preparation grade is poor (Sa 2 or St 2) due to structural or other reasons.

The method specified for touch-up painting is used if the structural parts are removable. Good results have been achieved by using sprayed zinc coating to recoat railings. A sprayed zinc surface must be sealed with vinyl paint wherever roads are salted.
3.2 Stress classes

Metal corrodes as a result of reactions with the environment. Therefore, the environmental conditions of a bridge and its structural parts must be determined before a surface treatment plan is compiled. The bridge under repair is a complete structure subject to the stresses of a certain type of climate, while structural parts of the bridge may additionally be subject to exceptional stress from the nearby surroundings. The corrosive effect of the environment is comprised of several factors. The period of time during which the surface of a structure is moist is a decisive factor, but gaseous and solid impurities also cause corrosion to advance rapidly. Sulphur compounds released into the air as emissions have the greatest effect on corrosion.

A standard has been compiled as a basis for corrosion prevention. The standard classifies environmental conditions into five classes (M0 - M4). Classes M2 - M4 describe conditions that affect bridges, and they are defined in more detail in table 3.

Table 3. Environmental stress classes in bridges.

<table>
<thead>
<tr>
<th>Stress class</th>
<th>Corrosive effect</th>
<th>Environment and stresses</th>
<th>Structural part</th>
</tr>
</thead>
<tbody>
<tr>
<td>M2</td>
<td>Moderate climatic stress.</td>
<td>Clean rural climate.</td>
<td>Steel bridge structures on unsalted stretches of road.</td>
</tr>
<tr>
<td>M3</td>
<td>Heavy climatic stress.</td>
<td>City, coastal or industrial climate. Rural climate where the structures are often moist.</td>
<td>Steel bridge structures, no exceptional stresses. Superstructure near the surface of water.</td>
</tr>
<tr>
<td>M4</td>
<td>Exceptional stresses that exist in addition to climatic stress.</td>
<td>Exceptional stresses that locally affect bridge structures: - splashes of water and snow that contain salt, sand or other impurities - mechanical stress - underwater or underground location - alkaline water filtering from concrete - wood preservatives.</td>
<td>Typical steel bridge structures that are subject to exceptional stresses: - railing bases and railings on roads that are salted - boundary surfaces of steel and other materials that gather moisture and dirt - areas under the influence of water (susceptible to splashing and freezing) - horizontal steel surfaces that get dirty easily - access openings - suspended bars and cables - outer surfaces of pylons up to two metres above the road surface, and inner surfaces, if they are not ventilated - steel parts of the anchor compartment of a bascule bridge.</td>
</tr>
</tbody>
</table>
3.3 Degrees of damage

Damage to the coating of steel structures of bridges is caused by:
1) design and work errors: structural errors, insufficient or careless preliminary treatment, wrong type of paint or unsuccessful painting,
2) damage caused by use: impacts by maintenance equipment and vehicles in traffic, or vandalism.

On the other hand, it should be remembered that all surface treatment methods have a limited life span. It is important to methodically monitor the condition of bridge coatings in conjunction with bridge inspections in order to detect deteriorating condition.

The results of these observations are presented by plotting a curve depicting the degree of rusting (figure 16). The curve is plotted on a form, Finnr 735174, which is appended to an annual bridge inspection form. Changes in the thickness of the metallic coating are presented on the same form.

![Figure 16. A curve depicting the degree of rusting of a bridge](image)

The condition of a coating is defined with the help of a reference scale compiled for bridges. Blistering, cracking and flaking of a paint coating are always classified. During the inspection phase of bridge repair, the main attention is placed on surface rusting and damage to the coating. During the repair phase, emphasis is placed on the cleaning of the surface.

The following classification of the degree of rusting is usually used in bridge repair:
- maintenance painting of structures in stress class M4 is done as touch-up painting no later than when the degree of rusting is Ri 2
- maintenance painting of structures in stress classes M2 and M3 is done as touch-up painting no later than when the degree of rusting is Ri 3
- if the degree of rusting is Ri 4 or Ri 5, maintenance painting involves repainting. Maintenance painting is marked on the bridge-specific curve depicting the degree of rusting (figure 16).
3.4 Surface treatment plan

3.4.1 Compiling a plan

In compiling a surface treatment plan, it should be noted that the following problems may be encountered during maintenance painting:
- Grit blasting may not be used because of structural reasons or a dust hazard.
- It may be difficult to mask the areas to be repaired, and the results may be unsatisfactory if the layers of paint should not overlap.
- Technical difficulties are encountered.
- Spray painting may not be used due to the paint mist.
- Weather conditions may intermittently hinder or prevent surface treatment.
- The surfaces may need to be shielded because they become moist due to low temperatures and high relative humidity.
- Scaffolding is needed, which considerably raises costs.

The surface treatment plan is compiled in the form of a work specification, and necessary structural drawings are enclosed. Environmental hazards and work safety should also be taken into account when compiling the plan.

3.4.2 Contents of the plan

The surface treatment plan should include:
- Coating combinations and the required film thicknesses.
- Necessary work specifications.
- Phases of work and a schedule.
- Required surface treatment conditions and other information.

If necessary, drawings that clarify the site are included in the plan.

If the work is contracted, generic names are used in the request for bids and the target level of quality is defined. The selected contractor compiles a work plan for approval by the builder before starting work. The plan specifies the paints, putties, and other surface treatment materials, using their product names.

The operating instructions and work safety bulletins must be at the job site.

All changes agreed upon during the work are marked in the surface treatment plan. The surface treatment plan is appended to the qualification certificate made of the repainting.

Documents compiled of the surface treatment of the steel structures are also appended to the bridge-specific annual inspection form.
4. SURFACE TREATMENT

4.1 Surface treatment conditions

4.11 General

The surface to be coated must be dry. Paint applied on a moist or dirty surface is the most common reason why paint loosens from the base. Weather conditions in Finland are often unsuitable for painting. Therefore, weather protection and heaters should be considered in even slightly demanding surface treatment work related to bridge repair. This will ensure better quality results. Also, a cost savings may be realized in the long term, because the work can be done without interruptions and the cost of purchasing protective covering is distributed among several projects.

4.12 Air temperature and humidity

Air temperature and relative humidity affect the drying and film-forming characteristics of different types of paints in different ways. Product labels give drying times at +23°C. The minimum temperature at which the paint will dry is also given, as well as suggested minimum or maximum values for relative humidity.

In bridge repair, the air temperature should be at least +10°C and the relative humidity should be below 80% during painting and drying. The general recommendations may be deviated from, depending on the type of paint, within the limits specified on the product labels. In bridge repair, the limits given in table 4 are usually applicable.

Table 4. Approximate limits for temperature and relative humidity.

<table>
<thead>
<tr>
<th>Type of paint</th>
<th>Minimum temperature</th>
<th>Relative humidity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alkyd</td>
<td>+ 5°C</td>
<td>max. 80%</td>
</tr>
<tr>
<td>Polyurethane</td>
<td>+10°C</td>
<td>max. 80%</td>
</tr>
<tr>
<td>Chlorinated rubber</td>
<td>+ 0°C</td>
<td>max. 80%</td>
</tr>
<tr>
<td>Vinyl</td>
<td>+ 0°C</td>
<td>max. 80%</td>
</tr>
<tr>
<td>Epoxy</td>
<td>+ 10°C</td>
<td>max. 80%</td>
</tr>
<tr>
<td>Zinc silicate</td>
<td>+ 0°C</td>
<td>50 -- 90%</td>
</tr>
<tr>
<td>Epoxy tar</td>
<td>+ 10°C</td>
<td>max. 80%</td>
</tr>
<tr>
<td>Resin-modified epoxy</td>
<td>+ 10°C</td>
<td>max. 80%</td>
</tr>
</tbody>
</table>

When spraying zinc or aluminum coatings, the air temperature should be at least +5°C and the relative humidity should be below 70%.

4.13 Temperature of the metal being coated and relative humidity of the air

The temperature of the metal being coated must be at least three 3°C above the dew point of the air. The dew point is the temperature to which the air must cool to raise the relative humidity to 100%. The dew point value may be read from a dew point dial, for example (figure 17), when the air temperature and relative humidity have been measured. Reliable instruments should be used to measure temperature and relative humidity (figure 17). The instruments should be periodically calibrated. The relative humidity should be monitored already during the grit blasting phase. The relative humidity should be below 70% for grit blasting. To prevent corrosion from setting in, painting should follow immediately after grit blasting.

Usually, a surface whose temperature is above +50°C should not be painted, because rapid evaporation of the solvent may create pores in the film of paint and cause poor adhesion.

Figure 17. Dew point dial, thermometer, surface temperature gauge and hygrometer.
4.2 Preliminary treatment

4.21 General

Special attention should be paid to preliminary treatment of the metal surface to be coated, because it has been proven that preliminary treatment has a decisive effect on the durability and economy of the coating (figure 18). The preliminary treatment method and the requirement level depend on the selected surface treatment system. In bridge repair, preliminary treatment consists of:

- removal of dirt and grease
- removal of salt
- removal of rust
- rounding of corners and edges
- cleaning of welded joints
- removal of old paint
- scarifying the surface

Conventional tools are used in preliminary treatment (figure 19), with special consideration of work safety and environmental protection. Harmful quantities of chrome or lead pigments or other impurities must not be allowed to contaminate the environment. Waste materials should be gathered on protective coverings below the structure being cleaned, or removed by vacuuming.

4.22 Removal of dirt and grease

Metal surfaces are cleaned of impurities such as waste, oil, dirt and salt, which hinder removal of rust and the old coating. Solid waste, such as concrete and thick layers of damaged paint, are removed by scraping or with a stippler (figure 20) or a pneumatic chipper. Scaping is the primary method used. Pneumatic tools may also be used. Grease and oil are usually removed with an alkaline wash (figure 21). High-pressure cleaners (60-150 kg/cm²) and warm water (50-70°C) are recommended for large surfaces. A solution of cleaning agent is prepared according to product-specific instructions. The cleaning agent is allowed to affect for 0.5 - 2 minutes, after which the alkaline waste is carefully rinsed from the surfaces with a high-pressure washer. Washing can also be done by hand, in which case the cleaning agent solution is diluted (1-6%). Salts on the surface are removed by brushing and rinsing with water, because chlorides are water-soluble. Careful removal of salts is necessary before grit blasting, or the salts will stick to the surface. Wire brushed surfaces are washed and dried after brushing. Salts remaining on the surface will form electrolytic solutions when moist, forming rust underneath the coating.
The presence of salt on the surface may be determined by spraying a silver nitrate solution on a moistened surface. Salt is present if a white sediment forms on the surface. In that case, cleaning must be continued. The silver nitrate solution (0.1-N) is prepared by dissolving 17 g of powdered silver nitrate in distilled water to make 1 litre. The solution is kept in a dark bottle away from sunlight. The solution is usable for a period of one month. The solution is sprayed on the surface with a spray bottle. The solution stays usable in the spray bottle for one week. Instructions on handling silver nitrate are given in a safety bulletin.

4.23 Rust removal

Roll scale, rust and layers of old paint are removed from the steel surface to achieve the desired preparation grade for maintenance painting or other surface treatment of the bridge. Mechanical rust removal methods employed at the bridge site are:
- scraping and wire brushing (figures 22, 23, 24)
- grit blasting (figure 26)
- flame cleaning.

The rust removal method is selected to provide a sufficiently rough surface for the selected surface treatment.

The edges of the area requiring touch-up painting should be straight and the edge of the paint is ground to a taper (figure 25).

In addition to using mechanical methods, small areas may be treated chemically as described in section 2.1. Rust removal from bridge structures should result in preparation grades corresponding to those defined in the reference scale for bridges.

Scraping and wire brushing are the simplest methods of rust removal used in bridge touch-up painting and railing post base and bearing renewal. A scraper with a replaceable hardened blade is used for scraping (figure 22), and wire brushing is done either manually (figure 23) or mechanically (figure 24) to obtain a preparation grade of St 2.

Manual wire brushing is seldom sufficient for bridge structures. Usually, pneumatic brushing machines are used, which have various types of brushes suitable for different brushing speeds and structures. A high speed of 6000-7000 rpm is usually used.

Grinding is suitable for even surfaces, but the resulting surface may be too smooth. A grinding disk is used to smooth sharp edges and welded seams. The edge of any old paint is tapered, and sandpaper disks are used for rust removal (figure 25). The sandpaper is glued to a soft disk, so that the paper conforms to the shape of the surface.
Grit blasting is the most commonly used and most efficient mechanical method of rust removal and scarifying. Grit blasting has been used in preliminary treatment of bridges since the mid 1960's. Surfaces that were coated earlier most likely have a layer of roll scale underneath the coating. This should be taken into consideration when evaluating the condition of the coating and deciding on measures to be taken. The roll scale always must be removed before repainting.

Grit blasting mechanically cleans and scarifies the surface, removing impurities with a spray of granular material (figure 26). In bridge repair, pressure chamber type open blast devices are used, which spray the granular material at the surface using compressed air. With most grit blasters, work must be interrupted while the container is refilled.

Correct selection of a grit blasting nozzle has a decisive effect on work efficiency and economy. If high speed cleaning is important, a venturi nozzle is used, which is more efficient than a straight nozzle. A grit blasting angle of 50-70° and a distance of 30-50 cm (figure 27) is most efficient for cleaning a metal surface for coating. However, a small grain size, smaller angle and greater distance should be used when grit blasting a surface for touch-up painting, to cause minimal damage to the surrounding film of paint (figure 29).

A good compressor that supplies a sufficient volume of dry, clean air is also a prerequisite for good grit blasting results. The air pressure should be 6-8 kp/cm². An efficient cooler and water and oil separators are often required to guarantee good air quality.

The grain size and quality of the blasting material depends on the difficulty of cleaning and the required roughness of the surface. Disposable granular material (grain size 0.5-1.7 mm) is usually used. If dust is not allowed, a vacuum blasting unit is used, but this method is slow and therefore it is only suitable for minor touch-up painting.

The thickness of the material being cleaned should be considered, because grit blasting wears away the metal surface. The structure should be at least 3 mm thick. If thinner structures are blasted, the wearing effect should be minimized by using fine-grained blasting material, decreasing particle velocity or increasing the blasting distance.
Flame cleaning is a thermal preliminary treatment method in which an oxyacetylene flame is used to clean steel surfaces of rust and roll scale. Loosely attached layers of rust and other loose impurities are mechanically removed from the surface before flame cleaning. Post-treatment, usually wire brushing, is done after flame cleaning. Flame cleaning may be considered if work has to be done in moist or freezing conditions. Paint must be applied on a warm surface to avoid surface rusting. Flame cleaned plates should be at least 5 mm thick. Thinner plates should not be flame cleaned unless they are well stiffened.

The preparation grade is specified using reference scales /1/. The preparation grades shown in table 5 are used in bridge repair. Paint requirements must be taken into account.

Table 5. Preparation grades in bridge repair and corresponding degrees of rusting and preparation grades.

<table>
<thead>
<tr>
<th>Reference scale</th>
<th>Degree of rusting</th>
<th>Preparation grade</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Painting</td>
</tr>
<tr>
<td>1</td>
<td>Ri 2</td>
<td>St 2³</td>
</tr>
<tr>
<td>2¹</td>
<td>Ri 3</td>
<td>St 2³</td>
</tr>
<tr>
<td>3²</td>
<td>Ri 3</td>
<td>Sa2/Sa2.5⁴</td>
</tr>
<tr>
<td>4</td>
<td>Ri 4</td>
<td>Sa2/Sa2.5⁴</td>
</tr>
<tr>
<td>5</td>
<td>Ri 5</td>
<td>Sa2/Sa2.5⁴</td>
</tr>
</tbody>
</table>

¹) touch-up painting
²) repainting
³) steel brush and flexible disk
⁴) depends on the type of paint

4.24 Shaping the structure

If structural parts need to be renewed during bridge repair, the parts should be shaped according to the general guidelines. The edges of old steel structures are nearly always too sharp for surface treatment. The edges should be rounded by grinding them with sandpaper fixed to a rubber disk (figure 30), and roll faults should be removed. Rusty welded seams and unevenness should be ground smooth. If necessary, and the ground surfaces should be grit blasted.

If water accumulates on top of a structure, a drain hole (ø ≥ 25 mm) is made at the lowest point, or a splash guard is constructed to prevent water from entering the structure. The holes are located in places indicated by the designer or other expert, so the load-bearing capacity of the structure is not weakened.
4.3 Painting

4.31 General

Painting is done according to a surface treatment plan drawn up individually for each bridge. Careful preliminary treatment is the basic requirement for successful painting. Carefulness and a responsible attitude also guarantee success in the actual painting work. The instructions given on the paint specification sheets and safety bulletins should be followed closely.

Painting requires good professional skill. Therefore, known, reliable contractors should be used. On the other hand, even the work of a good contractor should be supervised.

4.32 Scaffolding and weatherproof shields

It is important that the surface being painted is accessible. Therefore, scaffolding is often needed in painting bridges. The type of scaffolding is selected individually for each bridge. The following types of scaffolds are suitable for bridge painting:

- roller-mounted scaffolds; movable scaffolds that are mounted on wheels or that have railing-mounted rollers (figure 32)
- tubular scaffolding; scaffolding assembled from steel or aluminum tubing, with movable wooden platforms
- lifting platforms (figure 33); vertically or both vertically and horizontally movable (sky lift) working platforms mounted on a vehicle or machine
- bridge crane (figure 34); a device built on a vehicle body that moves in different directions below the roadway, providing access to the space underneath a bridge
- maintenance carriage; a structure that is permanently fixed to a bridge and moves along rails in the longitudinal direction of the bridge.

If necessary, the scaffolding is built on a barge or pontoons to ensure that all the surfaces to be painted are equally accessible. The scaffolding should be inspected according to the instructions given in section 1.43. Shields mounted on the scaffolding may be used to prevent blasting material and paint mist from spreading into the surroundings and on vehicles.

The weather conditions in Finland are variable and the best painting season is short. Therefore, the use of portable weatherproof shields (figure 35) and covering is recommended in even slightly larger projects. Even in bad weather, the required working conditions may be achieved by using weatherproof shields and heaters.
4.33 Puttying

Putties are used in bridge structures to prevent water and dirt from penetrating structures or entering cracks that are difficult to paint. Such structures include seams in steel profiles, suspension bar through-holes and the surface of suspension cables (figure 36). Putty is usually applied after surface treatment, but in special cases it may be applied directly on the primer paint. The places that are to be puttied and the type of putty used are specified in the surface treatment plan.

4.34 Brushwork

Brushwork is the oldest method of painting. In brushwork, the paint penetrates well into the pores of the painted surface. Moisture does not have such a great effect on painting, either. Therefore, brushwork is used especially in places where the base has corroded. Brushwork is also used in places where spray painting would result in excess missing. Brushwork is suitable for touch-up painting (figure 37) and for thickening the coat on corners, edges and welding seams (figure 38).

A wide variety of brushes are available (figure 39). The type of brush designed for a given job should be used for that job. The brushes should be sufficiently large and they should hold paint. For most paints, the thickness of the dry film of paint achieved with one sweep of a brush is 25 - 30 μm. The film thickness of thick film-type paints that are applied with a brush is not as great as the thickness given in the specifications, which are based on spray painting.

Brushwork is slow and the cost of painting a large surface is high.
4.35 Spray painting

Spray painting is the most commonly used method of painting large surfaces (figure 40). A high-pressure sprayer is usually used for anti-corrosive painting. A shunt sprayer is used if improved appearance is the most important reason for painting. That is rarely the case in bridge painting.

In a high-pressure sprayer, paint is forced by means of high pressure through a small nozzle (figure 41), causing a pressure difference that disperses the paint into small droplets. The resulting paint mist consists of quite small particles that hit the surface at a high velocity.

A suitable spraying distance is 30-40 cm. The spray pistol is pointed directly at the surface (figure 42), and the pistol is moved in straight lines (figure 43). Test spraying is used to check the suitability and functioning of the nozzle. The diameter of a high-pressure sprayer nozzle determines the amount of paint passing through the nozzle and the dispersion angle of the nozzle determines the width of the spray of paint.

The best high-pressure sprayer nozzle size for each product is given in the paint specifications. Painting is done using as low a pressure as possible that still disperses the paint into droplets. The pressure of high-pressure sprayers varies from 200-700 kp/cm²).
4.36 Painting work

Repainting is done according to general painting procedures. In touch-up painting, the primer and intermediate layer coats are applied by following the edges of the various layers of paint. Overlapping of different nonsuitable types of paint should be avoided.

In painting work it is important to follow the manufacturer's instructions regarding intervals between painting and film thicknesses. Furthermore, the following items should be emphasized in bridge repair:

- a surface that has undergone preliminary treatment should be painted immediately
- the paint should be mixed well before it is used and while it is being used
- the use of thinners should be avoided
- at least the primer coat on corners and edges should be thickened using brushwork
- the colour of the paint is selected to suit the surroundings
- the layers of paint should be applied using crossing brush strokes
- the painted surfaces should be protected from rain and moisture until they are dry to the touch
- if paints purchased earlier are used, the manufacturer should verify their usability.

4.37 Thickness of the film of paint

Paint types, the number of paint layers and the nominal thickness of the film of paint according to stress class are given in job-specific work specifications.

No more than 5% of the measured values should be more than 20% thinner than the nominal thickness.

4.38 Calculating paint consumption

Theoretical paint consumption $M_t$ is calculated using the following equation:

$$ M_t = \frac{K_k \times A}{10 \times V} $$

Where:

- $M_t$ = theoretical paint consumption
- $K_k$ = thickness of a dry film ($\mu m$)
- $A$ = surface area to be painted ($m^2$)
- $V$ = dry ingredient content of the paint (% volume)

Actual consumption ($M_k$), which takes paint loss into account, is always greater than theoretical consumption ($M_t$). Paint loss results from paint that is sprayed past the object being painted and paint left in containers and painting utensils. An uneven profile also increases paint consumption. Actual paint consumption $M_k$ is calculated using the following equation:

$$ M_k = \frac{10 \times K_k \times A}{V (100 - H)} $$

$H$ = loss percentage

Loss percentage is usually 40 - 50% for spray painting.

Paint consumption may be greater than normal when painting pipes.
4.4 Metal spraying

Metal spraying or hot spraying coats a structure with fine particles that are in a molten state when they leave the sprayer. In bridge repair, a wire pistol is usually used, which sprays molten aluminum or zinc onto the metal surface by means of compressed air. A wire of additive material is fed through a wire nozzle. A gas flame burning in front of the nozzle melts the wire, and compressed air blown through an air nozzle sprays the molten material, which is a mist of molten metal droplets, onto the surface being coated (figure 44).

Figure 44. Wire pistol spraying equipment

The purity of the wire of additive material should be 99.50% for aluminum and 99.99% for zinc. After preliminary cleaning, the surface to be sprayed is cleaned and scarified using shot blasting to achieve a preparation grade of Sa 2.5. Scarification is important, because the metal only adheres mechanically to the surface. The sprayed surface is porous and rough, because spaces are left between the droplets of metal. The thickness of the coating is easily adjusted from 40-300 μm.

Because of its porosity, a zinc coating should be painted to improve its resistance to rust. The surface should be painted immediately after spraying, to prevent formation of corrosion products of zinc on the surface. Vinyl paint is used to seal and protect the surface. On the other hand, the corrosion products clog the pores, so painting is not absolutely necessary on unsalted roads.

Sealing is not usually needed after aluminum is sprayed, because aluminum oxidizes quickly, and the corrosion products clog the pores.

Good results have been obtained in bridge repair from metal spraying on site.
4.5 Hot dip galvanizing

Hot dip galvanizing is a method in which a part to be coated is immersed in molten zinc (figure 45). Factors affecting hot dip galvanizing that should be taken into account in the design stage are:

- the galvanizing vat restricts the size and shape of the parts that are treated
- the thinner the material, the thinner the coating
- the silicon content of the metal affects the thickness of the zinc coating that is formed.

Painted parts that will be hot dip galvanized should be cleaned of dirt and grease. Then the old paint should be removed using grit blasting. Rust and roll scale are removed by means of pickling, a normal phase of the hot dip galvanizing process. Pickling involves dipping the part in a bath of hydrochloric or sulphuric acid, after which the part is rinsed in water and immersed in a flux bath. The flux forms a thin layer of salt on the surface, preventing oxidization of the metal. The clean steel part is immersed in molten zinc. The part is kept immersed until the whole part reaches the temperature of the zinc. The temperature of the zinc is 450-460°C, and normal immersion time is 1-5 minutes.

In hot dip galvanizing of bridge structures, the goal is to achieve a coating layer thickness of ZnK 800. This means the average thickness of a specified number of zinc coatings should be 115 μm. This requirement can normally be met using ordinary structural steel. Electrolytic zinc is used in piece galvanizing, where the zinc content should be 98.5%. It should be noted that the amount of zinc (g/m²) on sheet metal structures refers to the total amount of zinc on both surfaces of the sheet.

Steel loses its strength during the galvanizing process, but it gains nearly all of its original strength after it is cooled. Old structures may warp when they are galvanized, and poorly welded joints may open, because internal tensions are released as a result of the heat.

Figure 45. The phases of hot dip galvanizing
5. QUALITY CONTROL AND INSPECTIONS

5.1 The purpose of quality control

Quality control refers to the control and inspection of work, materials, tools, conditions and coatings related to corrosion prevention. This is to ensure that the finished coating meets the specified quality requirements.

Quality control should prevent errors from happening, and it has a decisive role in reducing the overall cost of corrosion prevention.

The extent of control depends on the importance, size and location of the structure.

The contractor or supplier is primarily responsible for the quality of surface treatment and quality control. The contracting authority may also make inspections that are deemed necessary.

If surface treatment is done in-house, work quality is controlled according to these guidelines.

5.2 Qualification

Measurements and other procedures that are to be carried out to verify qualification should be agreed upon in conjunction with the contract agreement. The procedures and the distribution of work between the contractor and the contracting authority are unambiguously defined in the job-specific part of the contract schedule.

Furthermore, the agreement should specify how the results of the inspections should be recorded in the qualification certificate, and how detected deficiencies should be made known.

5.3 Supervisor's tasks and equipment

The supervisor’s tasks include supervision, inspection and approval of the various phases of work that affect the end result of corrosion protection, as well as reporting to the extent specified in the agreement. The supervisory work should be done with accuracy and care. The supervisor should be familiar with the materials, tools and methods used. He/she should also have a command of methods of control and measurement and the related equipment.

The supervisor should know how and where to focus his/her supervision to obtain the best results. He/she should be realistic, evaluating the work in light of existing conditions. In practice, all work cannot be done perfectly.

Supervision should be planned well. The supervisor should have a copy of the contract agreement and the surface treatment plan, including the job specification and necessary drawings, compiled for the site. He/she should also have paint specifications, colour charts, standards and measurement equipment, which consists of a thermometer, a hygrometer, and wet and dry film thickness meters. Necessary tools include: a flashlight, a knife, a mirror with a handle and an illuminated loupe.

The supervisor must not change the surface treatment plan without permission. The supervisor appointed by the contracting authority is not responsible for the contractor's work, and therefore cannot interrupt or terminate work in progress without special instructions. If conditions or other factors do not meet the requirements of the agreement, the contracting authority’s supervisor should make the matter known and record it in the job site log.

Before work is started, the supervisor together with the supplier’s representative should review the surface treatment plan and the contract agreement to eliminate the possibility of delays due to different interpretations. If necessary, the parties should prepare and approve a reference surface for each phase of the process. The supervisor should check the following well in advance:

- surface cleaning and painting conditions meet the requirements
- the materials are according to the job specification
- the work methods and tools are correct

During the course of the painting work, the supervisor should check the following:

- work is done only in the specified moisture and temperature conditions
- preliminary cleaning is done according to standards
- rust is cleaned to the required preparation grade
- paints are mixed so they are homogenous
- the mix ratios of two-component paints are correct and the pot life is not exceeded
- paint is applied evenly, without running or unpainted spots
- the paint is allowed to dry before the next layer or treatment is applied, or before the part is moved or taken into use
- the finished painting meets the requirements of film thickness, non-porosity, appearance and colour.
5.4 Measurements

5.41 Measuring the thickness of the film

The thickness of a wet film of paint is measured with a comb gauge (figure 46) or a disk gauge (figure 47) immediately after the paint is applied, before the solvent has evaporated from the film. The thickness of the wet film \( (K_m) \) may be read directly from the gauge. The corresponding dry film thickness is given in the manufacturer's specification sheet. The dry film thickness \( (K_d) \) may be estimated by calculating it using the equation:

\[
K_d = \frac{K_m \times V}{100}
\]

\( V \) = dry material content of the paint as % volume

The thickness of a dry film may be measured by means of an invasive or a non-invasive method. The measuring device is used according to the manufacturer's instructions. The thickness of a dry film is usually measured using a permanent magnetic meter (figure 48) or an electromagnetic meter (figure 49). An invasive measurement can be used in case of disagreement.

Before they are used, film thickness meters should be calibrated using calibration pieces according to the manufacturer's instructions. The calibration pieces may be films or coated pieces approved by an official inspection office.

Calibration using films is done on a cold-rolled or similar smooth steel surface. The steel sheet must be a sufficiently large piece of material of the same quality and thickness as the part being measured; for example, 100 x 100 mm² and 5-10 mm thick. If a smooth surface is used for calibration, a grit blasted surface will give readings (10-40 µm) because of its profile, even though it hasn't been painted yet. This error is taken into account in defining the nominal film thickness of paint combinations exceeding 120 µm. The effect of the profile should be taken into account when measuring thinner layers of paint.

The calibration film should be in good condition. The person taking the measurements should have two sets of films, so that the condition of the set in use may be periodically checked using an unused set of films. The films should be replaced as necessary.

The influence of the working methods of the person taking measurements may be reduced by using a sensor that operates at a constant pressure. The sensor should always be placed perpendicular to the surface being measured. If a
meter that operates on the principle of gravity is used in a horizontal position or upside down, it must first be calibrated in that position. Film thickness measurements are made on a representative surface.

A sufficient number of measurement areas should be selected, depending on the size of the representative surface being measured, to give a correct picture of the thickness distribution of the film of paint. Several readings must be taken of each measurement point because of random variation of the measurement results that is typical of the meter. At least three measurements are made at each measurement point. The average value is the thickness of the film at that measurement point. The average value of the thickness measurements of an individual measurement area is the local film thickness. The minimum film thickness is the minimum local film thickness measured from the representative surface. The number and magnitude of deviations is reported for each measurement area. The size of the measurement area for repainting is defined as follows: one 10 m² measurement area is selected for each 100 m² area of the representative surface. Twenty measurements are made within the measurement area. In minor touch-up painting, at least three measurements are made at each place that is painted.

5.42 Measuring the adhesion of a coating film

Adhesion of a coating film refers to the adherence of a film to a metal base due to the attractive forces at the border between the film and the metal surface. Adhesion of paint to a base is usually tested using a tensile test. The adhesion of zinc and aluminum coatings to a base may be measured by means of a scoring test.

### 5.5 Qualification certificate

Before maintenance painting is started, the type of coating combination previously applied on a bridge always needs to be determined. If the coating is damaged, the cause of the damage should also be determined. Incorrectly done work is often the cause in surface treatment work. This may be determined if job-related information has been systematically recorded during the course of the work. Therefore, it is necessary to compile a qualification certificate for each surface treatment job. At least the following information should be recorded:
- the coated area and the preparation grade
- the coating combination (exact product names of paints)
- a summary of the thickness measurements of the paint or metallic coating
- working conditions
- the date and the names of the supervisors

The information in the qualification certificate for each bridge is updated each time touch-up painting or other minor surface treatment work is done. A new qualification certificate is compiled if the bridge is repainted. If the work is done by outsiders, the contractor or supplier compiles the qualification certificate. The points of supervision defined in the supervision agreement are included in the qualification certificate. A representative of the contracting authority makes sure the qualification certificate is properly filled out and the information is correct. The curves depicting the degree of rusting are included in the qualification certificate. The curves are used in scheduling touch-up painting or repainting. The surface treatment plan and other documents prepared for the surface treatment are also kept with the qualification certificate. The qualification certificate and the enclosed documents together form a complete report of surface treatment work done on each bridge. The original qualification certificate and the appendices are archived in the district bridge file.

### 5.6 Other directives

1/ Finnra 735175. Steel bridge structures. Reference scales; degree of rusting and preparation grades. (SILKO 1.353, 1.354 and 1.355)
Concrete structures of bridges may contain minor damage that is repairable without using formwork. Such damage is usually caused by incorrect work procedures. Examples of minor damage are:
- cavities (honeycombs) formed during concreting, poorly compacted areas and indentations left by formwork
- single reinforcement bars left on the surface
- loose formwork binder patches
- damage caused by salt corrosion and
- breaks in concrete caused by motor vehicle impacts or water freezing at the base of a railing post, for example.

Patch work is most often unsuccessful because the cement-based patch mortar hasn't adhered to the substrate or the mortar has shrunk excessively and loosened.

The vertical surfaces of the concrete substructures and the bottom surfaces of the concrete superstructure of a bridge may contain minor damage (0.5 - 5 dm³) that should be repaired to avoid consequential damage or to improve appearance. Such damage is usually repaired in conjunction with rehabilitation of the bridge.

Damage on the top surface of the deck slab should be repaired before the waterproofing is renewed or patched.
THE STAGES OF THE REPAIR WORK

PRELIMINARY TEST

10

IN ESTECTION OF STRUCTU R E

12

CHISELING

13

MACHINING OR REPAIR OF STEEL PARTS

14

PATCHING

15

FINISHING

16

ERECTION OF SCAFFOLDING

11

THE REQUIRED RESOURCES

WORK FORCE:  a construction craftsman and a construction worker.

JOB EQUIPMENT:  a 5-9 kW generator or a 3-7 m³/min compressor
- an angle grinder or a circular saw and diamond-tipped disks or a dry-cutting blade
- a chipping hammer and chisels
- a drill (approx. 250 rpm) and a mixer and a set of steel brushes
- if necessary, a concrete cover measuring instrument.

JOB SITE ARRANGEMENTS AND WORK SAFETY:

- a service cage, a passenger lift (bridge crane) or tubular scaffolding
- eye and ear shields when using a chipping hammer
- eye shields when mixing grouts or mortars.

MATERIALS:

- thixotropic cement-based or polymer-based patch mortar, or plastic cement-based or polymer-based grout (SILKO 3.231) and possibly a product-specific adhesive material.
- if necessary, antirust material
- possibly plastic plug nails or screws
- possibly steel or plastic fiber.

ESTIMATED WORK OUTPUT:

- a patch smaller than 1 dm³ 10 - 20 / shift
- a patch approximately 10 dm³ 3 - 10 / shift
PLANNING THE PATCHING

The degree of carbonization of the concrete and the thickness of the concrete cover over the reinforcement should always be determined.

If the damage is caused by salt corrosion, the chloride content of the concrete should be determined. The chloride content of a normally reinforced structure may be 0.07% by weight of the concrete for acid soluble measurement and 0.05% for water soluble measurement. The concrete should be chiseled away if the chloride content is higher.

If the reinforcement bars are rusty, the state of corrosion of the reinforcement should be determined using a potential measurement. Usually, the reinforcement has already begun to corrode outside the exposed area. The potential values are used to determine the extent of the area that should be chiseled. The reinforcement should be exposed if the potential is more negative than -200 mV (Cu/CuSO₄ electrode).

The chiseling limit should be carefully defined, because experience has shown that the damage renews itself quickly if concrete with too high a chloride content or if carbonated concrete is left around the reinforcement.

The patch material should be selected carefully with the help of the SILKO 3.231 directive. Materials that have given good results in practice should be used. It is not recommendable to continuously experiment with new materials. Thixotropic patch materials should be used on the substructure, on the bottom surface of the superstructure, and also on bevels. Plastic patch materials should be used to patch the top surface of the deck slab and places with raised edges that prevent material flow. Cement-based materials should primarily be used (figure 3). Expensive polymer-based materials should only be used to patch small areas (1 - 2 dm³).

Figure 4. Disturbingly visible patches.

Fibers and course aggregate may be added to grouts according to product-specific instructions.

The patch should not be disturbingly visible from the surrounding surface (figure 4). Blending of the patch should be preliminarily tested, unless the structure will be coated. Cement-based patch materials may be tinted.

Figure 3. Plastic cement-based grout and thixotropic cement-based patch mortar.
CHISELING

The reinforcement bars are located using an electromagnetic concrete cover measuring instrument (figure 5).

The area to be patched is outlined, usually with straight lines, using an angle grinder or a circular saw with a diamond-tipped disk (figure 6). Care should be taken not to damage the reinforcement bars. A formwork fixing bar or other similar bar that is visible may be removed by chiseling the concrete away from around the bar and then cutting the bar approximately 30 mm below the surface of the concrete.

A light or midweight chipping hammer is used for initial chiseling (figure 7). A heavier hydraulic hammer may be used on the top surface of the deck slab. Lighter equipment or manual chiseling is used near concrete that will remain in place. The chiseled surface should be uneven and rough. Grit blasting is recommended to clean the surface. The adhesive surface should not contain any loose material or impurities.

A patch on a vertical surface should be shaped so that the side and bottom edges are perpendicular to the surface being patched, and the top edge is beveled (figure 8). On other surfaces the edges of the patch are shaped so they are perpendicular to the surface being patched.

Chiseling should reach deep enough to leave a space equal to the diameter of the reinforcement bars, or at least 20 mm, behind the bars (figure 8). If there are no reinforcement bars in the area being patched, adhesion should be guaranteed by using plastic plug nails or screws that do not come closer than 30 mm to the surface of the patch.

A steel brush mounted on a drill is used to clean rust from the reinforcing bars.
The recommended temperature for patching is +10 - +15°C. The temperature of the structure should be at least +5°C while the patch hardens. Patch materials should be stored at approximately +20°C.

Patch materials differ decisively from each other in that cement-based patch mortars and grouts require a moist adhesive surface, while polymer-based patch mortars and grouts must be applied on a dry surface. Patch materials usually require a product-specific adhesive material (primer). Product-specific instructions must be followed exactly. Characteristics that vary greatly from product to product include pot life, hardening, mixing and curing. Clear instructions or work specifications and safety instructions should be available at the job site, and the workers should be aware of them.

It is extremely important in patching work that mixing instructions are followed closely. The mortar or grout is mixed at low speed using a mixer attached to a drill. The mixer should be shaped so that no unmixed material is left in the corners of the container (figure 9). Suitable mixing time is 3 - 5 min., depending on the product. Only enough mortar or grout is mixed that will be consumed within the pot life. Products containing two or more components are usually ready-proportioned.

If the adhesive surface needs to be moistened with water, it should not be wet (shiny) when patching is started.

The patching work proceeds as follows:

1. The adhesive surface is treated with a primer and the reinforcing bars are coated with an antitrust material (figure 10). The mortar should not be thinned if a product-specific primer is available.
2. The patch material is mixed and applied. Grout is poured on the area being patched. Patch mortar is applied using a trowel, starting at the bottom edge (figure 11). No empty spaces should be left behind the reinforcement bars or in the corners. A patch on a vertical surface may be made so it protrudes a little, and then the excess is cut away using a steel trowel.
3. A trowel, board or sponge is used to finish the surface of the patch (figure 12). If a surface that resembles the old formwork is desired, a movable board formwork is tapped lightly with a hammer.

Figure 9. A good mixer.

Figure 10. Applying a primer using a brush.

Figure 11. Patching a vertical surface using a trowel.

Figure 12. Concrete patching equipment.
DAMAGE

This directive deals with the repair of extensively damaged concrete structures. The diameter of the patching area is usually at least 300 mm. Repair of underwater damage is not covered.

Extensive damage usually results from:
- Cavities and separated regions in the structure caused by concreting errors.
- Insufficient concrete cover.
- Concrete deterioration caused by salt and freeze-thaw cycles.
- Structures broken by impacts.

Concrete deterioration is the most common type of damage. It is caused by water that enters the pores of the concrete and loosens the surface layer by layer when it freezes. When deterioration advances to the point where the reinforcing bars are exposed, corrosion of the bars quickly increases the damage.

This type of damage is usually located at water level on bridges and ferry docks. Damage caused by impacts appears in edge beams, arches and pillars.

THE NEED FOR REPAIR

A break from impact that extends to prestressed steel should be repaired as soon as weather conditions permit. A repair plan should be compiled if the reinforcement is damaged.

Damage in a massive structure may advance considerably without causing dangerous consequential damage. Such damage is usually repaired in conjunction with rehabilitation of the bridge.

Edge beam repair and small patching is done according separate instructions.

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THE STAGES OF THE REPAIR WORK

10. INSPECTION OF STRUCTURES
11. PLANNING THE REPAIR WORK
12. TRAFFIC ARRANGEMENTS
13. ERECTION OF SCAFFOLDING
14. CHISELING
15. CURING
16. RENEWAL OF REINFORCEMENT
17. ERECTION OF FORMWORK
18. CONCRETING
19. FINISHING
20. HIGH-PRESSURE WATER JETTING
21. CHISELING WITH A ROBOT

THE REQUIRED RESOURCES

WORK FORCE:
- a supervisor, 2 construction craftsmen and 2 construction workers.

JOB EQUIPMENT:
- a hydraulic power unit, a 5-9 kW generator or a 1.5-4 m³/min compressor
- a 700-1000 bar high-pressure water jet unit or a machine-mounted hydraulic chiseling hammer
- an angle grinder or a circular saw and diamond-tipped disks or a dry-cutting blade
- a chipping hammer and chisels
- a table saw and an electric drill
- a steel bar cutting and bending unit
- if necessary, a concrete mixer, wheelbarrows and internal vibrators.

JOB SITE ARRANGEMENTS AND WORK SAFETY:
- eye and ear shields when using a chipping hammer
- eye shields when mixing cement-based patch materials
- if necessary, tubular scaffolding.

MATERIALS:
- standard concrete: proportioned concrete, polymer cement concrete, or corresponding dry products (SILKO 3.211), or plastic cement-based grout (SILKO 3.231)
- dimensioned or tongue and groove boarding (SFS 2511) or sheet formwork or steel sheeting
- if necessary, reinforcing bars A 500 HW (SFS 1215) or reinforcement mesh (SFS 1257) and possibly driven or wedge anchors (DIN 1651)
- possibly thixotropic cement-based patch mortar (SILKO 3.231)
- possibly steel or aluminum guide rails and fasteners
- possibly formwork liner
- possibly an expanding additive
- possibly steel or plastic fibers.

ESTIMATED WORK OUTPUT:
- high-pressure water jetting 10 - 30 m² / shift
- chiseling with a robot 10 - 40 m² / shift
- boarding: 1 - 3 m² / shift
- concreting: 1 - 5 m³ / shift.
PREPARING THE REPAIR WORK

The degree of carbonization of the concrete and the thickness of the concrete cover over the reinforcement should always be determined.

If the damage is caused by salt corrosion, the chloride content of the concrete should be determined. A core sample at least 40 mm deep must be taken, because chlorides usually penetrate deep, and the purpose of the sample is to determine the thickness of the layer that has to be chiseled away. The chloride content of a normally reinforced structure may be 0.07% by weight of the concrete for acid soluble measurement and 0.05% for water soluble measurement. The concrete should be chiseled away if the chloride content is higher.

If the reinforcement bars are rusty, the state of corrosion of the reinforcement should be determined using a potential measurement. Usually, the reinforcement has already begun to corrode outside the exposed area. The potential values are used to determine the extent of the area that should be chiseled. The reinforcement should be exposed if the potential is more negative than -200 mV (Cu/CuSO₄ electrode). The chiseling limit should be carefully defined, because experience has shown that the damage renews itself quickly if concrete with too high a chloride content or if carbonated concrete is left around the reinforcement.

Selection of concrete used for repair is the most important stage of planning. The following concretes are recommended:
- Standard concrete for pours of substructure encasings.
- Cement-based grout for repairing impact damage and for pouring hard-to-reach places.
- Cement-based patch mortar for reinforcing the concrete cover on the bottom surface of the superstructure.

Preliminary testing is not required if standard concrete is used. The match of the colour of the patch with that of the surrounding structure should be checked if the surface will remain visible.

Steel or polymer fibers may be added to the patch material. An expanding additive usually may be used in standard concrete, but this should be verified in each case.

The repair plan should include at least the following:
- the limit of the area to be removed and the method used
- scaffolding and formwork structures
- anchorages of the new structures
- possible use of additives and fibers
- concreting method
- curing method
- work safety and environmental protection
- local conditions affecting the work, such as the proximity of a railroad (negotiations with railroad authorities), traffic during working hours, waterways, etc.
- possible protection of the repaired surface and surrounding surfaces, or the need for coating because of appearance.

Alternative repair methods - guniting, ejection and concrete injection - are presented in separate directives.

If necessary, a traffic arrangement plan is compiled.

Figure 3. Pour of a substructure encasing.

Figure 4. A steel form used in repairing impact damage is left in place.
CHISELING AND RESTORATION OF REINFORCEMENT

Scaffolding and work platforms are dimensioned according to construction work directives and work and safety scaffold instructions. Tubular scaffolding is usually used. If the edge of a lane of traffic is closer than one metre to the work area, a safety railing is constructed by the side of the work area adjacent to the lanes of traffic. If high-pressure water jetting is used to remove structures, a protective wall must be constructed to protect against flying stones and other material.

To avoid unnecessarily damaging the reinforcement during concrete removal, an electromagnetic concrete cover measuring instrument is used to locate the reinforcement bars and measure the thickness of the concrete cover.

The area to be patched is outlined, usually with straight lines, using an angle grinder or a circular saw with a diamond-tipped disk (figure 5). High-pressure water jetting or a chipping hammer is used for chiseling. High-pressure water jetting is preferable, because it leaves a better adhesive surface. If a chipping hammer is used, microcracking should be avoided by using lighter equipment near concrete that will remain in place. The chiseled surface should be uneven and rough. A high-pressure water-jetted surface is rinsed with clean water. Grit blasting is used to clean a surface chiseled otherwise. The adhesive surface should not contain any loose material or impurities. A patch on a vertical surface should be shaped so the side and bottom edges are perpendicular to the surface being patched, and the top edge is beveled (figure 6). On other surfaces the edges of the patch are shaped so they are perpendicular to the surface being patched. Chiseling should reach deep enough to leave a space equal to the diameter of the reinforcement bars, or at least 20 mm, behind the bars (figure 6). The thickness of the patch is determined by the thickness requirements of the concrete cover.

A reinforcement bar that is rusted or damaged during chiseling, so that its cross-sectional area is reduced by 30% or more, should be replaced.

If there are no reinforcement bars in the area being patched and the area is larger than one square metre, or if a layer of concrete will be poured around the structure, the area should be reinforced using 5-150 reinforcement mesh. The mesh is fixed using driven or wedge anchors (2 - 4 pcs/m²). The concrete cover over the reinforcement should be 50 mm thick in a substructure, 45 mm in an edge beam and at least 35 mm in other structures.

Figure 5. An outlined and chiseled area on the lower part of an abutment.

Figure 6. The shape of a patch on a vertical surface.
ERECTING THE FORMWORK

The formwork is erected using reusable formwork elements or by constructing it from lumber at the bridge site. The surface material of the formwork is selected so the appearance of the patched area matches that of the old structure. Usually, air-dried (moisture class 3), fifth grade, 20 mm tongue and groove or dimensioned boarding is used. The sawed surface faces the concrete. Formwork made from dimensioned boarding should be kept moist.

Formwork plywood may be used in place of boarding if the appearance of the patch does not suffer. Steel formwork is used in repairing impact damage, in which case the formwork is usually left in place to protect the structure.

The formwork should be fixed sturdily. Attention should be paid to pressure on formwork in large patches. Plasticizing additives increase the pressure. The pressure is also higher if the patch is made using pressure casting into enclosed formwork. The formwork must be tight enough to prevent concrete paste from extruding from the joints or edges of the formwork. It is most important to keep the formwork boarding from drying (shrinking). Rubber or plastic seals may be used to seal the edges.

Three wooden formwork systems developed in conjunction with bridge repair are presented in the following:

1. Plank formwork fixed with formwork binders.
2. Plywood formwork supported by guides.
3. Movable plank formwork supported by guides.
1. **Plank formwork fixed with formwork binders**

This formwork system is a conventional form with a pressure cover. The pressure cover ensures that no empty space is left at the top of the patch. However, a pressure cover is not necessary when using materials recommended in this directive. If a pressure cover is not used, the upper part of the patch should be vibrated before the concrete sets.

The formwork is constructed of air-dried, fifth grade lumber. Aluminum rods are used as formwork binders. Steel bars may be used where the surface will remain hidden. The binders must not touch the reinforcement. The patch preferably be poured from the side that will remain hidden. Formwork with two or more sides is used in repairing a wall or pillar (figure 7). If the height of the formwork exceeds 800 mm, the side of the formwork from which the patch is poured should be divided into sections, so that the patch may be poured in 250 - 300 mm layers. The fit of the sections of formwork should be checked before pouring is started. The formwork of the other surfaces is erected in one piece before pouring. If the width of the patch exceeds 2.5 m, braces should be placed inside the formwork. The braces are removed during the pour.

![Figure 7. Two-sided formwork.](image-url)
One-sided formwork is used in repairing the surface of a structure. The formwork is anchored to the structure (figure 8). If the height of the cavity exceeds 800 mm, the formwork is divided into sections as explained earlier. Driven or wedge anchors are used to anchor aluminum formwork binders to the chiseled rear wall of the cavity. If the width of the patch exceeds 2.5 m, the upper part of the formwork should be fixed to the concrete structure.

The patch is poured so that the top surface of the concrete extends 50 - 100 mm above the edge of the patch. The concrete left in the pour channel is chiseled away as soon as possible, usually the next day. Chiseling is started at the bottom. If necessary, the surface is ground using an angle grinder, or evened by chiseling with a Philips screwdriver.

Figure 8. One-sided formwork.
2. Plywood formwork supported by guides

Plywood formwork supported by guides is used, for example, to increase the thickness of the concrete cover over a large area on the bottom surface of the superstructure. The maximum width of the patch is two metres. Usually, 200 mm wide formwork elements are constructed from 16 mm formwork plywood, which is stiffened using strips of wood (figure 9). The number of elements needed during one day should be constructed. The formwork progresses as follows (figure 9, the phases of work are numbered in the drawing):

1. Wooden guides are fixed outside the area to be patched using wedge anchors or plastic plug nails. The thickness of the wooden guides depends on the required thickness of the layer of concrete.

2. Thixotropic cement-based patch mortar is spread on the formwork element. A frame of suitable thickness may be used at the edges of the formwork.

3. The formwork element is installed in place and fixed at each corner by screwing it to the wooden guides.

4. The cement-based patch mortar is tamped using a pointer, for example. Patch mortar is added to completely fill the formwork. If necessary, the formwork may be tightened at the centre of the wooden stiffeners using screws or a brace and wedges.

5. The formwork is stripped the following day. The formwork elements are cleaned and reused.

Figure 9. Plywood formwork supported by guides.
3. **Movable plank formwork supported by guides**

Movable plank formwork supported by guides is used, for example, in repairing the bottom surfaces of beams or in repairing pillars, where it is necessary to make sure the thixotropic cement-based patch mortar adheres. The cement-based mortar is selected according to the desired pot life. The formwork may be used in place of plank formwork that is fixed using formwork binders. In that case planks are added as the pour progresses. Thicker planks or formwork plywood should be used if the width of the patch exceeds one metre.

A preliminary test should be made before starting to determine how quickly the formwork may be moved and to observe the quality of the surface.

The pour surface of the formwork is made from 200 mm wide, 18 mm formwork plywood or 20 mm dimensioned boarding. The formwork progresses as follows (figure 10, the phases of work are numbered in the drawing):

1. Steel or aluminum profiles are fixed outside the area to be patched using wedge anchors or plastic plug nails. If necessary, the profiles may be connected to each other with steel bars.
2. The formwork elements are treated with formwork oil and wedged into place using wooden wedges. The corners are beveled.
3. The cement-based patch mortar is tamped into the cavity being patched using a pointer, for example. The patch mortar is mixed and the work is done according to the manufacturer's instructions.
4. The formwork is stripped once the patch mortar has set. The surface may be carefully smoothed with a damp sponge as soon as the pot life has expired.
5. The formwork is cleaned and wedged into the following position so that it overlaps the previous pour by 20 - 30 mm.

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**Figure 10. Movable plank formwork supported by guides.**
CONCRETING

The following instructions mainly apply to pours that are made using formwork fixed with formwork binders or formwork fixed to vertical surfaces with the help of guides (figure 11).

The air content of the concrete is measured on-site. The air content requirements are as follows:
- standard concrete without silica 5%
- standard concrete with silica 5%
- polymer cement concrete 3.5 - 6%

Curing should preferably be done by wetting with water. If the formwork needs to be stripped as soon as possible, a curing agent should be sprayed on all the surfaces. The effect of the curing agent corresponds to 3.5 days of wetting. The curing agent must not prevent possible application of a protective material or surface coating. If the formwork can be left in place, water curing is continued for 1 - 2 weeks. The best results are achieved by covering the surface with a fibrous cloth, which is kept wet, and with a plastic sheet. Water curing cannot be used above a railroad with electric power lines if they contain current. Polymer cement concrete (latex concrete) differs totally from other concretes in that it is water cured for 24 hrs, and then curing is finished.

The formwork is usually stripped a week after the pour. It may be stripped earlier if proportioned concrete is used. If the formwork is stripped early, extreme care must be taken to avoid breaking the edges in the structure. The surfaces must be cured very carefully, because thermal shock brought about by the removal of the formwork causes microcracking.

If cracks appear in the edge beam, they must be injected immediately /1/. Any cavities in the patch should be patched with thixotropic cement-based patch mortar /2/.

Cement-based patch mortars and grouts require a damp adhesive surface. Product-specific instructions should be followed carefully. Grouts are mixed at low speed using a mixer attached to a drill. The mixer should be shaped so that no unmixed material is left in the corner of the container (figure 13). Mixing time is 3 - 5 min., depending on the product. Only enough grout is mixed at one time that will be used within the pot life.

The formwork and prepared surfaces should be wetted well 24 hours before concreting and protected from rain and sunshine. When concreting is started, the concrete surfaces should be moist, but not wet (shiny).

The concrete is compacted with a 25 - 48 mm internal vibrator. The vibrator is kept upright. The vibrating time is approximately 400 sec/m². Vibration is sufficient when the surface is smooth and no bubbles rise to the surface. Recompaclion should be done during the vibrating stage. Unless more detailed instructions are given, recompaction may be done if the vibrator sinks into the concrete by its own weight. The additional effect of plasticizers on the vibration must be taken into account.

The temperature should be at least +5°C. High temperatures should be avoided because of the increased risk of cracking due to shrinkage.

Because only a small amount of concrete is needed, mixing concrete from dry products at the job site should be considered (figure 12). The manufacturer's instructions should be followed carefully. Special care should be taken to add the correct amount of water and to mix the concrete sufficiently long. The plasticity requirement is 1 - 2 sVB.
Finnra’s DIRECTIVES USED IN REPAIR WORK
