CHAPTER 23

FEASIBILITY STUDY OF GUADALUPE BRIDGE
REHABILITATION PLAN
CHAPTER 23

FEASIBILITY STUDY OF GUADALUPE BRIDGE (BOTH SIDES)
REHABILITATION PLAN

23.1 DETAILED BRIDGE SURVEY AND ASSESSMENT

This section is discussed in line with the flow chart shown in Figure 13.1-1, Chapter 13 of this report. The survey level follows the procedure as defined in the Manual prepared by the Study Team which corresponds to “Feasibility Study Level”.

23.1.1 Review of Design and Repair Works

(1) Review of Design

The references of the review of design are the construction drawings of the Guadalupe Bridge and the Bridge Retrofit Program Report of BRP both furnished by DPWH.

(a) Outline of Guadalupe Bridge (Both Sides)

![Photo 23.1.3-1 Panoramic View of Guadalupe Bridge](image)

- Structural Type : Three (3) Span PC Gerber Bridge Foundation Type for Pier and Abutment are PSC Piles.
- Bridge Length : 114.44m (abutment to abutment)
- Date of Construction : 1979

(b) General Notes for Widening of Guadalupe Bridge (Both Sides)

- Drawing of the Guadalupe Bridge (Both Sides) was prepared by Ministry of Public Works.
**Construction and Materials**


- The Guadalupe Bridge (Both sides) was constructed by general contractor UMALI-PAJARA Construction Company in 1979.

**Dimensions**

- Dimension and elevation are written in meters, weight and stresses are written in pound, feet and inch.

- October 17, 1974 Ministry of Public Highway for Widening of The Guadalupe Bridge,

**Concrete**

- Reinforced concrete fc' = 3000 psi (21 MPa)
- Prestressed concrete fc' = 5000 psi (35 MPa)

**Reinforcing Steel**

- ASTM A615 or AASHTO M31 (fy = 40,000 psi)

**Structural Steel**

- ASTM A36 or AASHTO M 183

**Prestressing Steel**

- ½” ø seven-wire high tensile strands confirming to ASTM A416 or AASHTO M203

**Foundations**

- 0.35m x 0.35m (14” x 14”) precast prestressed concrete piles with safe bearing capacity of 90 Metric tons each.

(2) **Review of Repair Works**

The actual field verification for retrofitting were cross checked with as-built drawings of retrofitting of the Guadalupe Bridge under the Bridge Retrofit Program of 1997. The retrofitting works were verified on the bridge, as follows:

- Longitudinal and transverse shear keys at coping of piers, and abutments.
- Longitudinal cable strainers at all piers to prevent the spans from falling off since the deck remain discontinuous.
• Vertical cable restrainers at abutments for uplift prevention.

**Problems/Issues of Previous Repair Works**

• Cracks at gerber hinge parts of exterior girders.
• Exposed rebar of mostly PC members.

(3) **Historical Background**

The Guadalupe Bridge (Both Sides) has no historical importance according to the National Historical Institute and interposes no objection to its rehabilitation.

### 23.1.2 Natural Condition Survey

(1) **Topographic Survey**

(a) **Control Monument**

Two (2) GPS Stations were established as control points for the Guadalupe Bridge as shown in Table 23.1.2-1.

<table>
<thead>
<tr>
<th>STATION</th>
<th>GPS COORDINATES</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NORTHING</td>
</tr>
<tr>
<td>BM-1</td>
<td>1611106.327</td>
</tr>
<tr>
<td>BM-2</td>
<td>1611481.641</td>
</tr>
</tbody>
</table>

All elevations were reckoned from existing PCGS, BM and were added a constant 10.475 meter to be consistent with the previous study’s vertical control system.

(b) **Topographic Survey**

Topographic Survey was conducted using the established control points and through the use of Calibrated Total Station Survey Instrument with Electronic Data Recorder. Two (2) GPS Stations were established and were tied to existing NAMRIA GPS Stations MMA-1 and MMA-46 located at Fort Bonifacio and Cultural Center of the Philippines to conform with PRS-92 coordinates system.

Table 23.1.2-2 shows the scope of works of topographic survey. Topographic plan is shown in Appendix 23.1.2-1.
Table 23.1.2-2 Scope of Works of Topographic Survey

<table>
<thead>
<tr>
<th>Description</th>
<th>Original Scope</th>
<th>Actual Work</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONTROL POINT SURVEY (GPS)</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>PROFILE SURVEY</td>
<td>115 m Bridge Section + 200 m Each of Both Approach Roads (200 x 2)</td>
<td>125.83 m Bridge Section + 217.07m + 217.10 m at each approach roads</td>
</tr>
<tr>
<td></td>
<td>Total = 515 m</td>
<td>Total = 565 m</td>
</tr>
<tr>
<td>ROAD CROSS-SECTION SURVEY</td>
<td>Bridge Section (115m) : @ 10m Interval</td>
<td>Bridge Section (115m) : 14 sections</td>
</tr>
<tr>
<td></td>
<td>Approach Roads (400m) :</td>
<td>Approach Roads (466.31m) : 21 sections</td>
</tr>
<tr>
<td></td>
<td>@ 20 m Interval</td>
<td>Width: 119 m</td>
</tr>
<tr>
<td></td>
<td>Width: Bridge 19m + 50m each at both sides = 119m</td>
<td>Width: 119 m</td>
</tr>
<tr>
<td></td>
<td>Total = 35 Sections</td>
<td>Total = 35 Sections</td>
</tr>
<tr>
<td>TOPOGRAPHIC SURVEY</td>
<td>515 m (Length) x 119 m (Width) = 61,285 sq. m</td>
<td>560 m (Length) x 119 m (Width) = 66,640 sq. m</td>
</tr>
<tr>
<td>RIVER CROSS-SECTION SURVEY</td>
<td>Edges of Bridge: 2</td>
<td>Edges of Bridge: 2</td>
</tr>
<tr>
<td></td>
<td>Upstream Side: 2</td>
<td>Upstream Side: 2</td>
</tr>
<tr>
<td></td>
<td>Downstream Side: 2</td>
<td>Downstream Side: 2</td>
</tr>
<tr>
<td></td>
<td>Total = 6 Sections</td>
<td>Total = 7 Sections</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(2) Geotechnical Survey

One offshore borehole was drilled at the bridge site (see Appendix 23.1.2-2). It was drilled down to a final depth of 30.0 meters from the top of the existing riverbed.

The granular formation extends in thickness from the surface down to the 25.0 meter depth. It is made up of poorly graded sand, silty gravelly sand and silty sand with traces of gravel. Relative density varies from loose (N=9) near the surface to medium dense and dense (N=11 to 50) down to 22.0 meters. The rest of the formation is very dense (N>50) down to 25.0 meter depth. A thin silty clay layer with fine sand is sandwiched at 12.0 to 13.0 meter depth (N=40). Underlying the predominantly granular formation is a tuffaceous sandstone formation described as very poor.

(3) Scour Survey

There was no scouring observed around substructure of the bridge.

23.1.3 Bridge Condition Survey and Identification of Damages

(1) Shape and Dimension Measurement

(a) Objective

The main purpose of this activity was to perform measurements on the main and secondary members of the bridge.

(b) Inspection Teams

Teams were formed to conduct hands-on verification of shapes and dimensions of all elements or members of the bridge.
(c) Coverage Area

The bridge was divided into three (3) general inspection areas namely: road deck level, below deck level, and substructure including bearings (see Photo 23.1.3-2 to 23.1.3-4).

Verification below deck level were taken on all 8 girders on every span. The spacing of girders were measured as well as intermediate and end diaphragms. Gerber hinges were also measured.

(d) Reference Information

The Study Team was furnished with copies of as-built drawings, and retrofitting drawings of Guadalupe Bridge (Both Sides), and used them as reference in planning different activities.

(e) Equipment and Procedure

Each team was equipped with safety gear (hard hats, safety belts, safety shoes, and goggles), measurement tools (steel tape and caliper) for verification, hammer, steel brush, digital still camera, forms and pencils for documentation (see Photo 23.1.3-5).

In verification of measurements on road deck level and sidewalk, dimensions were made easily using tape measure.

Verification of measurements below deck level required the use of suspended foot bridge or Gondola (see Photo 21.1.3-6). This system was used on high superstructure locations.
Each activity and inspected damages were supported with photos and dimensions were recorded. Results of special tests were also supplemented with photos.

(f) Miscellaneous Structures

Miscellaneous structure, including non-structural elements, were noted and photographs of these were taken. These includes 20 - φ 100mm PVC Telecommunication Pipe attached on the downstream side of exterior girder of upstream bridge. (See Photo 21.1.3-7).

(g) Results

Table 23.1.3-1 lists the drawings that summarize the data presented in the verification forms. Dimensions that were shown in the drawings were utilized in structural modeling and analysis.

Table 23.1.3-1 List of Drawings

<table>
<thead>
<tr>
<th>Sheet No.</th>
<th>Title</th>
<th>Appendix</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>General Plan and Elevation</td>
<td>Appendix 23.1.3-1 (1/3)</td>
</tr>
<tr>
<td>2</td>
<td>Girder Section and Gerber Hinge Details, Girder Elevation and Framing Plan</td>
<td>Appendix 23.1.3-1 (2/3)</td>
</tr>
<tr>
<td>3</td>
<td>Details of Abutment A1 &amp; A2, Details of Pier 1 &amp; 2.</td>
<td>Appendix 23.1.3-1 (3/3)</td>
</tr>
</tbody>
</table>

(2) Close-up Visual Inspection

(a) Objective

The close up visual inspection’s purpose is to determine the damages on the bridge and to be able to make detailed documentation including digital still photos.

A few available drawings were taken and used in planning for this activity.

(b) Inspection Team

The inspection teams were tasked to conduct close-up visual inspection of damages on the bridge.

(c) Coverage Area

The inspection covered the entire superstructure, road/deck, below deck level and substructure including bearings.

(d) Reference Information
The Study Team was furnished with copies of revised design drawings of the bridge and used them as reference in various activities and analysis of the structure.

(e) Equipment and Procedure

This activity was conducted simultaneously with the verification of shapes and dimensions.

(f) Criteria for Damage Rating

The criteria used for damage rating follows the criteria set forth Section 6.4 of Chapter 6.

(g) Results

- Large cracks were observed mostly on exterior girder. The suspended portion of the girder at gerber hinge connection exhibited deflection.

- The major damages of the bridge are shown in Figure 23.1.3-1. The damage rating of main members based on Close-up Visual Inspection is shown on Table 23.1.3-2.

- The damage sheets were completely documented in Appendix 23.1.3-2 (1/12 to 12/12).
Figure 23.1.3-1 Close-Up Visual Inspection of Major Damages in the Guadalupe Bridge

Girder 1, Gerber Hinge Damage – Crack Width 0.5mm – 1mm

Photo 23.1.3 Sidewalk Fascia Damage – Exposed Rebar

Girder 8, Gerber Hinge Damage – Crack Width 2.0mm

Girder 8, Gerber Hinge Damage – Crack Width 3.0mm

Girder 5, Gerber Hinge Damage – Crack Width 2.0mm – 5.0m
### Table 23.1.3-2 Damage Rating of Members by Close-up Visual Inspection

<table>
<thead>
<tr>
<th>Component</th>
<th>Item</th>
<th>Member / Location</th>
<th>Damage Rating</th>
<th>Damage Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SUPERSTRUCTURE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Material Damage</td>
<td>Span 1 : Deck Slab, Sidewalk</td>
<td>II</td>
<td>Corrosion of rebar</td>
<td></td>
</tr>
<tr>
<td>Material Damage</td>
<td>Span 2 : Gerber Hinge 1, L, of Girder 5</td>
<td>II</td>
<td>Corrosion of rebar</td>
<td></td>
</tr>
<tr>
<td>Material Damage</td>
<td>Span 2 : Gerber Hinge 1, R, of Girder 8</td>
<td>II</td>
<td>Corrosion of rebar</td>
<td></td>
</tr>
<tr>
<td>Material Damage</td>
<td>Span 2 : Middle of Span of Girder 5</td>
<td>II</td>
<td>Corrosion of rebar</td>
<td></td>
</tr>
<tr>
<td>Material Damage</td>
<td>Span 2 : Gerber Hinge 2, L, of Girder 1</td>
<td>II</td>
<td>Corrosion of rebar</td>
<td></td>
</tr>
<tr>
<td>Material Damage</td>
<td>Span 1 : Bottom of Center Span of Girder 1,4,5 &amp; 8</td>
<td>III</td>
<td>Cracks thickness of 0.10mm, Severe corrosion of rebar</td>
<td></td>
</tr>
<tr>
<td>Material Damage</td>
<td>Span 2 : Gerber Hinge 1, L, of Girder 1</td>
<td>I</td>
<td>Wide cracks at gerber hinge with crack widths of 0.5mm to 2mm with some spalling and exposed rebars.</td>
<td></td>
</tr>
<tr>
<td>Material Damage</td>
<td>Span 2 : Gerber Hinge 1, R, of Girder 1</td>
<td>I</td>
<td>2mm wide, cracks. Condition of corrosion of rebars is severe.</td>
<td></td>
</tr>
<tr>
<td>Material Damage</td>
<td>Span 2 : Gerber Hinge 1, L, of Girder 5</td>
<td>I</td>
<td>3 locations of wide cracks from 1.5mm to 5mm. Condition of corrosion of rebars is severe.</td>
<td></td>
</tr>
<tr>
<td>Material Damage</td>
<td>Span 2 : Gerber Hinge 1, R, of Girder 5</td>
<td>I</td>
<td>0.50mm wide cracks condition of corrosion of rebars is severe.</td>
<td></td>
</tr>
<tr>
<td>Material Damage</td>
<td>Span 2 : Gerber Hinge 1, R of Girder 8</td>
<td>I</td>
<td>0.10mm cracks at center of span 2. Condition of corrosion of rebars is severe.</td>
<td></td>
</tr>
<tr>
<td>Material Damage</td>
<td>Span 2 : Middle of Span of Girder 8</td>
<td>III</td>
<td>Many cracks with thickness ranging from 0.10mm to 0.20mm. Condition of corrosion of rebars is severe</td>
<td></td>
</tr>
<tr>
<td>Material Damage</td>
<td>Span 2 : Gerber Hinge 2, R, of Girder 1</td>
<td>I</td>
<td>Cracks width varies from 1.0mm to 5.0mm. Condition of corrosion of rebars is severe.</td>
<td></td>
</tr>
<tr>
<td>Material Damage</td>
<td>Span 2 : Gerber Hinge 2, R, of Girder 5</td>
<td>I</td>
<td>2mm to 5mm wide cracks. Condition of corrosion of rebars is severe.</td>
<td></td>
</tr>
<tr>
<td>Material Damage</td>
<td>Span 2 : L, Girder 5</td>
<td>I</td>
<td>Crack width of 1.0mm spacing less than 50 cm. Condition of corrosion of rebars is severe.</td>
<td></td>
</tr>
<tr>
<td>Material Damage</td>
<td>Span 2 : Gerber Hinge 2, L, of Girder 8</td>
<td>I</td>
<td>3 Crack locations with crack widths of 1.0mm to 3mm. Condition of corrosion of rebars is severe</td>
<td></td>
</tr>
<tr>
<td>Material Damage</td>
<td>Span 2 : Gerber Hinge 2, R, of Girder 8</td>
<td>I</td>
<td>2mm to 3mm wide cracks. Condition of corrosion of rebars is severe.</td>
<td></td>
</tr>
<tr>
<td>Material Damage</td>
<td>Span 2 : Gerber Hinge 2, L-R, Girder 6</td>
<td>II</td>
<td>Corrosion of rebar</td>
<td></td>
</tr>
<tr>
<td>Material Damage</td>
<td>Span 2 : Gerber Hinge 1, L-R, Girder 7</td>
<td>II</td>
<td>Corrosion of rebar</td>
<td></td>
</tr>
<tr>
<td>Material Damage</td>
<td>Span 1 : Bottom of Center Span of Girder 3,4,6 &amp; 7</td>
<td>III</td>
<td>Alligator cracks having thickness of 0.1mm. Condition of corrosion of rebars is severe.</td>
<td></td>
</tr>
<tr>
<td>Material Damage</td>
<td>Span 2 : Gerber Hinge 1, R, Girder 6</td>
<td>I</td>
<td>0.20mm thick cracks. Condition of corrosion of rebars is severe.</td>
<td></td>
</tr>
<tr>
<td>Material Damage</td>
<td>Span 2 : Gerber Hinge 1, L, Girder 7</td>
<td>I</td>
<td>One crack location with thickness of 0.20mm. Condition of corrosion of rebars is severe.</td>
<td></td>
</tr>
<tr>
<td>Material Damage</td>
<td>Span 2 : Gerber Hinge 2, L, Girder 6</td>
<td>I</td>
<td>Crack thickness of 2 mm with spacing of 50 cm. Condition of corrosion of rebars is severe.</td>
<td></td>
</tr>
<tr>
<td><strong>SUBSTRUCTURE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Material Damage</td>
<td>Bearing of G8, Pier 1</td>
<td>III</td>
<td>Rust scattered and generated extensively is observed, section loss is small, less than 10%.</td>
<td></td>
</tr>
<tr>
<td>Material Damage</td>
<td>Bearing of G5, Pier 2</td>
<td>III</td>
<td>Rust scattered and generated extensively is observed, section loss is small, less than 10%.</td>
<td></td>
</tr>
<tr>
<td>Material Damage</td>
<td>Pier 2 Wall D/S</td>
<td>III</td>
<td>Corrosion of rebar</td>
<td></td>
</tr>
<tr>
<td>Material Damage</td>
<td>Pier 2 Wall U/S</td>
<td>III</td>
<td>Corrosion of rebar</td>
<td></td>
</tr>
<tr>
<td>Material Damage</td>
<td>Abutment A2</td>
<td>II</td>
<td>Alligator cracks with thickness of 0.3mm located on the downstream face of abutment.</td>
<td></td>
</tr>
</tbody>
</table>

**Note:**
1 - Damage Rating Level is based on the X, Y, Z Damage Rating Method
2 - Rating 1 = Determined through engineering judgment by Team Leader through consultation with governing organization.
(3) Non-Destructive Test of Superstructure

(a) Objective

In conducting this activity, results of close-up visual inspection and importance of the member/joint were considered in deciding the location of the non-destructive test.

(b) Results

Table 23.1.3-3 shows the results of non-destructive tests conducted in the Guadalupe Bridge.

<table>
<thead>
<tr>
<th>Test</th>
<th>Description &amp; Results</th>
<th>Reference Appendices</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultrasonic Pulse Velocity Test (To determine depth of cracks on concrete members)</td>
<td>Results of crack depths vary from no evident cracks to full depth cracks.</td>
<td>Appendix 23.1.3-3 (1/3 to 3/3)</td>
</tr>
<tr>
<td>Schmidt Rebound Hammer Test (To determine the in-situ uniformity, surface hardness, and approximate compressive strength of concrete)</td>
<td>Measured compressive strength ranged from 38 Mpa to 49 Mpa.</td>
<td>Appendix 23.1.3-4</td>
</tr>
<tr>
<td>Phenolphthalein Test (To determine the depth of carbonation)</td>
<td>The depth of carbonization ranges from 5mm to 12mm.</td>
<td>Appendix 23.1.3-4</td>
</tr>
<tr>
<td>Chloride Test (To assess the distribution of chlorides)</td>
<td>Test revealed chloride levels were not detected from the two (2) core samples.</td>
<td>Appendix 23.1.3-4</td>
</tr>
<tr>
<td>Compression Test (To obtain the compressive strength of concrete)</td>
<td>Results of the compression test ranged from 21.1MPa to 30.7MPa.</td>
<td>Appendix 23.1.3-4</td>
</tr>
</tbody>
</table>

(4) Special Test

No special test was performed for this bridge.

(5) Assessment of Critical Damages

(a) Evaluation Criteria

Damages of bridge members were inspected under the close-up visual inspection and non-destructive test of material were identified and evaluated in compliance with the procedure set forth in Section 4.10 of the Manual.

(b) Damage Rating with X, Y, Z Method

This section follows the procedures and criteria set forth in Section 6.4, Chapter 6.

Evaluation of Damages

Evaluation results on damages of main members were summarized in Table 23.1.3-4.
Table 23.1.3-4 Evaluation of Major Damages on Guadalupe Bridge

<table>
<thead>
<tr>
<th>Location</th>
<th>Evaluation Based on Field Survey</th>
<th>Evaluation Based on Non-Destructive Test</th>
<th>Evaluation based on Special Test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Member</td>
<td>Node</td>
<td>Damage Type</td>
</tr>
<tr>
<td></td>
<td>City Sidewalk Slab</td>
<td>33</td>
<td>SER</td>
</tr>
<tr>
<td></td>
<td>Gerber GH1, L</td>
<td>44</td>
<td>SER</td>
</tr>
<tr>
<td></td>
<td>Gerber GH1, L-R</td>
<td>43</td>
<td>SER</td>
</tr>
<tr>
<td></td>
<td>Gerber GH 1, L-R</td>
<td>42</td>
<td>SER</td>
</tr>
<tr>
<td></td>
<td>Gerber GH 1, R</td>
<td>41</td>
<td>SER</td>
</tr>
<tr>
<td></td>
<td>Girder</td>
<td>60</td>
<td>SER</td>
</tr>
<tr>
<td></td>
<td>Gerber GH2, L</td>
<td>80</td>
<td>SER</td>
</tr>
<tr>
<td></td>
<td>Girder</td>
<td>17–21, 23, 24</td>
<td>CR</td>
</tr>
<tr>
<td></td>
<td>Gerber GH1, L</td>
<td>48</td>
<td>CR</td>
</tr>
<tr>
<td></td>
<td>Gerber GH1, R</td>
<td>48</td>
<td>CR</td>
</tr>
<tr>
<td></td>
<td>Gerber GH1, L</td>
<td>44</td>
<td>CR</td>
</tr>
<tr>
<td></td>
<td>Gerber GH1, R</td>
<td>44</td>
<td>CR</td>
</tr>
<tr>
<td></td>
<td>Gerber GH1, R</td>
<td>43</td>
<td>CR</td>
</tr>
<tr>
<td></td>
<td>Gerber GH1, L</td>
<td>42</td>
<td>CR</td>
</tr>
<tr>
<td></td>
<td>Gerber GH1, R</td>
<td>41</td>
<td>CR</td>
</tr>
<tr>
<td></td>
<td>Girder</td>
<td>57</td>
<td>CR</td>
</tr>
<tr>
<td></td>
<td>Gerber GH2, R</td>
<td>80</td>
<td>CR</td>
</tr>
<tr>
<td></td>
<td>Gerber GH2, L</td>
<td>76</td>
<td>CR</td>
</tr>
<tr>
<td></td>
<td>Gerber GH2, R</td>
<td>76</td>
<td>CR</td>
</tr>
<tr>
<td></td>
<td>Gerber GH2, L</td>
<td>75</td>
<td>CR</td>
</tr>
<tr>
<td></td>
<td>Gerber GH2, L</td>
<td>73</td>
<td>CR</td>
</tr>
<tr>
<td></td>
<td>Gerber GH2, R</td>
<td>73</td>
<td>CR</td>
</tr>
<tr>
<td></td>
<td>Bearing</td>
<td>33</td>
<td>CO</td>
</tr>
<tr>
<td></td>
<td>Bearing</td>
<td>84</td>
<td>CO</td>
</tr>
<tr>
<td></td>
<td>Pier 2 Wall, D/S</td>
<td>81–84</td>
<td>SER</td>
</tr>
<tr>
<td></td>
<td>Pier 2 Wall, U/S</td>
<td>81–84</td>
<td>SER</td>
</tr>
<tr>
<td></td>
<td>Abutment A2</td>
<td>113–116</td>
<td>CR</td>
</tr>
</tbody>
</table>

*Ultrasonic Pulse Velocity Test - Varies from no evidence to full depth cracks OK

*Schmidt Rebound Hammer Test - OK

*Compression Test - OK, fc’ Range 21.1 - 30.7 MPa
23.1.4 Presumption of Original Design

(1) Objective

The purpose of the presumption of original design is to prepare the structural shapes, dimensions and properties for the analysis model of the Load Rating.

(2) Structural Shapes and Dimensions

Superstructure

Most structural data of the superstructure does not need to be assumed because all the dimensions and details were measured. Appendix 23.1.4-1 (1/10 to 10/10) shows the shapes, dimensions, and details of the superstructure for the structural analysis.

Substructure

The dimension of exposed portion of the substructure were all measured. It is necessary to calculate the dead load and live load for the estimation of the scale of foundation.

The type of foundation were determined from the as-built drawings. The availability of materials and construction were known.

Appendix 23.1.4-2 shows the shapes and dimensions of substructures.

(3) Structural Soundness (LOAD RATING)

The bridge superstructure was modeled with 3D beam elements using a commercial FEM software. An analysis for Load Effects was performed on the model under different loading conditions. The AASHTO MS-18 live load was used in the analysis.

Live load rating factors were calculated at two levels: inventory and operating levels. The allowable stress that was adopted for inventory level evaluation was 21 MPa in compression and 2.96 MPa in tension for prestressed girders.

For the formula in calculating the Rating Factor, see Section 7.4, of Chapter 7.

Analysis Result

The calculated values of Rating Factor for each main member is presented in Appendix 23.1.4-3. The results on minimum RF by the location were shown in Table 23.1.4-1.
Table 23.1.4-1 Minimum RF by the Location

<table>
<thead>
<tr>
<th>LOCATION</th>
<th>SERVICEABILITY LIMIT STATE</th>
<th>STRENGTH LIMIT STATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>MEMBER</td>
<td>NODE</td>
<td>ALLOWABLE STRESS RF</td>
</tr>
<tr>
<td>Girder</td>
<td>1</td>
<td>2.03</td>
</tr>
<tr>
<td>Girder</td>
<td>2</td>
<td>4.92</td>
</tr>
<tr>
<td>Girder</td>
<td>3</td>
<td>1.64</td>
</tr>
<tr>
<td>Girder</td>
<td>4</td>
<td>0.00</td>
</tr>
</tbody>
</table>

(4) Vulnerability to Disaster

(a) Earthquake

The earthquake vulnerability of a bridge can be assessed by considering the following factors discussed in details in Chapter 10.

Bridge Site

Guadalupe Bridge (Both Sides) is located 1.5km from the Marikina Fault Valley System (MVFS). As rule, bridge structures less than 5km distance are considered highly vulnerable. The 1.5km distance of Guadalupe Bridge (Both Sides) make it highly vulnerable to earthquake. However, the type of soil and its response characteristics will have to be properly evaluated and considered in the design of strengthening.

Construction Details

The existing superstructure is supported by wall-type pier. The piers were extended to accommodate the new Prestressed Girder Superstructure. Shear keys on piers and longitudinal restraining cables at gerber hinge were installed during retrofitting works in 1997.

Structural Configuration

The regular configuration of Guadalupe Bridge (Both Sides) is structurally favorable.

Date of Construction

Guadalupe Bridge (Both Sides) was constructed in 1979. Before and during those times AASHTO have minimal recommendations with regards to seismic designs. But, the existence
of Caltrans 1973 provisions may have been covered in the detailed design, wherein seismic force is dependent on distance to fault, soil at site and dynamics of bridge. However, Guadalupe Bridge (Both Sides) could still be prone to present seismic forces.

**Analysis Results**

The safety of the bridge under earthquake was determined from the capacity and stability of the substructure. Vulnerability of the bridge to earthquake is presented by capacity-demand ratio under earthquake.

The existing dimensions and structural data of the substructure were determined from actual field surveys, as-built plans and “Presumption of Original Design” using the original code.

**Table 23.1.4-2** shows the C/D ratio of substructures under the original code and the latest code.

<table>
<thead>
<tr>
<th>Substructure</th>
<th>Original Code</th>
<th>Latest Code</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pier Wall</td>
<td>Foundation</td>
</tr>
<tr>
<td>Pier 1</td>
<td>1.24</td>
<td>1.19</td>
</tr>
<tr>
<td>Pier 2</td>
<td>1.24</td>
<td>1.19</td>
</tr>
</tbody>
</table>

The calculations of the above assessment is presented in **Appendix 23.1.4-4**.

(b) **Wind**

The National Structural Code of the Philippines (NSCP 2001) recommends a design basic wind speed of 200 kph but AASHTO recommends only 160 kph. The maximum cyclone center wind velocity of 225 kph passing Metro Manila where Guadalupe Bridge (Both Sides) is located was recorded in 1995 with a gust velocity reaching to 255 kph. This indicates that Guadalupe Bridge (Both Sides) has been exposed to more than 200 kph basic design wind speed specified in the Philippine Code. Therefore, Guadalupe Bridge (Both Sides) is not vulnerable to wind action.

(c) **Flood**

The pressure from flood water flow is usually quite small comparing to the lateral design force adopted under the earthquake in the Philippines. This means that the earthquake forces dictate the scale and the safety of the bridge. Moreover, the present profile of Guadalupe Bridge deck is more than sufficient to clear the maximum flood level.
(d) Special Issues

Vessel Collision

Pasig River is a major river for water navigation, and the vessels navigating the river are the motorized tug boats, barges motor tankers, bankers and fishing boats.

- **Vessel Collision with Girder**
  
The regulated vertical clearance by PCG is 3.75m, the actual vertical clearance of Guadalupe Bridge is sufficient at 8.3m.

- **Vessel Collision with Pier**
  
The ideal navigation span of piers should be more than the maximum vessel length of 60m. However, the preferable span of bridge piers for one vessel at Pasig River is 43 meters to allow passage at the deflection angle of 45 degrees. The navigational clearance between piers of Guadalupe Bridge is 34.2m which is less than the preferable space of 43m.

Utilities

The existing utility lines attached to the Bridge are listed below:

a) 20-100 mmØ PVC Telecommunication lines

Informal Settlers

There are two (2) families living under the Bridge.

23.1.5 FEM Analysis of Gerber Hinge Support

The Finite Element Method (FEM) analysis was employed to estimate mathematically the causes of cracks on gerber hinge support parts and to verify the effectiveness of the rehabilitation measure which was recommended in Section 23.2.4.

(1) The approach for estimation of crack causes and verification of rehabilitation measure is as follows:

- To set-up nonlinear finite element models of a typical gerber hinge supporting the suspended post-tensioned girder spans (36.70m) of the Guadalupe Bridge,

- To simulate the existing condition of the gerber hinge part, specifically the occurrence and pattern of cracks under servie load, and
• To estimate the live load capacity of the gerber hinge support with the proposed rehabilitation measure.

(2) Methodology

(a) Nonlinear Finite Element Modeling of Typical Gerber Hinge part

Four (4) finite element models of a typical Gerber Hinge supporting the center span post-tensioned girder (36.70m) was set-up using the software Ucwin/WCOMD, which had been developed by Prof. Maekawa and his colleagues at the University of Tokyo. Descriptions of the models are listed in Table 23.1.5-1.

Two types of 8-noded quadrilateral plane stress (2D) elements were used in modeling: namely, RC Plates for zones of concrete in which reinforcements are embedded and Plain Concrete Plates for areas in which no reinforcement is embedded. Both element types take into account the highly nonlinear behavior of reinforced concrete.

Post-tensioning was applied as an initial force in the analysis.

The Model Failure Criteria used in the software were the following:

• Maximum tensile strain normal cracks (Et): 3.00%
• Maximum compressive strain parallel to cracks (Ec): -1.00%
• Maximum shear strain parallel to cracks (Esh): 2.00%

Outline of the crack model used in the software is illustrated in the Figure 22.1.5-1, Item 22.1-5, Chapter 22.

Table 23.1.5-1 Description of Finite Element Models

<table>
<thead>
<tr>
<th>Model</th>
<th>Description</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>E</td>
<td>To simulate existing condition: Effective post-tensioning forces are 0.50fsu for all tendons specified in the design code. The amount of reinforcements shown in the construction drawings is used (See Figure 23.1.5-1).</td>
</tr>
<tr>
<td>2</td>
<td>Et</td>
<td>To simulate existing condition: Effective post-tensioning forces are 0.35fsu for Tendon 3, 0.20fsu for Tendon 2 and 0.50fsu for Tendons 1 and 4. The amount of reinforcements shown in the construction drawings is used (See Figure 23.1.5-1).</td>
</tr>
<tr>
<td>3</td>
<td>Es</td>
<td>To simulate existing condition: Effective post-tensioning forces are the same as Model E. The amount of vertical reinforcements is reduced from 75mm spacing to 150mm.</td>
</tr>
<tr>
<td>4</td>
<td>Rt</td>
<td>To simulate rehabilitated condition: Assumptions of existing post-tensioning forces and/or the amount of reinforcements are the same as Model Et.</td>
</tr>
</tbody>
</table>
(b) Simulation of Existing Condition and Occurrence of Cracks

Models E, Et and Es were used to simulate the existing condition of the gerber hinge, and the occurrence and pattern of cracks. Loads were applied monotonically in stages. Table 23.1.5-2 shows the loading stages for this simulation.

Table 23.1.5-2 Loading Stages for Simulation of Existing Condition

<table>
<thead>
<tr>
<th>Action</th>
<th>No. of Loading Stages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Self weight</td>
<td>1</td>
</tr>
<tr>
<td>Effective Post-tensioning Force (0.50fsu for Model E and Model Es)</td>
<td>3</td>
</tr>
<tr>
<td>Dead Load</td>
<td>5</td>
</tr>
<tr>
<td>Live Load</td>
<td>To be loaded until failure at 25kN loading increment</td>
</tr>
</tbody>
</table>

(c) Estimation of Live Load Capacity with the Rehabilitation Measure

Models R, Rt, or Rs were used to model the rehabilitated condition of the gerber hinge, considering the most probable mechanism of cracking as would be evident from the results of the simulations using the Models E, Et and Es.
Similar to (b) of this section of the proposed methodology, loading was applied monotonically in stages, with live load last to be applied. Table 23.1.5-3 shows the loading stages for this analysis.

<table>
<thead>
<tr>
<th>Action</th>
<th>No. of Loading Stages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Self weight</td>
<td>1</td>
</tr>
<tr>
<td>Effective Post-tensioning Force (0.50fsu for Model E and Model Es)</td>
<td>3</td>
</tr>
<tr>
<td>Dead Load</td>
<td>5</td>
</tr>
<tr>
<td>Post-tensioning Force of Slanted Cables</td>
<td>10</td>
</tr>
<tr>
<td>Live Load</td>
<td>To be loaded until failure at 25kN loading increment</td>
</tr>
</tbody>
</table>

(3) Analysis Results

Figure 23.1.5-2 show the patterns and locations of cracks for each Model; those observed cracks are shown in Figure 23.1.5-4 for comparison. From these figures, the following were observed:

- The most probable model to explain the observed crack pattern is Model Et.
- This suggests that effective post-tensioning under construction were smaller than that specified in the design.
- The effective post-tensioned forces affect the occurrence of cracks more than the amount of reinforcement as compared to the results of Model Et and Es.
- The rehabilitation measure recommended in Section 23.2.4 is revealed to be effective.

Figure 23.1.5-3 indicates the crack pattern prior to failure of Model Et and load-deflection relationship at the loaded point.

From the results, the following are observed:

- In case of Model Et which simulates well the existing crack condition among analysis models, integrated behavior is under the situation of yield zone or almost failure zone when the service load (design live load) is loaded.
- Model Rt presenting rehabilitation measure is very effective to increase the capacity of gerber hinge part.
- The integrated behavior of rehabilitated gerber hinge part is still within the elastic zone.
- Even at load level prior to failure, any crack occurrences at girder on top of the pier did not appear.
Figure 23.1.5-2 Crack Patterns and Locations at Service Load in Each Model

(b) Model E,

d) Model R,

(c) Model E,
(a) Crack Pattern Prior to Failure (Model E)

(b) Load – Deflection Relationship

Figure 23.1.5-3 Crack Pattern Prior to Failure and Load-Deflection Relationship at Reaction Force Loaded Point.
Figure 23.1.5-4 Observed Crack Pattern in Gerber Hinge Part of Guadalupe Bridge

23.1.6 Overall Assessment of Bridge Condition

The present state of the bridge was assessed based on the following informations:

(1) Superstructure

Major Damage Description and Causes

- The outer faces of exterior girders at gerber hinge parts have many cracks. Most of the cracks were full depth as tested non-destructively. These cracks are due to insufficient flexural and shear reinforcement and unforeseen losses of prestressing forces.

(2) Substructure

The following results of analysis conducted on substructure were:

- Existing Pier walls and foundations are sound to carry the original design load but not enough to carry the loads required under the latest code as shown in Table 23.1.4-2.

- The instability of pier walls and foundations are due to the change of design code especially the design requirement.
(3) Social Environment

- Dislocation of people living under the bridge is compulsory upon project implementation.

(4) Conclusion

- Improvement work in the gerber hinge part is necessary to improve the durability of the existing superstructure.

- As for the substructure, a retrofit measure is recommended to conform with the requirement of the latest code.

Table 23.1.6-I summarizes the overall assessment of existing bridge.
<table>
<thead>
<tr>
<th>Items</th>
<th>Member/Location</th>
<th>Damage Rating</th>
<th>Damage Condition</th>
<th>Diagnosed (Y/N or N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Span 1</td>
<td>Deck Slab, Sidewalk, Span 1</td>
<td>II</td>
<td>Not so large section loss due to corrosion.</td>
<td>N</td>
</tr>
<tr>
<td>Span 2</td>
<td>GH1, L, Ext. Girder 5, Span 2</td>
<td>II</td>
<td>Not so large section loss due to corrosion.</td>
<td>N</td>
</tr>
<tr>
<td>GI1, R, Ext. Girder 8, Span 2</td>
<td>II</td>
<td>Not so large section loss due to corrosion.</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>Ext. Girder 5, Middle of Span 2</td>
<td>II</td>
<td>Not so large section loss due to corrosion.</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>GH2, L, Ext. Girder 1, Span 2</td>
<td>II</td>
<td>Not so large section loss due to corrosion.</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>GI1, L, Ext. Girder 6, Span 2</td>
<td>II</td>
<td>Not so large section loss due to corrosion.</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>GI1, L-R, Ext. Girder 7, Span 2</td>
<td>II</td>
<td>Not so large section loss due to corrosion.</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>Span 1</td>
<td>Bottom of Center Span of Main Girder, 0.104, 0.58, and 0.98 of Span 1</td>
<td>III</td>
<td>Alligator cracks observed at bottom of girders having crack thickness of 0.10mm. Condition of corrosion of rebars is severe. Concrete coverage of 40 - 70mm.</td>
<td>N</td>
</tr>
<tr>
<td>Span 2</td>
<td>GH1, L, Ext. Girder 1, Span 2</td>
<td>II</td>
<td>Wide cracks at girder flange with crack widths of 0.5mm to 2mm with some spalling and exposed rebars. Condition of corrosion of rebars is severe. Concrete coverage of 40 - 70mm.</td>
<td>Y</td>
</tr>
<tr>
<td>GH1, R, Ext. Girder 1, Span 2</td>
<td>II</td>
<td>Wide cracks. Condition of corrosion of rebars is severe. Concrete coverage of 40 - 70mm.</td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>GI1, L, Ext. Girder 5, Span 2</td>
<td>II</td>
<td>3 locations of wide cracks from 1.5mm to 6mm. Condition of corrosion of rebars is severe. Concrete coverage of 40 - 70mm.</td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>GH1, R, Ext. Girder 5, Span 2</td>
<td>II</td>
<td>0.07mm wide cracks condition of corrosion of rebars is severe. Concrete coverage of 40 - 70mm.</td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>Ext. Girder 6, Middle of Span 2</td>
<td>III</td>
<td>Many cracks with thickness ranging from 0.10mm to 0.20mm. Condition of corrosion of rebars is severe. Concrete coverage of 40 - 70mm.</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>GH2, L, Ext. Girder 5, Span 2</td>
<td>II</td>
<td>Crack width of 1.9mm spasing less than 40cm. Condition of corrosion of rebars is severe. Concrete coverage of 40 - 70mm.</td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>GH2, R, Ext. Girder 5, Span 2</td>
<td>II</td>
<td>2mm to 3mm wide cracks. Condition of corrosion of rebars is severe. Concrete coverage of 40 - 70mm.</td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>GH2, L, Ext. Girder 5, Span 2</td>
<td>II</td>
<td>2mm to 3mm wide cracks. Condition of corrosion of rebars is severe. Concrete coverage of 40 - 70mm.</td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>GH2, R, Ext. Girder 5, Span 2</td>
<td>II</td>
<td>5 locations with crack widths of 1.0mm to 3mm. Condition of corrosion of rebars is severe. Concrete coverage of 40 - 70mm.</td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>GH2, L, Ext. Girder 6, Span 2</td>
<td>II</td>
<td>2mm to 3mm wide cracks. Condition of corrosion of rebars is severe. Concrete coverage of 40 - 70mm.</td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>GH2, R, Ext. Girder 6, Span 2</td>
<td>II</td>
<td>2mm to 3mm wide cracks. Condition of corrosion of rebars is severe. Concrete coverage of 40 - 70mm.</td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>GH1, L, Ext. Girder 6, Span 2</td>
<td>II</td>
<td>0.02mm thick cracks. Condition of corrosion of rebars is severe. Concrete coverage of 40 - 70mm.</td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>GH1, R, Ext. Girder 7 Span 2</td>
<td>II</td>
<td>One crack location with thickness of 0.07mm. Condition of corrosion of rebars is severe. Concrete coverage of 40 - 70mm.</td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>GH2, L, Ext. Girder 6, Span 2</td>
<td>II</td>
<td>Crack thickness of 1.9mm with spacing of 40cm. Condition of corrosion of rebars is severe. Concrete coverage of 40 - 70mm.</td>
<td>Y</td>
<td></td>
</tr>
</tbody>
</table>

**Inventory Level**
- Girder Hinge part: Not Ok
- Equivalent Truck = 14 tons RF = 0.64

**Assessment of Substructure**
- Girder hinge part should be improved
- Piers 2 Wall C6R: Not Ok
- Piers 4 Wall U6S: Not Ok
- Bearing of G8, Pier 1: Rust scattered and generated extensively is observed, section loss is less than 15%
- Bearing of Pier 2: Rust scattered and generated extensively is observed, section loss is less than 15%
- Abutment 2: Alligator cracks with thickness of 0.3mm located on the downstream face of abutment. Condition of corrosion of rebars is severe. Concrete coverage of 40 - 70mm.

**Strength of Pier Body**
- Piers 1 & Piers 2: Strength of pier body sufficient (QD ratio = 0.8)
- Piers 1 PSC Piles: Underwater survey was not undertaken
- Piers 2 PSC Piles: Underwater survey was not undertaken
- Underwater survey was not undertaken
- Underwater survey was not undertaken
- Capacity of pile insufficient (QD ratio = 0.6)
- Capacity of pile insufficient (QD ratio = 0.6)
- Existing Pile Foundation does not comply with the latest code requirement.

**Assessment of Structural Soundness**
- Existing Bridge structure needs strengthening to meet the present required strength.

**Traffic Features**
- Vehicle Weight Limitation Use: 14 tons (RF = 0.44, girder hinge part)
- LOG: F (v_b = 1.51/2)
- Geographical Features: Fair including approach road
- Safety of Vessel Transport: Space between piers 342.4 - 440.6m, collision protection for girder and piers needed
- Assessment of Traffic Function: Insufficient

**Social Environment**
- Unicor suspended at the bridge: 20 - 80mm Telecommunication Line
- Squatters: Light, More than 2 families live around the Guadalupe Bridge
- Historical Aspects: No historical importance

**Assessment of Social Aspects**
- Historical situation shall not be considered

**Overall Assessment**
- Superstructure improvement work is necessary especially on girder hinge part
- Retrofit of substructure is recommended
23.2 COMPARATIVE STUDY ON REHABILITATION METHOD

23.2.1 Proposition of Rehabilitation Method

With the aid of criteria set forth in Chapter 14, three (3) schemes were proposed and compared for the best possible rehabilitation scheme. These three schemes were prepared based on engineering aspects needed to improve the present condition of the bridge. These are itemized as small-scale rehabilitation, medium-scale rehabilitation and large-scale rehabilitation.

(1) Small-Scale Rehabilitation

Major works for this scheme are as follows:

- Repair and sealing of concrete cracks, honeycomb and spalling.

Countermeasure in this scheme is not permanent because shear capacity at gerber hinge portion is insufficient. The least durable among schemes and no improvement in the overall bridge strength and integrity.

(2) Medium-Scale Rehabilitation

In addition to the repair and sealing of concrete cracks, honeycomb and spalling, major works for this scheme include:

- Rehabilitation of gerber hinge part by installation of slanted P/S cables.
- Reconstruction of diaphragm and partial reconstruction of deck slab at gerber hinge portion.

This scheme will improve the durability of the whole structure because the shear capacity is effectively increased on the gerber hinge portion.

(3) Large-Scale Rehabilitation

The following major works were considered for these scheme in addition to the medium-scale rehabilitation works.

- Additional elastometric bearing pads at diaphragm.
- Installation of transverse P/S cables at diaphragm of Gerber hinge portion.

More stability will be attained in this scheme by the addition of the transverse cables and is more durable and effective than the previous schemes. Addition of support at the center between each girder will lessen the loads of individual bearing support.
23.2.2 Evaluation of Rehabilitation Method

From the three schemes formulated above, the recommended as best scheme in terms of engineering aspects is Scheme 3 Large-scale Rehabilitation Scheme. Structural capacity and durability of the bridge will be improved considerably by installation of P/S cables at gerber hinge and at the diaphragm. Construction duration for this scheme is 12 months and cost is justifiable for the overall improvement of the bridge. For the detailed description of possible rehabilitation schemes, see Table 23.2.2-1.

23.2.3 Lifecycle Cost Analysis of the Bridge

(1) Procedure

Based on the bridge condition survey mentioned in Section 23.1 and engineering study made in Section 23.2.1, the life cycle cost (LCC) analysis of the Guadalupe Bridge is carried out in this section. The procedure of the LCC analysis of the Bridge employed is the same as that of Ayala Bridge as shown in Figure 14.3.1-1.

(2) Guadalupe Bridge Deterioration Situation

The standard deterioration curve of deck, superstructure and substructure between condition rating and age using the same equation mentioned in Section 14.3. According to the bridge condition survey, however, the deck and superstructure of Guadalupe Bridge have deteriorated more than two (2) times that of the standard deterioration due to the construction of superstructure being not appropriate.

The deterioration curve of the Guadalupe Bridge is estimated and shown in Figure 23.2.3-1.
### Table 23.2.2-1 Comparative Study of Possible Schemes for Guadalupe Bridge

<table>
<thead>
<tr>
<th>IMPROVEMENT TYPE</th>
<th>SCHEME 1: SMALL SCALE REHABILITATION</th>
<th>SCHEME 2: MEDIUM SCALE REHABILITATION</th>
<th>SCHEME 3: LARGE SCALE REHABILITATION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CRACK SEALING</td>
<td>SLANTED P/S CABLE STRENGTHENING</td>
<td>TRANSVERSE AND SLANTED P/S CABLE STRENGTHENING</td>
</tr>
<tr>
<td>FIGURES</td>
<td><img src="image1" alt="Diagram" /></td>
<td><img src="image2" alt="Diagram" /></td>
<td><img src="image3" alt="Diagram" /></td>
</tr>
<tr>
<td>LOCATION OF SIGNIFICANT STRUCTURE DAMAGE</td>
<td><img src="image4" alt="Diagram" /></td>
<td><img src="image5" alt="Diagram" /></td>
<td><img src="image6" alt="Diagram" /></td>
</tr>
</tbody>
</table>

#### MAJOR WORKS
- Repair and sealing of concrete cracks, honeycomb and spalling.
- Rehabilitation of Guerber hinge portion with slanted P/S cables.
- Reconstruction of diaphragm and partial reconstruction of deck slab at Guerber hinge portion.
- Repair and sealing of concrete cracks, honeycomb and spalling.
- Rehabilitation of Guerber hinge portion with slanted P/S cables.
- Reconstruction of diaphragm and partial reconstruction of deck slab at Guerber hinge portion.
- Additional reinforcing at corners of slabs.
- Installation of transverse P/S cables at diaphragms of Guerber hinge portion.

#### (1) STRUCTURAL ASPECT (30%)
- **STABILITY**
  - Countermeasures taken is not permanent because shear capacity at Guerber hinge portion is insufficient.
  - Slanted P/S cables at Guerber hinge will prevent shear failure due to diagonal tension and make cracks close.
  - Cracks at the Guerber hinge will be addressed efficiently. This is more stable than scheme 1.
  - Slanted P/S cables at Guerber hinge will prevent shear failure and diagonal tension.
  - Additional support at the center between each girder will lessen the loads of the individual bearing support.
  - Slanted P/S cables at Guerber hinge will prevent shear failure and diagonal tension.
  - Additional support at the center between each girder will lessen the loads of the individual bearing support.
- **DURABILITY**
  - Local durability among schemes.
  - Durability of the whole structure is improved because the shear capacity is effectively increased on the Guerber hinge portion.
  - The slanted P/S cables will effectively improve the durability of the Guerber hinge.
  - Durability of the whole structure is improved because the shear capacity is effectively increased on the Guerber hinge portion.
  - The slanted P/S cables will effectively improve the durability of the Guerber hinge.
  - Durability of the whole structure is improved because the shear capacity is effectively increased on the Guerber hinge portion.
  - The slanted P/S cables will effectively improve the durability of the Guerber hinge.
- **COST**
  - PHU $11,34 Million
  - PHU $18.20 Million
  - PHU $20.00 Million
  - PHU $12.50 Million
  - PHU $14.00 Million
  - PHU $16.00 Million
- **DURATION**
  - 15 (3) months.
  - 20 (5) months.
  - 25 (6) months.
  - 18 (4) months.
  - 22 (5) months.
  - 26 (6) months.
- **METHOD / DIFFICULTY**
  - Excavated and back to excavate.
  - Excavated and back to excavate.
  - Excavated and back to excavate.
  - Excavated and back to excavate.
  - Excavated and back to excavate.
  - Excavated and back to excavate.

#### (2) TRAFFIC / NAVIGATION FUNCTIONALITY (20%)
- Existing condition for traffic functionality and navigation clearance will be maintained.
- Existing condition for traffic functionality and navigation clearance will be maintained.
- Existing condition for traffic functionality and navigation clearance will be maintained.

#### (3) IMPACT TO TRAFFIC DURING CONSTRUCTION (15%) - Affected Lanes
- Traffic disturbance is minimal.
- Traffic disturbance is minimal.
- Traffic disturbance is minimal.

#### (4) LOAD CAPACITY REDUCTION
- Full lane vehicle load can be maintained during construction.
- Full lane vehicle load can be maintained during construction.
- Full lane vehicle load can be maintained during construction.

#### (5) SOCIAL / ENVIRONMENTAL IMPACT (10%)
- Application of structural epoxy will have minimal impact to lives.
- Application of structural epoxy will have minimal impact to lives.
- Application of structural epoxy will have minimal impact to lives.

#### OVERALL EVALUATION AND RATING

<table>
<thead>
<tr>
<th>Scheme</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A</td>
</tr>
<tr>
<td>2</td>
<td>A</td>
</tr>
<tr>
<td>3</td>
<td>A</td>
</tr>
</tbody>
</table>

**NOTES:**
- A = EXCELLENT (3.50 points)
- B = GOOD (2.50 points)
- C = SATISFACTORY (1.50 points)
- D = BRUISE SATISFACTORY (0.50 points)
- E = NOT RECOMMENDED (0.00 points)
(3) Rehabilitation Schemes and Cost Estimates

The engineering study proposed the rehabilitation schemes and cost estimates as shown in Table 23.2.2-1.

(4) Lifecycle Cost Analysis Model

In the life cycle analysis model, there are principally two (2) cases;

a. Replacement case
b. Rehabilitation case

The explanation of the lifecycle cost analysis model for these two (2) cases are as shown in Section 14.3.4;

(5) Extended Service Life by Improvement Proposals

From the deterioration curve in Figure 23.2.3-2, and using the relationship between investment cost and improvement condition rating shown in Figure 14.3.5-1 in Section 14.3.5, the expected extended service life of Guadalupe Bridge is calculated and shown in Figures 23.2.3-2 and 23.2.3-3. The service life of the Bridge is varied and extended depending on the type of rehabilitation. If large scale rehabilitation is implemented, the service life of the bridge is expected to extend 32 years so the total service life will be 38 years from 2007.

(6) Calculation of the Lifecycle Cost of the Guadalupe Bridge

The lifecycle cost of the Guadalupe Bridge is calculated and shown in Table 23.2.3-1 and judging from the LCC of alternative rehabilitation works, the large scale rehabilitation scheme is recommended for the rehabilitation of Guadalupe Bridge.
## Table 23.2.3-1 Lifecycle Cost Estimates of Guadalupe Bridge by Rehabilitation Types

<table>
<thead>
<tr>
<th>Scheme</th>
<th>LCC at Discount Rate of 15%</th>
<th>Recommended Rehabilitation Ranking from LCC Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small Scale Rehabilitation</td>
<td>43.9 (0.79)</td>
<td>3</td>
</tr>
<tr>
<td>Medium Scale Rehabilitation</td>
<td>43.9 (0.79)</td>
<td>2</td>
</tr>
<tr>
<td>Large Scale Rehabilitation</td>
<td>42.8 (0.76)</td>
<td>1</td>
</tr>
<tr>
<td>Replacement</td>
<td>55.8 (1.00)</td>
<td>4</td>
</tr>
</tbody>
</table>

Notes:
1) Discount rate is assumed to be 15%.
2) Recommended improvement ranking is based on the LCC
3) Ratio of life cycle cost to replacement

### Life Cycle Cost Model

- **Small Scale Rehabilitation**
  - Replace 128 m
  - SL(1)
  - SL(2)
  - SL(3)
  - SL(4)
  - SL(5)

- **Medium Scale Rehabilitation**
  - Replace 128 m
  - SL(1)
  - SL(2)
  - SL(3)
  - SL(4)

- **Large Scale Rehabilitation**
  - Replace 102 m
  - SL(1)
  - SL(2)

- **Replacement**
  - Replace 103 m
  - SL(1)
  - SL(2)

**Figure 23.2.3-3 Life Cycle Analysis of Guadalupe Bridge**
23.2.4 Recommendation

Based on the life-cycle cost analysis conducted on the possible rehabilitation schemes, the most recommendable scheme is the medium-scale rehabilitation scheme because it is the least expensive at a discount rate at 15%.