# Chapter. 8 Existing Condition and Site Inspection of the Study Bridges

## 8.1 Existing Condition of the 29 Bridges

The 29 Study Bridges comprise 17 concrete girder type bridges and 12 steel girder type bridges. These were selected in accordance with the predominant structural features of the bridges, although we have observed some composite bridges, which use a combination of steel and concrete. The bridge types are summarized as follows. General features of the study bridges are indicated in the Table.8.1.

### Table.8.1. General features of the Study Bridge

| No | Bridge Name | Route | Bridge Type | Spans (m) & Total length | | Design year | Completion |
|---|---|---|---|---|---|---|---|
| 1 | Colorado River | 1 | Suspension Slab (1-Span) + RC (4-Span) | 15+25+108+25+15 | 204 | 1968 | 1974 -1978 |
| 2 | Aranjuez River | | Continuous Steel Truss (3-Span) | 24+39+24 | 88 | 1944 | 1955 |
| 3 | Abangares River | | Simple Steel Truss (2-Span) | 40+60 | 100 | 1952 | 1953 |
| 4 | Piedras River | | Continuous RC (3-Span) | 17+31+1755 | 55 | 1952 | 1959 |
| 5 | Colorado River | | Continuous RC (4-Span) + Simple Concrete Arch (1-Span) | 5+6+30+6+5 | 52 | 1955 | 1954 |
| 6 | Ahogados River | | Simple Steel Truss (1-Span) + Continuous Steel Girder (2-Span) | 61+2*15 | 92 | 1951 | 1955 |
| 7 | Azufrado River | | Rigid Frame RC (3-Span) | 6+20+6 | 31 | 1953 | |
| 8 | Tempisquito River | | Simple Steel-I Girder (3-Span) | 22+27+22 | 71 | 1952 | 1955 |
| 9 | Volcán River | 2 | Simple RC (2-Span) + Simple Steel Truss (1-Span) | 18+46+12 | 77 | 1957 | 1961 |
| 10 | Ceibo River | | Simple Steel-I Girder (5-Span) | 25+3*31+15 | 132 | 1958 | 1961 |
| 11 | Curré River | | Simple Steel-I Girder (4-Span) | 22+31+31+22 | 105 | 1958 | 1961 |
| 12 | Puerto Nuevo River | | Simple Steel-I Girder (5-Span) | 21+2*22+25+15 | 105 | 1958 | 1961 |
| 13 | Zapote River | | Continuous RC (3-Span) | 17+21+17 | 55 | 1957 | 1961 |
| 14 | Terraba River | | Simple Steel-I Girder (4-Span) + Simple Steel Truss (3-Span) | 4*27+3*76 | 341 | 1956 | 1960 |
| 15 | Caracol River | | Continuous Steel-I Girder (3-Span) | 22+28+22 | 71 | 1957 | 1961 |
| 16 | Nuevo River | | Continuous RC (3-Span) | 17+21+17 | 55 | 1957 | 1961 |
| 17 | Chirripó River | 4 | Continuous PC-Box (3-Span) | 46+83+46 | 176 | 1975 | 1978 |
| 18 | San José River | | Connected PC-I (2-Span) | 20+20 | 41 | 1974 | 1978 |
| 19 | Sarapiquí River | | Gerber Type Steel-I (3-Span) | 22+55+22 | 98 | 1970 | 1978 |
| 20 | Sucio River | 32 | Continuous PC-Box (3-Span) | 55+102+30 | 173 | | |
| 21 | Toro Amarillo River | | Continuous PC-Box (4-Span) | 47+2*83+47 | 260 | 1975 | |
| 22 | Parismina River | | Simple PC-I (3-Span) | 35+35+35 | 106 | 1974 | |
| 23 | Reventazón River | | Continuorus PC-Box (5-Span) | 47+3*83+47 | 341 | 1975 | |
| 24 | Pacuare River | | Simple PC-I (10-Span) | 9*33+17 | 318 | 1972 | |
| 25 | Barbilla River | | Connected PC-I (3-Span) | 33+33+33 | 100 | 1968 | |
| 26 | Chirripó River | | Simple Steel-I (2-Span) + Continuous Steel-I (6-Span) | 16+59+67+2*73+67+59+16 | 432 | 1969 | 1974 -1978 |
| 27 | Cuba River | | Simple PC-I (3-Span) | 3*22 | 69 | 1968 | |
| 28 | Blanco River | | Simple PC-I (3-Span) | 17+22+17 | 29 | 1967 | |
| 29 | Torres River | 218 | Simple PC-I (3-Span) | 30+2*17 | 66 | 1979 | |

## 8.2 Method of Inspections

Prior to the site inspection, the relevant documents and data, e.g. MOPT bridge inventories, drawings, the repair history, traffic volumes, topography map, river information, were collected and reviewed to comprehend the condition of each bridge.

The site inspection for the study bridges was carried out using visual inspection methods. The MOPT bridge engineers joined the Study Team to carry out the inspection for all the bridges and to effectively use the inspection sheets as part of their “On-Job-Training”.

## 8.3 Results of the Inspections

### 1) Superstructure

Damage to the slab was observed on 14 bridges. All the bridges on Route 1 have damage to their deck slabs, whereas the bridges on Route 2 have no severe damage to their deck slabs, even though they were constructed at the same time as the bridges on the Route 1 in the 1960s to 1970s. We observed that the heavy traffic volume is one of the major causes of the damage to the deck slabs on Route 1.

Regarding other parts of the superstructure, the deck frames of the steel truss type bridges are severely damaged. Damage to the connection nodes between the stringer and crossbeam are widely observed. This damage is mostly caused by the lack of rigidity of the frames.

In the case of Bridge Nos.26, 27 and 28 on Route 32, which are located nearby Limon port, the main girders have been displaced by 10 cm along the transverse direction, and the earthquake of 1991 broke their bearings.

We have observed deformation of the main girders for the PC Box girder bridges No.17 and No.20. It is considered that these deformations were predominantly caused by insufficient quality control during construction.

### 2) Substructure

Slope collapses around abutments are observed at almost all bridges. Scouring around foundations at piers or abutments is also observed in some of the bridges. In the case of Bridge No. 16, the scouring of piers has reached such a critical level that the pile foundation is exposed for more than 2 m below the bottom of footings.

### 3) Accessory

Accessories such as expansion joints and railings are damaged due to insufficient maintenance for all of the 29 Study Bridges.

### 4) Anti-seismic Countermeasures

Neither anti-seismic countermeasures for the superstructure nor reinforcement for substructure, such as the enlargement of the overlapped length of girders and the width of bridge seat etc, are applied in Costa Rica.

### 5) Live Load and Condition of Deck Slab

Bridges on Route 1 and Route 2, which were constructed in the 1950s to 60s, and were designed based on the HS15-44 for live load whereas the bridges on other routes were designed using HS20-44. A Study is to be conducted to examine the load carrying capacity against HS20-44+25% of live load.

# Chapter. 9 Selection of 10 Bridges for Rehabilitation, Reinforcement

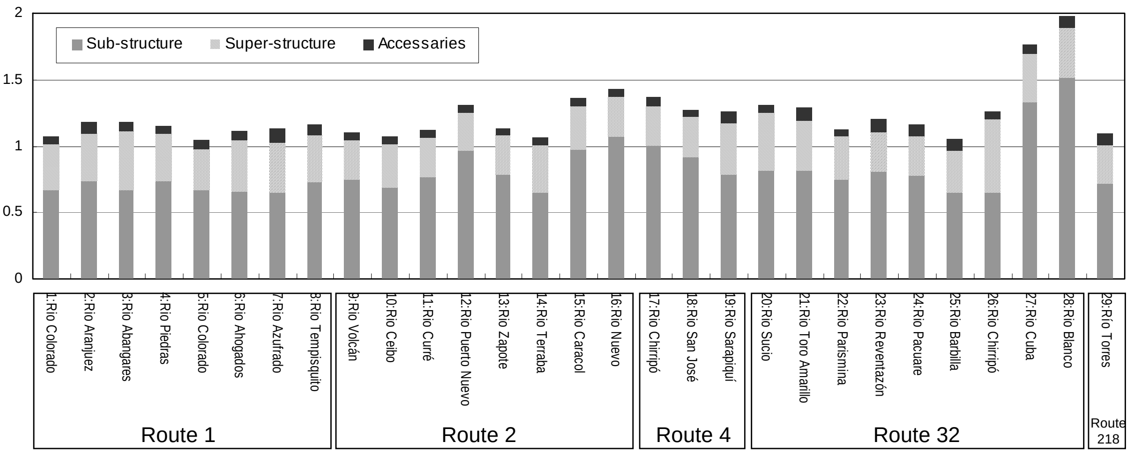
## 9.1 Method of Evaluation of Damage

The damage to bridges was visually inspected and recorded on the inspection sheets, which enable the deterioration of each structural part of the bridge to be precisely indicated.

Selection of the prioritized bridges for rehabilitation are processed and finalized in accordance with the comprehensive deficiency evaluation of bridges. The evaluation criteria consists of the degree of deterioration observed, a weight determined by the functional importance of the structural part as well as a weight determined by how the potential negative impact of the observed damage may affect structural parts of the bridge.

In this Study, the Analytic Hierarchy Process (AHP), a decision support method is to be utilized for the evaluation of bridge deficiency.

Under collaboration between MOPT bridge engineers and the Study team, the weight determined by the structural importance and the weight determined by the potential negative impact were calculated through a procedure based on pair wise comparisons with the AHP, and the evaluation method of the bridge deficiency is formulated. Results of the calculation of deficiency for the 29 bridges are summarized in Figure S.9.1.




Note) Vertical axis: Bridge deficiency index, Larger Value = Severer Deficiency (5.0 in Max.)

**Figure.9.1. Results of the Evaluation of the Bridge Deficiency**

The study excludes from the scope of work the bridges that require reconstruction. Bridges No.27 and No.28, whose substructures are so seriously damaged that reconstruction might be more viable than rehabilitation in terms of cost efficiency, are not selected.

## 9.2 Selection of Ten Bridges for Further Detailed Study

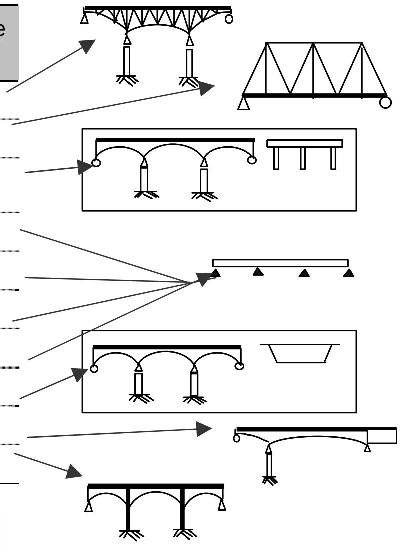
10 bridges for rehabilitation and reinforcement for the study shall be selected not only based on the results of the evaluation of the bridge deficiency, but also considering other points of view, which will indeed be a purpose of the Study, so that outputs of the study are widely applicable and expandable for bridge maintenance in Costa Rica. Through in-depth discussion and thorough examination together with MOPT bridge engineers, the selection was made paying particular attention to the following criteria.

- Different types of rehabilitation or repair method.
- Typical damage to bridges in Costa Rica.
- Locate on high priority roads.
- Different structural types of bridge.
- High priority for the need of repair

The selected 10 bridges are shown in Table.9.1 and Figure S.9.2.

**Table.9.1. Selected 10 Bridges**

| Point of View for Selection | Bridge Code & Name | | Deficiency Rank | Route |
|---|---|---|---|---|
| Superstructure Damage of Deck Slab | 2 | Rio Aranjuez | 14th | 1 |
| | 3 | Rio Abangares | 13th | 1 |
| Substructure Scouring | 16 | Rio Nuevo | 3rd | 2 |
| Anti-seismic Reinforcement | 12 | Rio Puerto Nuevo | 6th | 2 |
| | 19 | Rio Sarapiqui | 11th | 4 |
| | 26 | Rio Chirripo | 10th | 32 |
| | 29 | Rio Torres | 24th | 218 |
| Abnormal Deformation of Main Girder | 17 | Rio Chirripo | 4th | 4 |
| | 20 | Rio Sucio | 7th | 32 |
| Typical bridge | 7 | Rio Azufrado | 19th | 1 |



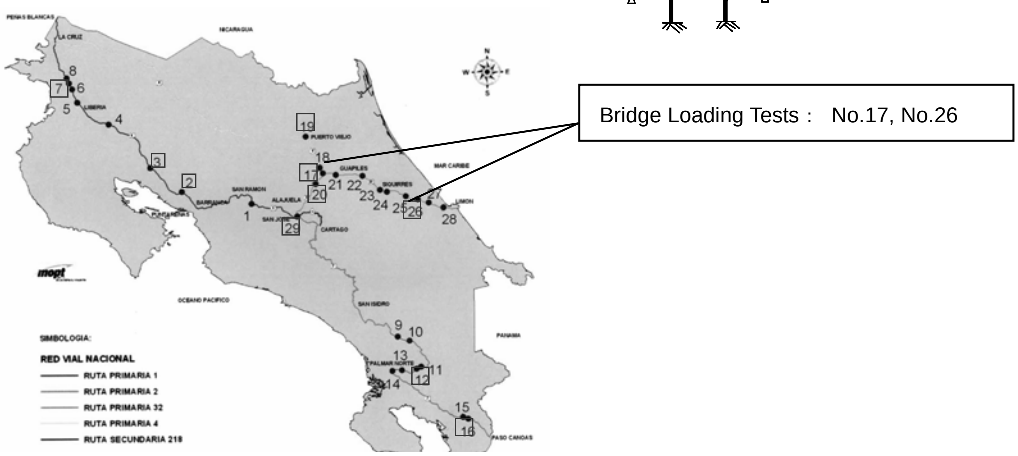



**Figure.9.2. Location of the 10 bridges**

# Chapter. 10 Plan for Rehabilitation, Reinforcement and Improvement of 10 Selected Bridges

## 10.1 Outline of the Plan for Rehabilitation, Reinforcement and Improvement

In general, planning and designing the rehabilitation, reinforcement and improvement for the 10 bridges are conducted in accordance with the results of the detailed inspection. For this particular part of the Study, since it is required to completely re-check and secure both the load carrying capacity satisfying HS20-44+25% and quake-resistance satisfying the local anti-seismic codes, a structural analysis with computed structural models was applied to verify the sectional forces or stresses in each member in order to determine the necessity as well as the specific conditions to reinforce. Thus, a plan for rehabilitation, reinforcement is to be formulated through an evaluation of results from both the detailed design and the structural analysis.

## 10.2 Classification and Predominant Causes of Deficiency/ Deterioration

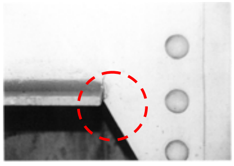
Table.10.1 shows the classification of the predominant examples of deficiency/ deterioration of concrete/ steel member and damage due to natural disasters with photographs and descriptions of the phenomena.

**Table.10.1. Classification of Deterioration**

1) Concrete Member

| Classification | Photograph | Description of Phenomenon |
|---|---|---|
| Crack |  | - Most common deterioration in concrete members<br>- Cracks occur firstly in one direction, and proceed to two directions, in a random pattern, with peeling off and holes |
| Isolated lime |  | - It is the result of a reaction between the lime in the concrete and water entering through cracks |
| Peeling off<br>Steel exposure |  | - Concrete fragments dropping cause danger to third parties beneath the bridge<br>- The phenomenon occur because of a shortage of cross section, shortage of cover, damage due to excessive live load and corrosion of Re-bar |
| Hole(s) |  | - The phenomenon mainly occurs in the deck slab due to over load, repeated load or abnormal live load impact<br>- Sometimes, the causes are defects such as shortage of deck thickness and so on |

2) Steel Member

| Classification | Photograph | Description of Phenomenon |
|---|---|---|
| Corrosion | <br> | - A sweeping corrosion is a phenomenon where the whole surface of the steel member corrodes uniformly<br>- A local corrosion is a phenomenon where a part of the steel member is corroded. This is usually in poor circumstances where drain water flows, water leaks from the expansion joints or through cracks in the deck slab and water is trapped around the configuration of complicated members<br>- A local corrosion often shows as a hole or a groove |
| Fatigue Damage | <br> | - The most influential factor of fatigue is the fluctuation and frequency of repeated stress. In case of steel material, as its strength increases, the fatigue stress also increases , whereas the strength of welding does not increase.<br>- Accordingly, an occurrence of small-scale cracks will not cause the member or the structure to collapse, in addition, by taking appropriate measures in the early stage of cracking, this enables the member or the structure to secure enough of its safety ratio to prevent unstable conditions occurring. |

3) Damage due to Natural Disaster

| Classification | Photograph | Description of Phenomenon |
|---|---|---|
| Damage due to Earthquake |  | - Earthquakes are the most likely natural disaster and cause the most dangerous damage.<br>- The superstructure may fall due to breakage of bearing and lack of seat length<br>- Parts of the substructure and foundations may suffer from damage due to earthquake |
| Scouring |  | - Scouring is an erosion that is the result of water flow washing away the river bed and banks as well as around piers and abutments of bridges.<br>- Scouring comprises "Whole scour" at the bridge and "Local scour" solely at the substructures such as piers or abutments. |

In addition, Table.10.2 shows Causes, Mechanism and Phenomenon of Deficiency/ Deterioration.

## Table.10.2. Causes, Mechanism and Phenomenon of Deterioration

Except disaster and Lack of Maintenance

| Cause of Deterioration | Deterioration mechanism | Phenomenon of deterioration | |
|---|---|---|---|
| | | Concrete member (incl. Re-bar) | Steel member |
| Carbonation | - In the chemical reaction of $CaCO_3$ generated by Ca(OH) and carbonic acid in the atmosphere, $Ca(OH)_2$ in concrete is consumed so that the pH reduces and is neutralized.Neutralization does not affect the concrete material directly but covers the Re-bar in a film so that Re-bar rusts with the risk of being destroyed | | |
| Salt corrosion | - Chloride ion affects steel causing rusting, then it affects the expansion of the bar causing cracks to develop, with separation of the concrete.<br>- Chloride ion is provided by the concrete member itself as a residue of the its production, and also by the marine environment such as in wind from the sea. | Crack<br>↓<br>Isolated Lime<br>↓ | Corrosion |
| Alkali aggregate reaction | - Alkali-silica gel is developed with $Na_2O$ or $K_2O$ in concrete after reaction with some aggregates. It expands easily by absorbing water and then causes cracking. | Peeling off Re-bar Exposure<br>↓ | |
| Faulty workmanship | - The defects are caused by design mistakes or defective quality of construction such as lack of cross section, cover, strength, and complicated member configuration | Hole | Corrosion |
| Increase of live load | - The incremented 25% of HS20-44 is applied for the design live load of bridges on the national highways<br>- The repeated loads and severe impacts due to the increased live loads affect especially the deck slab, steel floor system and steel structure | | Fatigue Damage |

## 10.3 Detailed Inspection

The detailed inspection was jointly conducted by the study team and MOPT bridge engineers based on inspection methods shown in Table.10.3.

**Table.10.3. Detailed Inspection**

| Methods of inspection | | Element of structure | | Purpose of test | Bridges to inspect |
|---|---|---|---|---|---|
| Visual Inspection method | | Superstructure<br>Substructure<br>Accessory | Concrete member | — | 10 selected bridges |
| | | | Steel member | | |
| | | Foundation | Scouring | | |
| Physical method | Concrete core sampling test | Concrete member | | Strength of concrete | Azufrado (No.7)<br>Sarapiqui (No.19)<br>Sucio (No.20) |
| | Schmidt hammer test | | | | 10 selected bridges |
| Chemical method | Phenolphthalein test | | | Carbonation | 10 selected bridges |
| Electrical method | Detection of R-bar | | | Position of R-bar<br>Thickness of cover | 10 selected bridges |
| Ultrasonic measuring method | Measurement of steel plate thickness | Steel member | | Thickness of steel member | Abangares (No.3)<br>Sarapiqui (No.19) |

Note: Concrete Core Sampling from both superstructure and substructure at Azufrado (No.7) as RC, Sucio (No.20) as PC. From substructure at Sarapiqui (No.19) as Steel bridge

Table.10.4 summarizes the results of the visual inspection.

**Table.10.4 Results of Visual Inspection for 10 Bridges**

| Member | Deficiency /Deterioration | R1 | | | R2 | | R4 | | R32 | | R218 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2 | 3 | 7 | 12 | 16 | 17 | 19 | 20 | 26 | 29 |
| | | ST | | RI | SI | RI | PB | SI | PB | SI | PI |
| Deck Slab | Hole | | ○ | | | | | | | | |
| | 2 directional crack | ○ | ○ | ○ | ○ | | | | | ○ | ○ |
| | 1directional crack | | | | | ○ | | | | | |
| Steel Girder | Rising/Peeling of paint | ○ | ○ | N/A | ○ | N/A | N/A | ○ | N/A | ○ | N/A |
| | Corrosion or Rusting | ○ | ○ | N/A | ○ | N/A | N/A | ○ | N/A | ○ | N/A |
| | Crack/Breaking | | ○ | N/A | | N/A | N/A | | N/A | | N/A |
| | Deformation | | | N/A | | N/A | N/A | | N/A | ○ | N/A |
| Concrete Girder | Crack | N/A | N/A | ○ | N/A | ○ | | N/A | | N/A | |
| | Deformation | N/A | N/A | | N/A | | ○ | N/A | ○ | N/A | |

| Member | Deficiency /Deterioration | R1 | | | R2 | | R4 | | R32 | | R218 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2 | 3 | 7 | 12 | 16 | 17 | 19 | 20 | 26 | 29 |
| | | ST | | RI | SI | RI | PB | SI | PB | SI | PI |
| Bearing and Bearing base | Corrosion/Deposit soil Leakage from Exp. joint | O | O | O | O | O | O | O | O | O | O |
| | Breakage of bearing | | | | | | | | | O | |
| Expansion Joint | Breakage | O | O | O | O | O | O | O | O | O | O |
| Railing | Breakage | | | O | | | | | | | |
| Pavement | Increased dead load by 5cm thick of overlay | O | O | O | O | O | O | O | O | O | O |
| Pier | Damage on surface | | | | | | O | | O | | |
| | Scouring of foundation | | | | | O | | | | | |
| Abutment | Collapse of front slope | O | O | O | O | O | O | O | O | O | O |

Note: ST; Steel Truss bridge, RI; RC I-Beam, SI; Steel Deck Girder, PB; PC Box, PI; PC I-Beam

- Cracks on Deck slab appear on most of the bridges and a hole is observed at the Abangares (No.3).
- Cracks appear on the Deck frames at the Abangares (No.3), sectional deficiency appears on the steel girder at the Sarapiqui (No.19) caused by corrosion.
- Cracks appear on the Concrete girder as much as on the Deck slab.
- Piers at the Sucio (No.20) and the Chirripo (No.17) are damaged with boulders. Scouring appears at pier foundation for the Nuevo (No.16).

Throughout the detailed inspections, the strength of concrete by the core sampling test and schmidt hammer test, carbonation by the phenolphthalein test are verified. The position of the reinforcing bar & thickness of concrete cover were inspected in order to both verify the as-built conditions in comparison with the original drawings and to implement core sampling. In addition, the thickness of steel plate was measured in order to verify the properties of the steel members when drawings are unavailable and/or the progress of corrosion. The results are summarized in Table.10.5.

**Table.10.5. Results of the Detailed Inspection with Physical, Chemical, Electrical and Ultrasonic methods**

| Inspection | | R1 | | | R2 | | R4 | | R32 | | R218 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2 | 3 | 7 | 12 | 16 | 17 | 19 | 20 | 26 | 29 |
| Strength of Concrete | Core sampling Test | | | O | | | | O | O | | |
| | Bridge No. 7<br>Bridge No.19<br>Brdige No.20 | Superstructure ; 320 ～ 460 $kg/cm^2$<br>Substructure ; 240 ～ 490 $kg/cm^2$<br>Elastic modulus ; 4.5 ～ 4.7 x $10^5 kg/cm^2$ | | | | | | | | | |
| | Schmidt hammer test (10 bridges) | Superstructure ; 430 ～ 460 $kg/cm^2$<br>Substructure ; 350 ～ 550 $kg/cm^2$ | | | | | | | | | |
| Depth of Carbonation [cm] (10 bridges) | | 2.6～6.0 | | | 0.1～1.0 | | 0.1～1.5 | | 1.4～4.5 | | 0.4 ～ 1.2 |
| Detection of R-bar (10 bridges) | | Position of R-bar mostly accorded with the drawings | | | | | | | | | |
| Thickness of steel plate | | | O | | | | | O | | | |
| Brdige No. 3<br>Bridge No.19 | | Plate thickness was measured as no existing drawings were available for implementing the structural analysis. | | | | | Plate thickness was measured in order to verify the actual state of sectional deficiency caused by corrosion. | | | | |

It is verified that the strength of concrete and the elastic modulus satisfy the design requirements.

It is observed that higher values of carbonation appear at the bridges along Route 1 and 32, which is possibly caused by exhaust fumes when traffic volumes counts are relatively high. It is not at a critical level, however. It is also verified that the placement of reinforcing-bars in the concrete structures was mostly appropriate.

## 10.4 Structural Analysis

In order to verify the load carrying capacity satisfying HS20-44+25% of the live load and the quake-resistance satisfying the local anti-seismic codes, a structural analysis with a computer-aided program "SAP2000" was conducted for the 10 selected bridges.

Increased live load based on HS20-44+25% affects the Superstructure. Although the substructure, including foundations, is not affected by the increase, the results show that reinforcement for improving earthquake-resistance is required. Results of the structural analysis are summarized in Table.10.6.

**Table.10.6. Results of the Structural Analysis**

| Items to be analyzed | Member | | Results |
|---|---|---|---|
| Load Carrying Capacity<br>Live load HS20-44+25%<br>〔Superstructure〕 | Deck Slab | | ・Bridges on Route 1 & 2 exceed the allowable stress by over 20 to60%, since HS15 is applied for the bridge design.<br>・Bridges with HS20 exceed the allowable stress by 20%. |
| | Steel Truss (No.2, 3) | Deck frame | ・Vertical members exceed the allowable stress over by 15 to 40% as much as deck slab, since these are on Route 1. |
| | | Main frame | ・Compressive members on the main frame exceed allowable stress over by 15 to 40%. |
| | Steel I-beam | | ・Girders with HS15 exceed the allowable stress by over 30 to 50%.<br>・No.19 bridge with HS20 exceeds the allowable stress by 45%. |
| | RCI-beam | | ・Girders with HS15 exceed the allowable stress by 10 to 65%. Shearing stress at the supports exceeds the allowable stress by over 20 to 50%. |
| | PC I-beam | | ・Girders of 30m long with HS20 exceed the allowable stress by 20%. Shearing stress of the shorter girders 17m long exceed it by 30%. |
| | PC Box (No.17, 20) | | ・Required capacity is provided. |
| 〔Substructure〕 | Beam on pier | | ・Tensile stress of R-bars exceeds the allowable stress. |
| Quake-resistance<br>〔Substructure〕 | Pier | | ・Tensile stress of R-bars for cylindrical and wall type piers exceeds the allowable stress. |
| | Abutment | | ・Quake-resistance is secured |
| | Foundation | | ・Width of footings is insufficient for the spread foundation.<br>・Width of footings, quantity of R-bars and piles are insufficient for the piled foundation. |

## 10.5 Bridge Loading Test

A Bridge Loading Test was conducted for the concrete girder bridge (No.17 Chirripo on route 4) and the steel deck beam bridge (No.20 Chirripo on route 32). An outline of the tests are described in Table.10.7.

**Table.10.7. Outline of the Bridge Loading Test**

| Name | Bridge Type/Span | Testing Items | Measuring Items | Remarks |
|---|---|---|---|---|
| No.17 Chirripo | PC Box 46+83+46 | Static load test | Deflections of girders | Dump truck 25tonne 4 units |
| No.20 Chirripo | Steel deck beam Simple beam ＋ Continuous beam 16+(59+67+2x73+67+59) | Static load test | Deflections Working stress | Dump truck 25tonne 1 unit |
| | | Stress frequency measuring (estimation of fatigue and residual life) | Working stress and Frequency | Traffic volume survey To verify interrelation between actual traffic volume and stress・frequency |

The measured value from the static loading test gave satisfactory accordance with the analyzed value based on structural models.

Abnormal deflections, which are possibly caused by a deficiency of the construction works, are observed at the center span of the Chrripo bridge (No.17). Results of the static load test state, however, that there are no severe structural problems with the bridge.

Results of the stress frequency test are briefly summarized as follows.

In general, fatigue failure tends to occur at structural members and/or parts where stress concentration and amplitude are largely appeared. In the Study, 4 positions such as connecting part with bearings (see Figure S.10.1), diagonal members and lateral members are selected to set the gauges. Stress frequency was monitored and recorded during 24 consecutive hours. Table.10.2 shows traffic volume per hour on the testing day. White painted of bars indicates a volume of the heavy traffic (5 axles), which causes large amplitude of stress. Traffic volume during 24 hours results 6,230 vehicles/day and 5 axles trucks were counted on 1,996 vehicles/day.

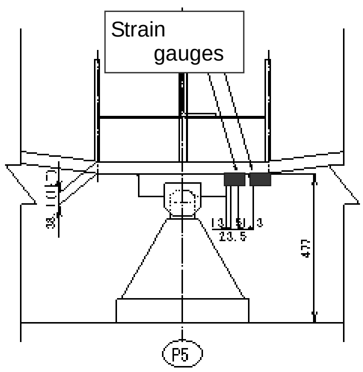



**Figure.10.1. Bearing Connection Strain gauge setting**

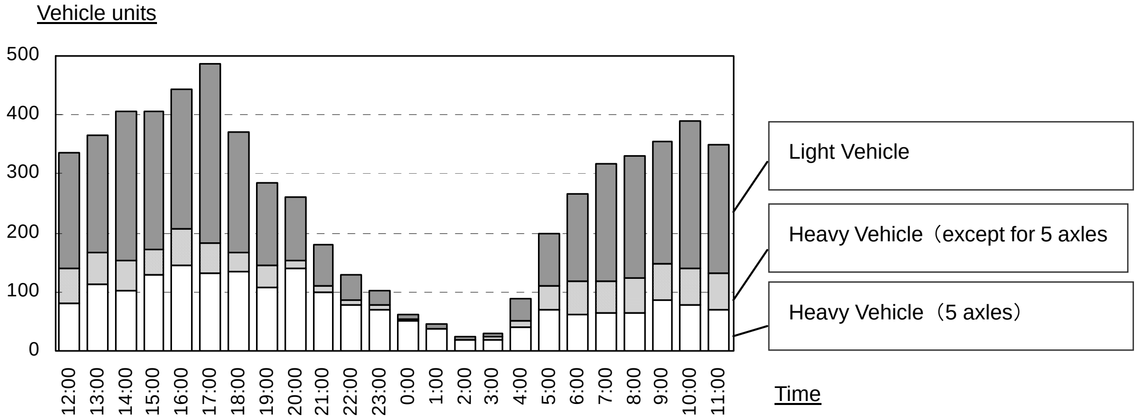



**Figure.10.2. Traffic Volume on the day of testing**

28 years have passed after Chirripo bridge (No.20), which stress frequency was measured, was constructed. On the simulation that the traffic volume keeps increasing with the current rate of growth, the residual life upon the fatigue limit of measured members is trial-calculated based on the accumulated traffic volume and the stress frequency. Figure S.10.3 shows the interrelation between the estimated time for the occurrence of the fatigue failure (residual life) and the accumulated traffic volume. In addition, estimated times per measured members are summarized in Table.10.8.

Results show that fatigue cracks will most likely appear at the connection with the bearing, which is the most critical part, by year 2030. The connections with the diagonal members still possess considerable tolerance. However, it will be essential to keep them monitored throughout the periodical inspections, since accidental errors in measuring and/or assumptions for structural modeling might cause certain variations to the test results.

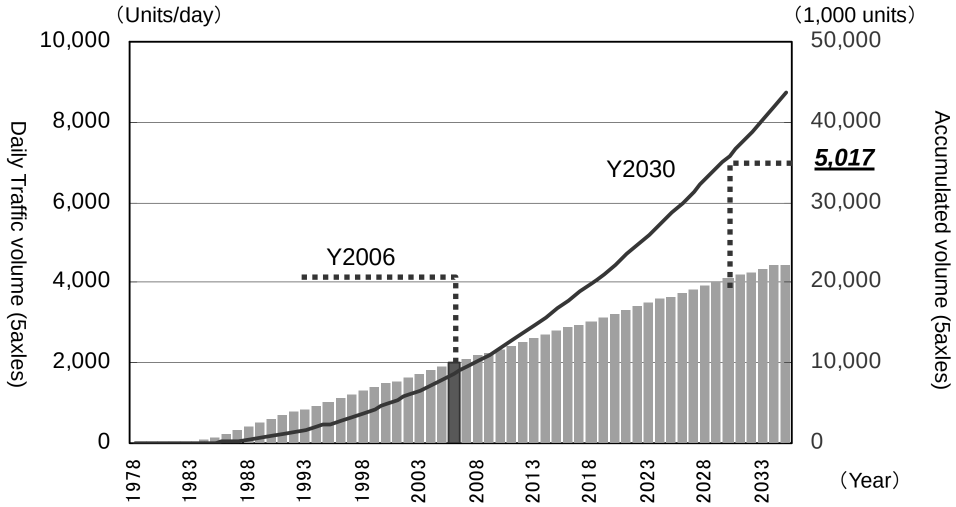



**Figure.10.3. Interrelation between Occurrence of the Fatigue Failure and the Accumulated Traffic Volume**

**Table.10.8. Estimated time of Occurrence of the Fatigue Failure**

| Position/Member | Daily traffic volume (5axle truck) Vp (No.) | Years after completion Yp (year) | Accumulated traffic volume at occurrence of fatigue failure Nf (No.) | Occurrence of fatigue failure | |
|---|---|---|---|---|---|
| | | | | Years after completion Yf (year) | Year |
| Connection with Bearing | 1,996 | 28 | 35 million | 52 | 2030 |
| Connection with diagonal members 1 | | | 107 million | 91 | 2069 |
| Connection with diagonal members 2 | | | 758 million | 241 | 2219 |
| Connection with lateral members | | | 52 million | 63 | 2041 |

MOPT engineers were engaged together with the Study team in planning, implementation and evaluation of the test. Throughout the presentation at the 4th technical seminar, the outline and results of the test were fully disseminated to local engineers by engineers from MOPT.

## 10.6 Natural Condition Survey

The river condition survey for the 29 bridges and the geological survey for the selected 10 bridges were carried out as the natural condition survey in this Study.

The river condition survey was carried out to understand the river flow, erosion and deposit conditions of riverbank and riverbed. This was investigated for 29 Study bridges.

The geological survey including mechanical drillings and laboratory tests was carried out for the selected 10 bridges and 21 boring samples in total were examined in order to comprehend the ground conditions for securing the foundation stability.

## 10.7 Basic Policy for Rehabilitation, Reinforcement and Improvement of 10 Bridges

The Plan for Rehabilitation, Reinforcement and Improvement was developed based on the comprehensive evaluation of the major factors mentioned earlier which comprise bridge deterioration & deficiency from the detailed inspection, load carrying capacity of the superstructure from the structural analysis and quake-resistance of the substructure.

The basic policy is summarized in Table.10.9 for specific structural members.

**Table.10.9. Basic Policy of Plan for Rehabilitation, Reinforcement and Improvement of 10 Selected Bridges**

| Members | | Basic Policy of Plan |
|---|---|---|
| Deck slab (Except for PC Box bridge) | | ・Increment of thickness (top or bottom side), adherence of FRP(top or bottom side), Steel plate adherence(bottom side), Replacement of the deck(pre-cast slab deck). Repair costs increase respectively in order. |
| Floor frame (Truss) | | ・No.2、3 replacement, addition and relocation of frames |
| Main frame (Truss) | | ・Increment of section of the existing members<br>・Decrease of working sectional force by additional members<br>・Reassembling of diagonal members to secure enough road space. |
| Steel I-beam | | ・Increment of section of the existing members<br>・Additional PC cable |
| RC I-beam | | ・Increase of girder height<br>・Adherence of FRP and steel plate |
| PC I-beam | | ・Adherence of FRP |
| Pier | | ・Concrete jacketing |
| Foundation | | ・Spread footing: Increase of width and/or thickness<br>・Piled footing: Increase of width, thickness and piles |
| Accessories | Expansion Joint | ・Replacement for all bridges |
| | Railing | ・Repair of damaged parts, in case of replacing deck slab, railing to be replaced, too. |
| | Pavement | ・5cm thick of overlay after waterproofing to protect deck slab. |

In order to improve the quake-resistance, bridge anti falling down system is to be employed. Specific application for each member of the selected bridges are described in detail in Chapter 11.

# Chapter. 11 Design for Rehabilitation, Reinforcement and Improvement of 10 Selected Bridges

## 11.1 Analysis of the Method for Rehabilitation, Reinforcement and Improvement

### 1) Superstructure

### (1) Deck Slab and Deck Support System

The load capacity of the existing deck slab is insufficient for the live load HA20+25% on all seven bridges except PC box girder bridges (No.17 Chirripo Bridge and No.20 Sucio Bridge) and PC I beam bridge (No.29 Torres Bridge), and deck slab reinforcement is required for these bridges.

The load capacity of the deck slab is insufficient, not only at the center of the span where the positive bending moment occurs, but also at slab support(on the girder) due to the lack of slab haunch thickness. The reinforcement methods are limited to those that can be carried out on the upper side of deck slab at the girder support. However, the steel bonding method on the upper side of deck slab cannot be applied because of a problem with the stability of adhesion of the asphalt paving on the steel plate.

Based on the above conditions, the applicability of the reinforcement methods for the deck slab were evaluated for each bridge type as shown in Table.11.1.

**Table.11.1. Applicability of Reinforcement Method for Deck slab for Each Bridge Type**

| Methods | Steel Bridge | RC I Bridge | PC I Bridge | Characteristics | Cost |
|---|---|---|---|---|---|
| Concrete Thickness Increase on Upper side | ○ | ○ | ○ | Increase of dead load is large. Can be considered as the effective part of main girder for RC I beam bridges. | Low |
| Concrete Thickness Increase on Lower side | × | × | × | Cannot be applied for the negative bending moment at girder support. | - |
| FRP Bonding on Upper and Lower Sides | ○ | ○ | ○ | Increasing of dead load is negligible. Not applicable for a badly damaged slab | Medium |
| Steel Plate Bonding on Upper and Lower Sides | × | × | × | Problem about the stability of adhesion of the asphalt paving on the steel plate. | - |
| Stringer Addition (for Deck support system of Truss Bridge) | ○ | ○ | ○ | Relatively easy to apply for steel bridges. Increase of dead load for RC I beam and PC I beam bridges. | Medium |
| Slab Replacement | ○ | × | ○ | Not applicable for RC I beam bridges, because slab was constructed together with the main girders (composite construction). | High |

The reinforcement methods for the deck slab were analyzed for each bridge type taking into account the structural and site conditions for each bridge. The results of the selection of reinforcement methods for the slab are described below.

Repair works, such as resin injection into cracks, will be carried out on the existing deck slab at the same time as the reinforcement, except where the deck slab replacement method is used.

As the load capacity of the deck support system in two steel truss type bridges (No.2 and

No.3) is also insufficient for the live load HA20+25%, the reinforcement method was selected taking account of the reinforcement for both deck slab and the deck support system at same time.

**Table.11.2. Results of Selection of Reinforcement Method for Deck slab and Deck support system of Steel Truss Bridge**

| Bridge | No.2 Aranjuez, No.3 Abangares | |
|---|---|---|
| Concrete Thickness Increase on Upper side | × | Damage of slab is too large (Hole, 2 directional crack) and exceeds the damage level, which can be reinforced. |
| FRP Bonding on Upper and Lower Sides | × | Ditto |
| Deck support system Improvement | ○ | Replacement and addition of stringer, and reinforcement of cross beam, because of the insufficiency of load capacity of deck support system for live load. |
| Deck slab Replacement | ○ | Replacement with Precast PC deck slab |

The FRP bonding method which does not increase the dead load was applied for the steel I beam bridges taking account of the load capacity of main girder.

**Table.11.3. Results of Selection of Reinforcement Method for Deck slab of Steel I Girder Bridge**

| Bridge | No.12 Puerto Nuevo. No.19 Sarapiqui, No.26 Chirripo | |
|---|---|---|
| Concrete Thickness Increase on Upper side | × | Not applicable, because the increase of dead load is too large and the reinforcement of girder becomes large-scale. |
| FRP Bonding on Upper and Lower Sides | ○ | Applied. Increase of dead load is negligible and does not affect the main girder. The level of construction cost is acceptable |
| Stringer Addition | × | Not applicable, because fixing work on main girder is large-scale. |
| Deck slab Replacement | × | Not applicable due to the high cost |

The method of increasing the concrete thickness on the upper side was selected for the RC I beam bridges where it can be applied. For the bridges where it cannot be applied, due to structural or site conditions, the FRP bonding method was applied.

**Table.11.4. Results of Selection of Reinforcement Method for Deck slab of RC I Girder Bridge**

| Bridge | No.7 Azufrado, No.16 Nuevo | | No.12 Puerto Nuevo | |
|---|---|---|---|---|
| Concrete Thickness Increase on Upper side | ○ | Applied. Effective as the reinforcement of main girder | × | Not applicable due to the occurrence of the slab height gap with the steel girder section next to this girder. |
| FRP Bonding on Upper and Lower Sides | × | No need to be applied. Cost is a little higher. | ○ | Applied. Cost is a little higher, but no structural problems. |
| Stringer Addition | × | Not applicable, because fixing work on main girder is large-scale. | × | Not applicable, because fixing work on main girder is large-scale. |

## (2) Main Girder

The applicability of the expected reinforcement methods for the main girder was evaluated for each bridge type as shown in Table.11.5.

**Table.11.5. Applicability of Reinforcement Method for Main Girder for Each Bridge Type**

| Reinforcement Method | Steel Truss Bridge | Steel I Girder Bridge | RC I Girder Bridge | PC I Girder Bridge | Characteristics | Cost |
|---|---|---|---|---|---|---|
| Member Section Increase | ○ | ○ | ○ | × | Can reinforce for bending moment, but not effective for shear force in RC I beam bridges. | Low |
| FRP Bonding | × | × | ○ | ○ | Increase of dead load can be ignored. | Medium |
| Steel Plate Bonding | × | × | ○ | ○ | Increase of dead load is small. | Medium |
| Member Addition | ○ | × | × | × | Applicable only for truss bridges | Medium |
| External Cable Addition | ○ | ○ | ○ | ○ | Material cost is high, but construction work is relatively easy | High |

The reinforcement methods for the main girder were analyzed for each bridge type taking account of the structural characteristics and site conditions for each bridge. The results of the selection of girder reinforcement methods for steel truss bridges are as shown in Table.11.6.

**Table.11.6. Results of Selection of Reinforcement Method for Main Frame of Steel Truss Bridge**

| Bridge | No.2 Aranjuez（Refer to Table.11.16） | | No.3 Abangares (Refer to Table.11.17) | |
|---|---|---|---|---|
| Main Frame | Load Capacity of bottom chord, vertical member and diagonal near intermediatesupports are insufficient | | Load capacity of bottom chord of short span 2 truss bridges is insufficient | |
| Member Section Increase | × | Not applicable. Required reinforcement exceeds the level that can be reinforced by increasing member section. | ○ | Applied. Can be reinforced by fixing cover plate (steel Plate) to member section. |
| Member Addition | ○ | Applied. By the addition of diagonal member for whole span, the stresses of above-mentioned member can be reduced within their allowable stress. | × | Not required |
| External Cable Addition | × | Cannot be applied due to structural type | × | Not required |

The main girders of two steel I beam bridges (No.12, No.19) will be reinforced by the external cable method. The areas where the steel plate thickness has decreased due to corrosion in the main girder of No.16 Bridge will be repaired.

**Table.11.7. Results of Selection of Reinforcement Method for Main Girder of Steel I Beam Bridge**

| Bridge | No.12 Puerto Nuevo | | No.19 Sarapiqui | No.26 Chirripo |
|---|---|---|---|---|
| Main Girder | Insufficient load capacity | | | Enough capacity |
| Member Section Increase | × | Not applicable. Required reinforcement exceeds the level, which can be reinforced by increasing member section. | | - |
| External Cable Addition | ○ | Costly, but only applicable method. | | - |
| Remarks | - | | -Thickness of steel plate at some parts of main girder, decreased due to corrosion. These parts will be repaired by the addition of new steel plate.<br>-To change the Gerber hinge, which is a structural weak point in a continuous bridge, it will be reinforced by steel plate. | - |

The concrete thickness increase method on the upper side of the deck slab has been selected for reinforcing the deck slab of RC I beam bridges (No.7, No.16) as shown in Table.11.4. The increased slab section can be regarded as a part of the main girder. Therefore, the reinforcement methods for the girder of these bridges were analyzed taking account of the increased slab section.

### Table.11.8. Results of Selection of Reinforcement Method for Main Girder of RC I Beam Bridge

| Bridge | | No.7 Azufrado | | No.12 Puerto Nuevo | | No.16 Nuevo | |
|---|---|---|---|---|---|---|---|
| Main Girder | Bending Moment | After consideration of Slab Increase<br>Insufficient Capacity<br>- at center of center span<br>- near intermediate pier | | Insufficient Capacity at center of center span | | After consideration of Slab Increase<br>Insufficient Capacity<br>at center of side spans | |
| | Shear Force | Insufficient Capacity near intermediate pier | | Insufficient Capacity near end of beam | | Insufficient Capacity near intermediate pier | |
| Member Section Increase | | ○ | Applied. Enforcing capacity for bending moment by increasing girder section. | × | Not applicable, because enforcing capacity works for bending moment becomes large-scale. | × | Same as Puerto Nuevo |
| FRP Bonding | | × | Not applicable, because number of required FRP sheets exceeds 10, which is the maximum number allowed in the Standard. | × | Same as Azufrado | ○ | Enforcing capacity for bending moment at center of side spans by FRP bonding on bottom of girder.<br>Enforcing capacity for shear force near intermediate pier by FRP bonding on both sides of web . |
| Steel Plate Bonding | | ○ | Applied.<br>Enforcing capacity for bending moment at center of center span by steel plate bonding on bottom of girder.<br>Enforcing capacity for shear force near intermediate pier by steel plate bonding on both sides of web. | ○ | Applied.<br>Enforcing capacity for bending moment at center of girder by steel plate bonding on bottom of girder.<br>Enforcing capacity for shear force near both ends of girder by steel plate bonding on both sides of web. | × | Not applied<br>FRP bonding is easier for works than this method. |
| External Cable Addition | | × | Not necessary | × | Not necessary | × | Not necessary |

PC I beam bridge No. 29 consists of one simple beam with a length of 30m and two simple beams with a length of 17 m. The short beam has enough load capacity for the bending moment, but not for the shear force. The reinforcement method was selected as shown in the Table below.

### Table.11.9. Results of Selection of Reinforcement Method for Main Girder of PC I Beam Bridge

| Bridge | | No.29 Torres | |
|---|---|---|---|
| Main Beam | Bending Moment | Insufficient Capacity (at center of beam with length of 30 m) | |
| | Shear Force | Insufficient Capacity (Near both ends of beams with length of 30 m and 17 m) | |
| FRP Bonding | | ○ | Applied |
| Steel Plate Bonding | | × | Not applicable<br>Anchor bolts are required for the steel plate bonding. It is impossible to make holes for anchor safely, because the location of PC wires in beam cannot be confirmed. |
| External Cable Addition | | × | Not required |

## 2) Substructure

The reinforcement of the pier beam is required due to the increased design live and dead loads of the superstructure for its reinforcement. Reinforcement of the column or wall of the pier is required due to the increased dead load of the superstructure and the application of anti-seismic design for some of bridges

### (1) Beam on Pier

The piers requiring beam reinforcement are the column type pier. The applicability of the reinforcement methods for beams was evaluated as shown in Table.11.10. As a result of the analysis of the reinforcement method for insufficient load capacity for both bending moment and shear stress, the member section increase method, which is the most economical, can be applied for all beams.

**Table.11.10. Results of Selection of Reinforcement Method for Beam of Pier**

| Reinforcement Method | Member Section Increase | FRP Bonding | Steel Plate Bonding | Prestress Introduction |
|---|---|---|---|---|
| Reinforcement for Bending Moment | Can be increased on both sides of beam (Longitudinal direction of the bridge). | Impossible to bond FRP sheet on the upper side of beam due to the existence of bearing support or superstructure. | Impossible to bond steel plate on the upper side due to the same reason as FRP bonding | Introducing prestress by increasing the section on both sides of beam. (Longitudinal direction of bridge) |
| Reinforcement for Shear Force | Possible by increasing the section on both sides of beam | Possible by bonding FRP on both sides of beam | Possible by bonding steel plate on both sides of beam | Impossible |
| Cost | Low | Medium | Medium | High |
| Evaluation | ○ | × | × | × |

## 3) Pier Column and Wall

The applicability of the reinforcement methods for pier column and wall was evaluated as shown in Table.11.11. The concrete jacketing method was selected due to its cost and benefit for maintenance.

**Table.11.11. Results of Selection of Reinforcement Method for Pier Column and Wall**

| Reinforcement Method | Member Section Increase | Steel Plate Bonding | FRP Bonding |
|---|---|---|---|
| Applicability for Piers in River | Applicable | Sectional loss due to corrosion Required for anticorrosion measurements | Not applicable. Could be damaged by drift rocks. Costly for Repairing damage |
| Disturbance for Cross-sectional Area of River Flow | Little Disturbance | No Disturbance | No Disturbance |
| Cost | Low | Medium | High |
| Evaluation | ○ | △ | × |

The piers of bridges No.17 and No.20, have enough load capacity, but are damaged by drift rocks in the river. Concrete jacketing protection works will be constructed around these piers where the river flow affects the pier.

### 4) Foundation

The increase of the design live load does not affect the stability of the foundations. However, the foundations of all bridges except No.20 Bridge are required to be reinforced against the increased dead load of the superstructure and/or substructure, and also against the application of seismic loads in the present design standards.

#### (1) Spread Foundation

Inadequate stability of the foundations and load capacity of the footings were found at 6 of the 7 bridges having spread foundations. The stability of foundation was achieved by widening the footing width in concrete, and the load capacity of the footing was achieved by increasing the depth of footing.

#### (2) Pile Foundation

The load capacity of the piles was found to be insufficient at 2 of the 3 bridges having pile foundations and there was insufficient load capacity of the footings at all 3 bridges.

The reinforcement method for the pile foundations with insufficient load capacity of piles is to add more of the same type of piles as existing ones. The pile foundation of P1 Pier at No.19 Sarapiqui Bridge will be reinforced by increasing the H-shape steel piles and by increasing the depth of footing.

In the existing structure of No.16 Nuevo Bridge, the superstructure is fixed at P1 Pier for the longitudinal movement, and the pier requires additional piles to overcome the insufficient load capacity. However, the clearance under the beam is insufficient for pile addition, therefore, the fixing point will be changed to A1 Abutment, where the reinforcement works can be carried out, as shown in Table.11.12

**Table.11.12. Results of Selection of Reinforcement Method for Pile Foundation of No.16 Nuevo Bridge.**

| Longitudinal Fixing Condition | Fixed at P1 Pier the same as Existing Condition | | | Change Fixing Point to A1 Abutment | |
|---|---|---|---|---|---|
| Purpose | As not changing fixing condition, to Increase the load capacity of P1 Pier. | | | To reduce the load acting on P1Pier, the possibility of reinforcement works of footing of A1 Abutment | |
| Pile Type | RC Driven pile (same as existing) | H-shape steel pile | Cast-in-place Concrete Pile | RC Driven pile (same as existing) | Cast-in-place Concrete Pile |
| Widening of Footing | Small | Large | Large | Large | Medium |
| Evaluation | Impossible to drive piles under existing beams | Requires special machine to drive piles under existing beams. Costly | Requires special machine to make piles under existing beams. Costly | Does not require works under existing beams | Not require works under existing beams |
| | × | × | × | △ | ○ Applied |

In addition, all the footings of the bridges with pile foundations have insufficient load capacity, and will be reinforced by increasing the footing depth on the upper side.

### 5) Prevention System for Bridge Collapse

As there is no prevention system for the collapse of the superstructure during earthquakes in Costa Rica, countermeasures for bridge collapse are planned for all bridges and the prevention systems for bridge collapse were applied as shown in Table.11.13.

**Table.11.13. Selected Prevention System for Bridge Collapse**

| Prevention System for Bridge Collapse | Structural Type |
|---|---|
| Securing of Bridge Seat Length | Widening of bridge seats on abutments and piers |
| Anti-seismtic Girder Connection | Connection with chain system between superstructure and substructure (for steel bridge) |
| Limitation System for Girder Movement | Setting concrete block to limit the girder movement on abutment and pier (for concrete bridge) |

### 6) Paving and Bridge Accessory

#### (1) Paving

The half inch on top of the concrete deck slab is considered as the pavement on most bridges in Costa Rica. However, when a crack occurs in the deck slab, water will penetrate into the crack and will accelerate the deterioration of the concrete deck.

Therefore, it was planned that during the deck slab reinforcement, waterproofing on top of deck slab and asphalt paving will be carried out to prevent deterioration of the deck slab.

#### (2) Bridge Accessory

Bridge accessories include bearing supports, expansion joints, railings etc.. Damaged or parts that have deteriorated will be repaired. As damaged expansion joints especially affect the safety and drivability of passing vehicles, the buffering impact on the deck slab, and the progress of deterioration of the bearing support due to water leaking from expansion joint, it was planned that all expansion joints will be replaced with new ones.

#### (3) Protection Works for Riverbed and Slope

Gabion mat riverbed protection works will be carried out around piers located in the river, where scouring was observed. Concrete riprap slope protection works will be carried out on slopes where a collapse/slip was observed in front of the abutment.

## 11.2 Design for Rehabilitation, Reinforcement and Improvement of 10 Selected Bridges

The rehabilitation, reinforcement and improvement methods for the 10 selected bridges are summarized in Table.11.14. The summaries of repair and reinforcement design for each bridge are as shown in Table.11.16 to 11.25.

**Table.11.14 Summary of Rehabilitation, Reinforcement and Improvement Method for Superstructures of 10 Selected Bridges**

(Methods marked with ○ will be applied)

| Member | Repair and Reinforcement Methods | R1 | | | R2 | | | R4 | | R32 | | R216 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2 | 3 | 7 | 12 | | 16 | 17 | 19 | 20 | 26 | 29 |
| | | ST | ST | RI | SI | RI | RI | PB | SI | PB | SI | PI |
| Deck slab | Concrete Thickness Increase on Upper side | | | ○ | | | ○ | | | | | |
| | FRP Bonding on | | | | ○ | ○ | | | ○ | | ○ | |
| | Replacement (PC Panel) | ○ | ○ | | | | | | | | | |
| Deck support system and Main Girder of Steel Bridge | Slab Replacement | ○ | ○ | N/A | | N/A | N/A | N/A | | N/A | | N/A |
| | Member Section Increase | | ○ | N/A | | N/A | N/A | N/A | ○ | N/A | | N/A |
| | Member Addition | ○ | | N/A | | N/A | N/A | N/A | | N/A | | N/A |
| | Steel Plate Replacement | | | N/A | | N/A | N/A | N/A | ○ | N/A | | N/A |
| | External Cable Addition | | | N/A | ○ | N/A | N/A | N/A | ○ | N/A | | N/A |
| Main Girder of RC, PC bridges | External Cable Addition | N/A | N/A | ○ | N/A | | | | N/A | | N/A | |
| | FRP Bonding | N/A | N/A | | N/A | | ○ | | N/A | | N/A | ○ |
| | Steel Plate Bonding | N/A | N/A | ○ | N/A | ○ | | | N/A | | N/A | |
| Bridge Accessory | Replacement of Expansion Joint | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| | Bearing Support Repair | | | | | | ○ | | | | ○ | |
| | Railing Replacement | ○ | ○ | | | | | | | | | |
| Paving | Asphalt Paving | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| | Waterproofing | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |

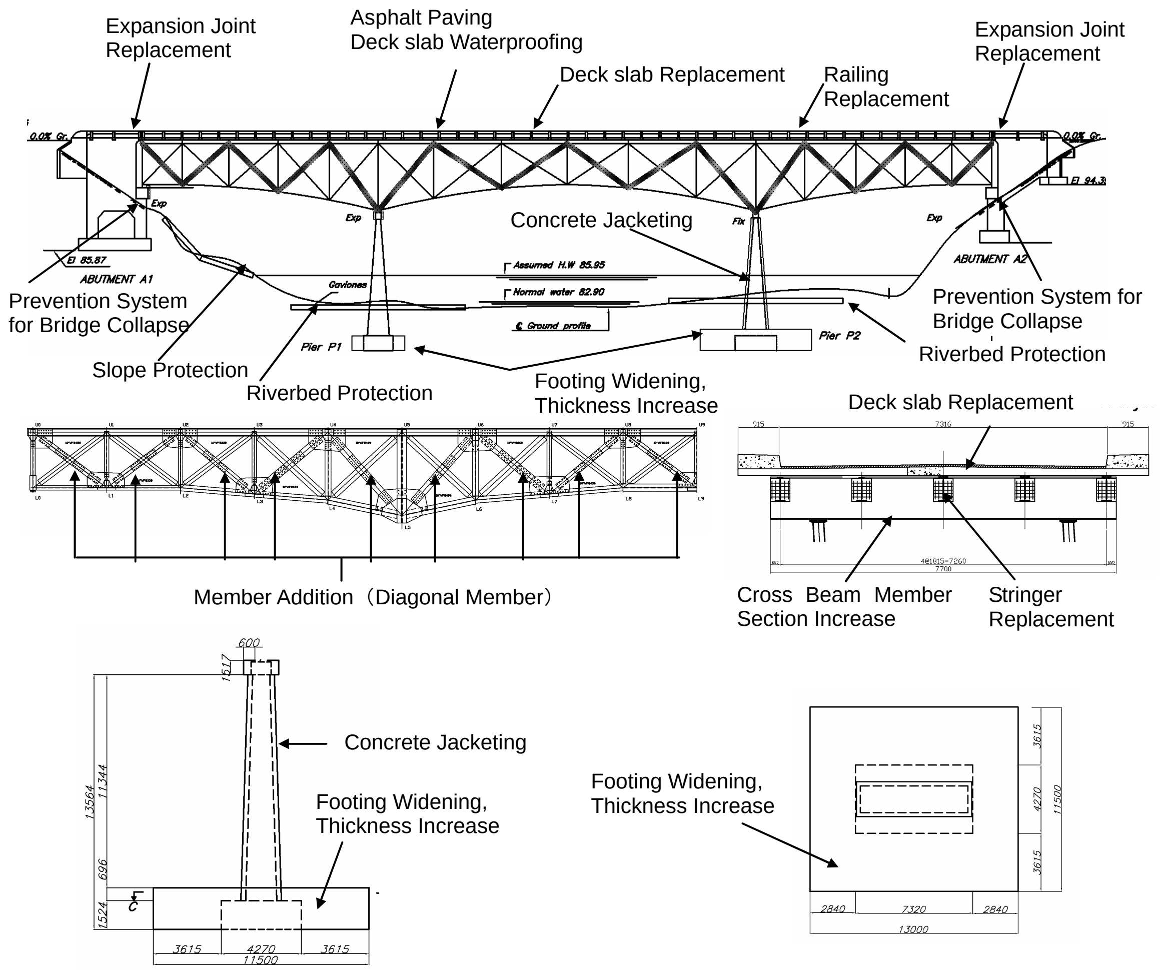
**Table.11.15 Summary of Rehabilitation, Reinforcement and Improvement Method for Substructures of 10 Selected Bridges**

(Methods marked with ○ will be applied)

| Member | Repair and Reinforcement Methods | R1 | | | R2 | | R4 | | R32 | | R216 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2 | 3 | 7 | 12 | 16 | 17 | 19 | 20 | 26 | 29 |
| | | ST | ST | RI | SI,RI | RI | PB | SI | PB | SI | PI |
| Substructure | Beam Section Increase | | | | ○ | | | ○ | | ○ | ○ |
| | Concrete Jacketing | ○ | ○ | ○ | | ○ | | | | | ○ |
| | Pier Protection | | | | | | ○ | | ○ | | |
| Foundation | Footing Widening | ○ | ○ | ○ | ○ | ○ | ○ | ○ | | ○ | ○ |
| | Pile Addition | N/A | N/A | N/A | N/A | ○ | N/A | ○ | N/A | | N/A |
| Prevention System for Bridge Collapse | Securing of Bridge Seat Length, Limitation System for Girder Movement | ○ | ○ | | ○ | ○ | | ○ | | ○ | ○ |
| | Anti-seismic Girder Connection | | ○ | | ○ | | | ○ | | ○ | |
| Protection Work | Slope Protection (Riprap) | ○ | | | ○ | ○ | | | | | |
| | Riverbed Protection (Gabion Mat) | ○ | ○ | | ○ | ○ | | | | ○ | ○ |

## Table.11.16 Summary of Repair and Reinforcement Design for No.2 Aranjuez Bridge

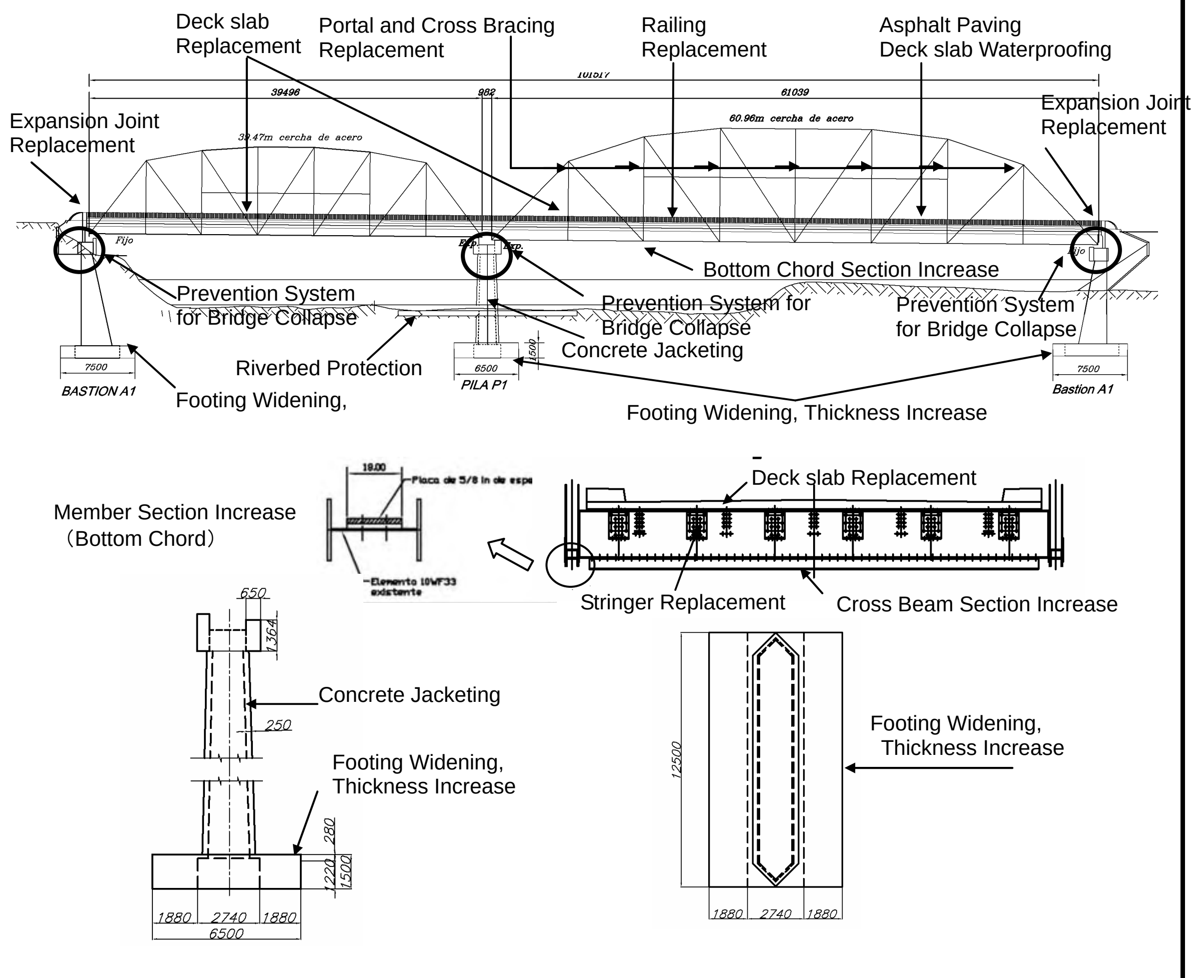
| | | | | |
|---|---|---|---|---|
| Bridge Name: | Rio Aranjuez | Route | National Road Route 1 | |
| Bridge Type: | 3 Span Continuous Steel Truss Bridge | | | |
| Bridge Length: | 87.780m | Spans | 24.40 + 39.01 + 24.40 m | |
| | A1Abutment | P1Pier | P2Pier | A2Abutment |
| Substructure Type | Rigid Frame | Wall | Wall | Rigid Frame |
| Foundation Type | Spread | Spread | Spread | Spread |
| Design Live Load: | HS15-S12 | | | |




| | | | |
|---|---|---|---|
| Super-structure | Deck slab | Replacement (Precast PC Panel) | |
| | Deck support system | Stringer: Replacement　　Cross Beam: Member Section Increase | |
| | Main Structure | Diagonal Member: Member Addition | |
| Sub-structure | Bridge Seat | Prevention System for Bridge Collapse: A1,A2 | |
| | Column | Concrete Jacketing:P2 (1.66 x 6.71 m →2.16 x 7.21 m) | |
| Foundation | Footing | Widening, Thickness Increase | P1 (3.05 x 7.32 x 1.52 m → 5.50 x 9.00 x 1.52m)<br>P2 (4.27 x 7.32 x 1.52 m → 11.50 x 13.00 x 2.20m) |
| Accessory | Expansion Joint | Replacement: A1, A2 | |
| | Railing | Replacement: Steel Railing (Whole Length) | |
| Paving | | Asphalt Paving: t=5cm, Waterproofing: Deck slab (Whole Area) | |
| Protection | | Slope Protection: Riprap（A1） | |
| | | Riverbed Protection: Gabion Mat (A1, P1, P2) | |

## Table.11.17 Summary of Repair and Reinforcement Design for No.3 Abangares Bridge

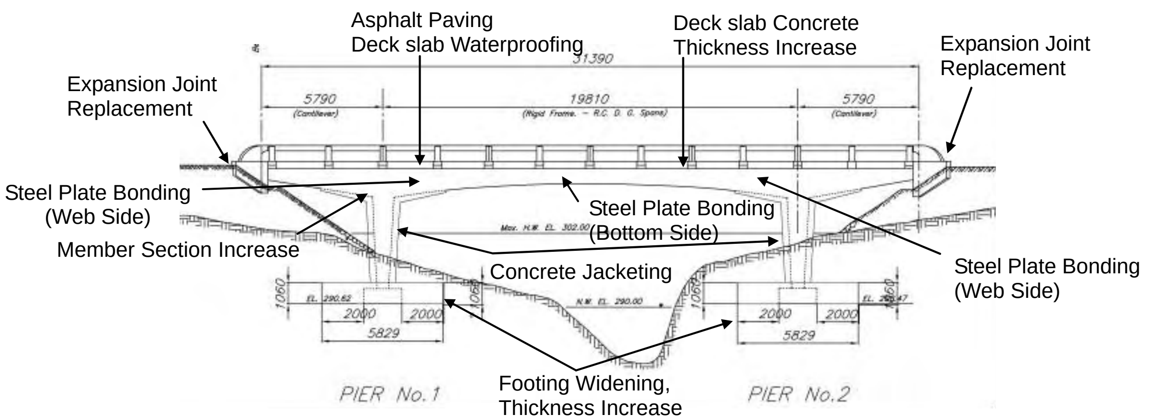
| | | | | |
|---|---|---|---|---|
| Bridge Name: | Rio Abangares | | Route: | National Road Route 1 |
| Bridge Type: | Simple Steel Truss x 2 Spans | | | |
| Bridge Length:: | 101.517 m | | Spans: | 39.496 + 61.039 m |
| | A1Abutment | P1Pier | A2Abutment | |
| Substructure Type | Rigid Frame | Wall | Rigid Frame | |
| Foundation Type | Spread | Spread | Spread | |
| Design Live Load: | HS15-S12 | | | |

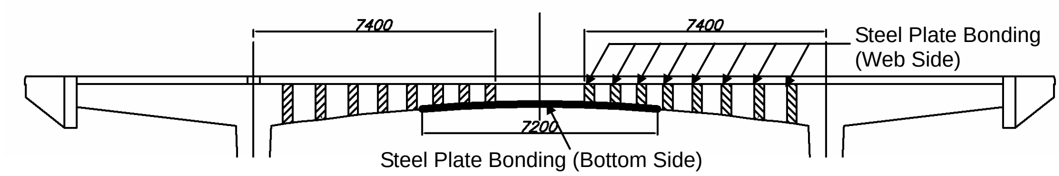


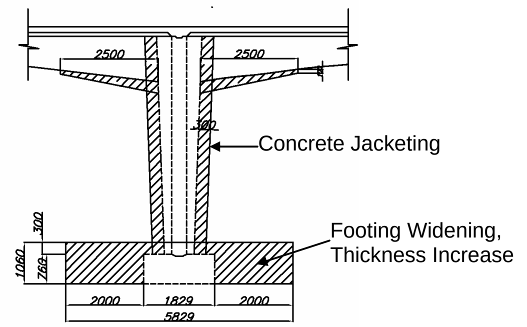

| | | | |
|---|---|---|---|
| Super-structure | Deck slab | Replacement (Precast PC Panel) | |
| | Deck support system | Stringer: Replacement Cross Beam: Member Section Increase | |
| | Main Structure | Bottom Chord: Member Section Increase (Cover Plate)<br>Portal Bracing: Replacement | |
| Substructure | Bridge Seat | Prevention System for Bridge Collapse:A1,P2,A2 | |
| | Column | Concrete Jacketing:P1 (1.75 x 5.98 m →2.25 x 6.48 m) | |
| Foundation | Footing | Widening, Thickness Increase: | A1 (4.57 x 2.59 x 0.91 m → 7.50 x 4.50 x 0.91 m)<br>P1 (2.74 x 12.50 x 1.22 m → 6.50 x 12.50 x 1.50 m)<br>A2 (5.49 x 3.05 x 1.22 m → 7.50 x 5.00 x 1.22 mm) |
| Accessory | Prevention System for Bridge Collapse | Anti-seismic Girder Connection: Chain Type | |
| | Expansion Joint | Replacement: A1,P1, A2 | |
| | Railing | Replacement: Steel Railing (Whole Length) | |
| Paving | | Asphalt Paving: t=5cm, Waterproofing: Deck slab (Whole Area) | |
| Protection | | Riverbed Protection: Gabion Mat (P1) | |

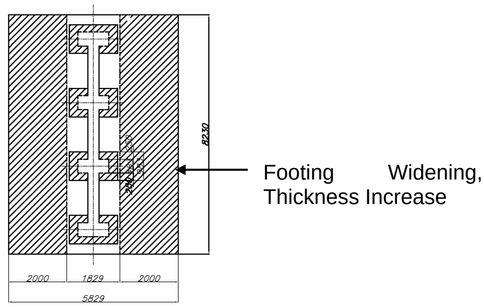
## Table.11.18 Summary of Repair and Reinforcement Design for No.7 Azufrado Bridge

| | | | |
|---|---|---|---|
| Bridge Name: | Rio Azufrado | Route | National Road Route 1 |
| Bridge Type: | 3 Span Continuous Rigid Frame RC I Girder | | |
| Bridge Length:: | 31.390 m | Spans | 5.790 + 19.810 + 5.790 m |
| | P1Pier | P2Pier | |
| Substructure Type | Wall | Wall | |
| Foundation Type | Spread | Spread | |
| Design Live Load: | HS15-S12 | | |



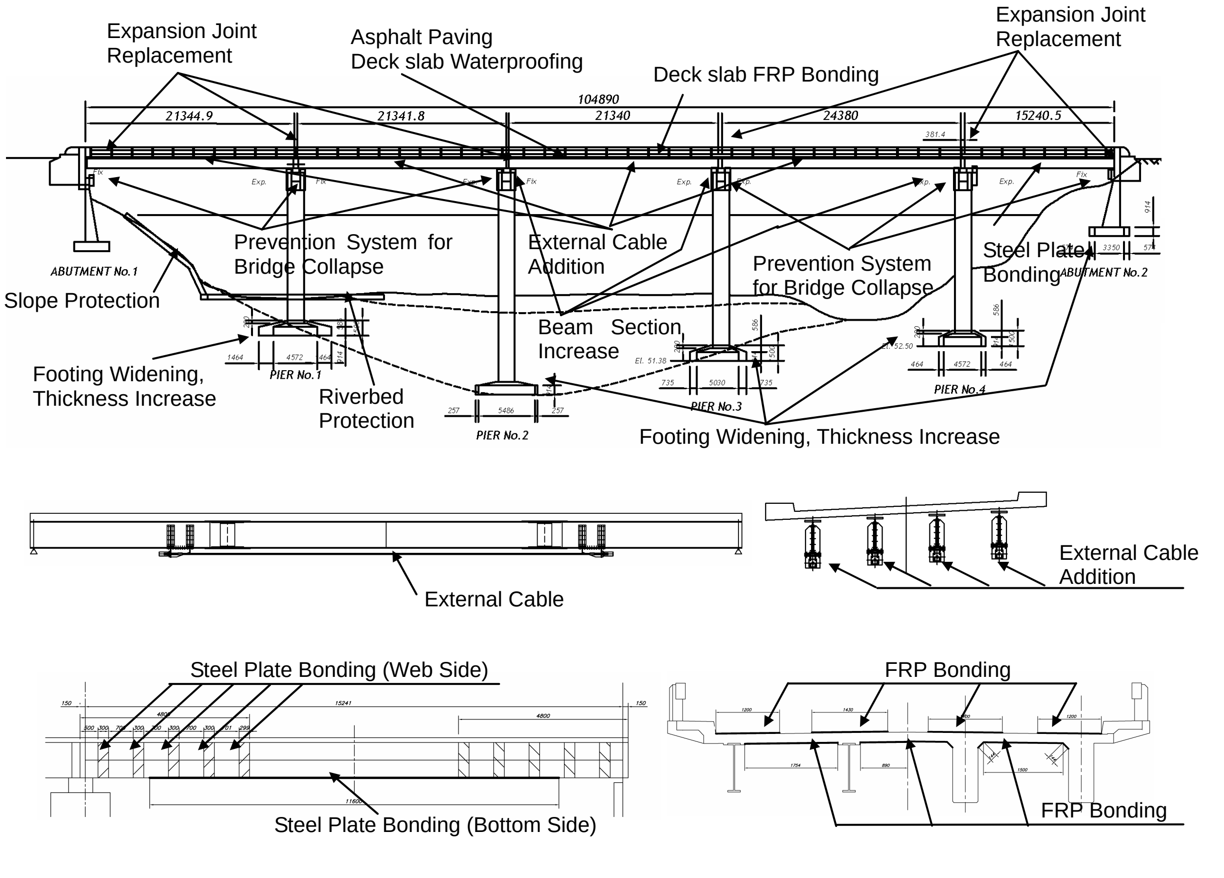




| | | | |
|---|---|---|---|
| Super-structure | Deck slab | Deck slab: Concrete Thickness Increase on Upper Side (9cm) | |
| | Main Girder | Bending Moment :Member Section Increase (30cm,Near Middle Pier :5.4mArea)<br>Steel Plate Bonding (b=40cm,t=9.5mm,<br>Center of Center Span: 7.20m)<br>Shear Force :Steel Plate Bonding(b=30cm,t=6.4mm,<br>Center Span Side near Pier 4.90m) | |
| Sub-structure | Column | Concrete Jacketing: P1,P2 (1.67 x 0.48 m x 4 →1.83 x 0.98 m x 4) | |
| Foundation | Footing | Widening,<br>Thickness Increase: | P1, P2 (1.83 x 8.23 x 0.76 m → 5.83 x 8.23 x 1.06 m) |
| Accessory | Expansion Joint | Replacement: A1, A2 | |
| Paving | | Asphalt Paving: t=5cm, Waterproofing: Deck slab (Whole Area) | |

# Table.11.19 Summary of Repair and Reinforcement Design for No.12 Puerto Nuevo Bridge

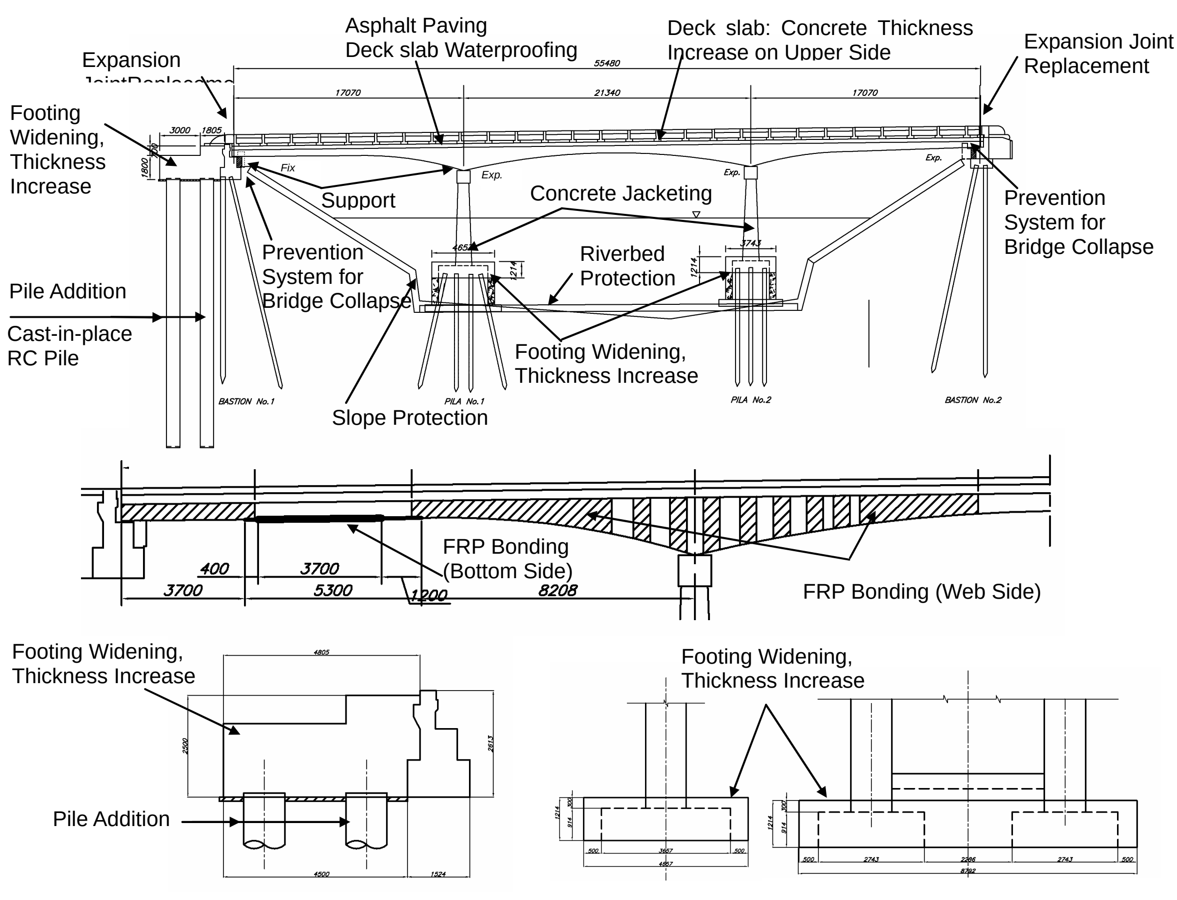
| | | | | | | |
|---|---|---|---|---|---|---|
| Bridge Name: | Rio Puerto Nuevo | | Route | National Road Route2 | | |
| Bridge Type: | Simple Steel I Beam x 4 Spans + Simple RC I Beam | | | | | |
| Bridge Length: | 104.890 m | Spans: 21.34 x 3 + 24.38 + 15.240 m | | | | |
| | A1Abutment | P1Pier | P2Pier | P3Pier | P4Pier | A2Abutment |
| Substructure Type | Rigid Frame | Column with Beam | Column with Beam | Column with Beam | Column with Beam | Rigid Frame |
| Foundation Type | Spread | Spread | Spread | Spread | Spread | Spread |
| Design Live Load: | HS15-S12 | | | | | |




| | | | | |
|---|---|---|---|---|
| Super-structure | Deck slab | | FRP Bonding: (Upper and Lower sides, 2 layers each) | |
| | Main Beam | Steel I Beam | External Cable Addition: (70ft Beam; 1500kNx2+ 570kNx2, 80ftBeam; 940kNx2 +740kNx2) | |
| | | RC I Beam | Bending Moment: Steel Plate Bonding（b=40cm ,t=9.5mm, Center 11.6m）, Shear Force: Steel Plate Bonding（b=40cm, t=6.4mm, Area 4.8m from edge） | |
| Sub-structure | Bridge Seat | | Prevention System for Bridge Collapse:A1,P1,P2,P3,P4,A2 | |
| | Pier Beam | | Beam Section Increase: P2,P3,P4 (0.91 x 1.83 m →1.96 x 1.83 m) | |
| Foundation | Footing | | Widening, Thickness Increase | P1 (4.57 x 4.57 x 1.22 m → 7.50 x 7.50 x 1.50 m)<br>P2 (5.49 x 5.49 x 1.50 m → 6.00 x 6.00 x 1.50 m)<br>P3 (5.03 x 5.03 x 1.22 m → 6.50 x 6.50 x 1.50 m)<br>P4 (4.57 x 4.57 x 1.22 m → 5.50 x 5.50 x 1.50 m)<br>A2 (3.35 x 2.44 x 0.91 m → 0.45 x 2.50 x 0.91 m) |
| Accessory | Prevention System for Bridge Collapse | | Anti-seismic Girder Connection: Chain Type (A1, P1, P2, P3, P4, A2) | |
| | Expansion Joint | | Replacement : A1, P1, P2, P3, P4, A2 | |
| Paving | | | Asphalt Paving: t=5cm, Waterproofing: Deck slab (Whole Area) | |
| Protection | | | Slope Protection: Riprap（A1） | |
| | | | Riverbed Protection: Gabion Mat (P1) | |

## Table.11.20 Summary of Repair and Reinforcement Design for No.16 Nuevo Bridge

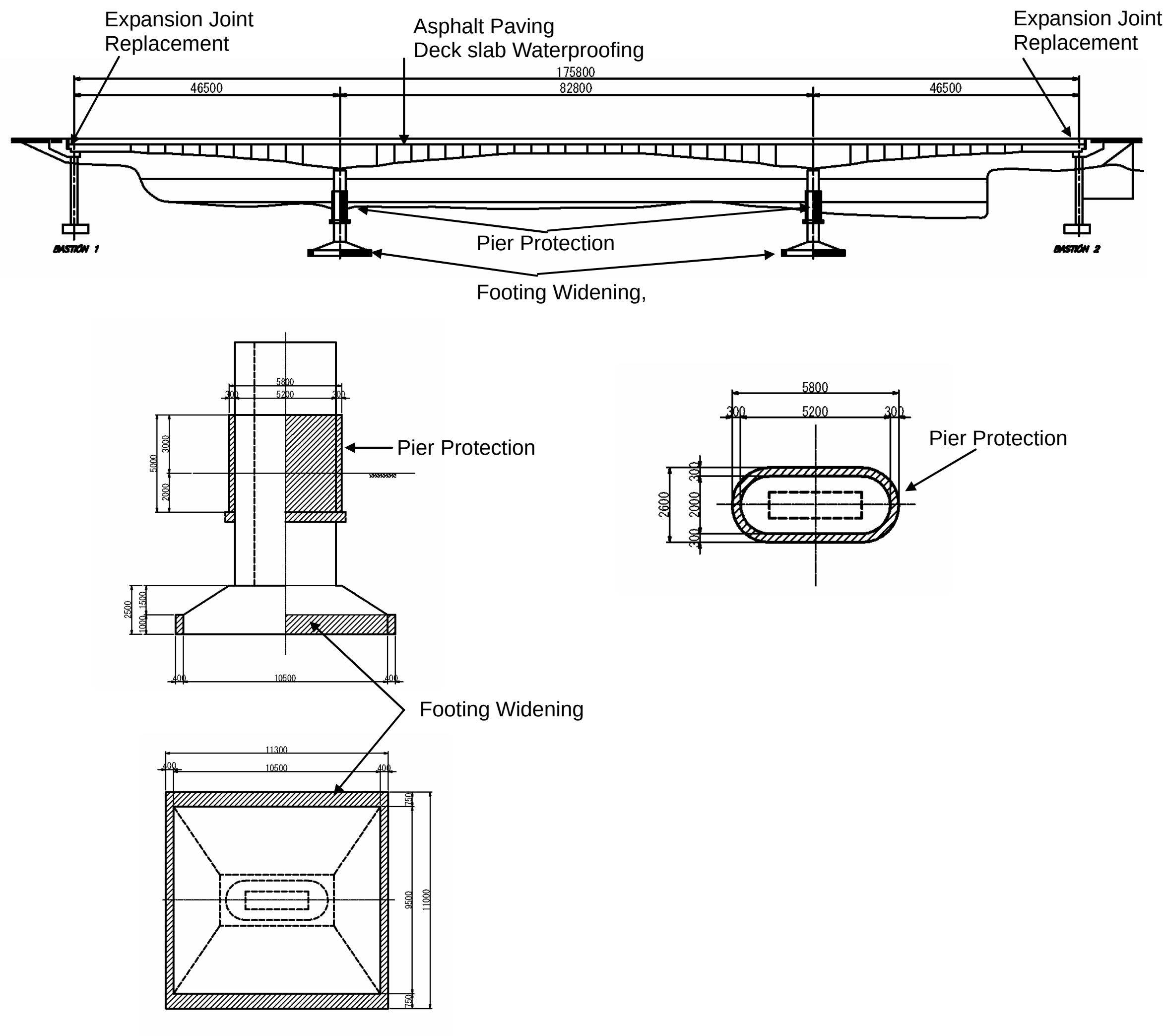
| | | | | |
|---|---|---|---|---|
| Bridge Name: | Rio Nuevo | | Route National Road Route2 | |
| Bridge Type: | 3 Span Continuous RC I Beam | | | |
| Bridge Length: | 55.480 m | Spans | 17.07 + 21.34 + 17.07 m | |
| | A1Abutment | P1Pier | P2Pier | A2Abutment |
| Substructure Type | Reversed T | Rigid Frame with Inner Wall | Rigid Frame with Inner Wall | Reversed T |
| Foundation Type | Pile Foundation (RC Pile) | Pile Foundation (RC Pile) | Pile Foundation (RC Pile) | Pile Foundation (RC Pile) |
| Design Live Load: | HS15-S12 | | | |




| | | | |
|---|---|---|---|
| Super-structure | Deck slab | Deck slab : Concrete Thickness Increase on Upper Side (9cm) | |
| | Main Beam | Bending Moment: FRP Bonding （b=48cm ,6 layers, Center of Both Side Span,3.70m）<br>Shear Force: FRP Bonding （b=30cm, 1Layer, Both beam ends 4.0m, Both sides near Intermediate Pier 8.50m） | |
| Sub-structure | Bridge Seat | Prevention System for Bridge Collapse: A1,A2 | |
| | Column | Concrete Jacketing: P2,P3 (Filling Open Area) | |
| Foundation | Footing | Widening, Thickness Increase | A1 (1.52 x 9.04 x 0.91 m → 6.02 x 9.50 x 1.80 m)<br>P1 (3.67 x 2.74 x 0.91 m x 2No. → 4.67 x 8.77 x 1.21 m )<br>P2 (2.74 x 2.74 x 0.91 m x 2No. → 4.67 x 8.77 x 1.21 m |
| | Pile | Pile Addition: A1, Cast in Site RC Pile (D=1000 mm x 8No.) | |
| Accessory | Bearing Support | Repairing : (Changing fix point from P1 to A1) | |
| | Expansion Joint | Replacement: A1, A2 | |
| Paving | | Asphalt Paving: t=5cm, Waterproofing: Deck slab (Whole Area) | |
| Protection | | Slope Protection: Riprap（A1,P1&P2, A2） | |
| | | Riverbed Protection: Gabion Mat (A1, P1, P2, A2) | |

## Table.11.21 Summary of Repair and Reinforcement Design for No.17 Chirripo Bridge

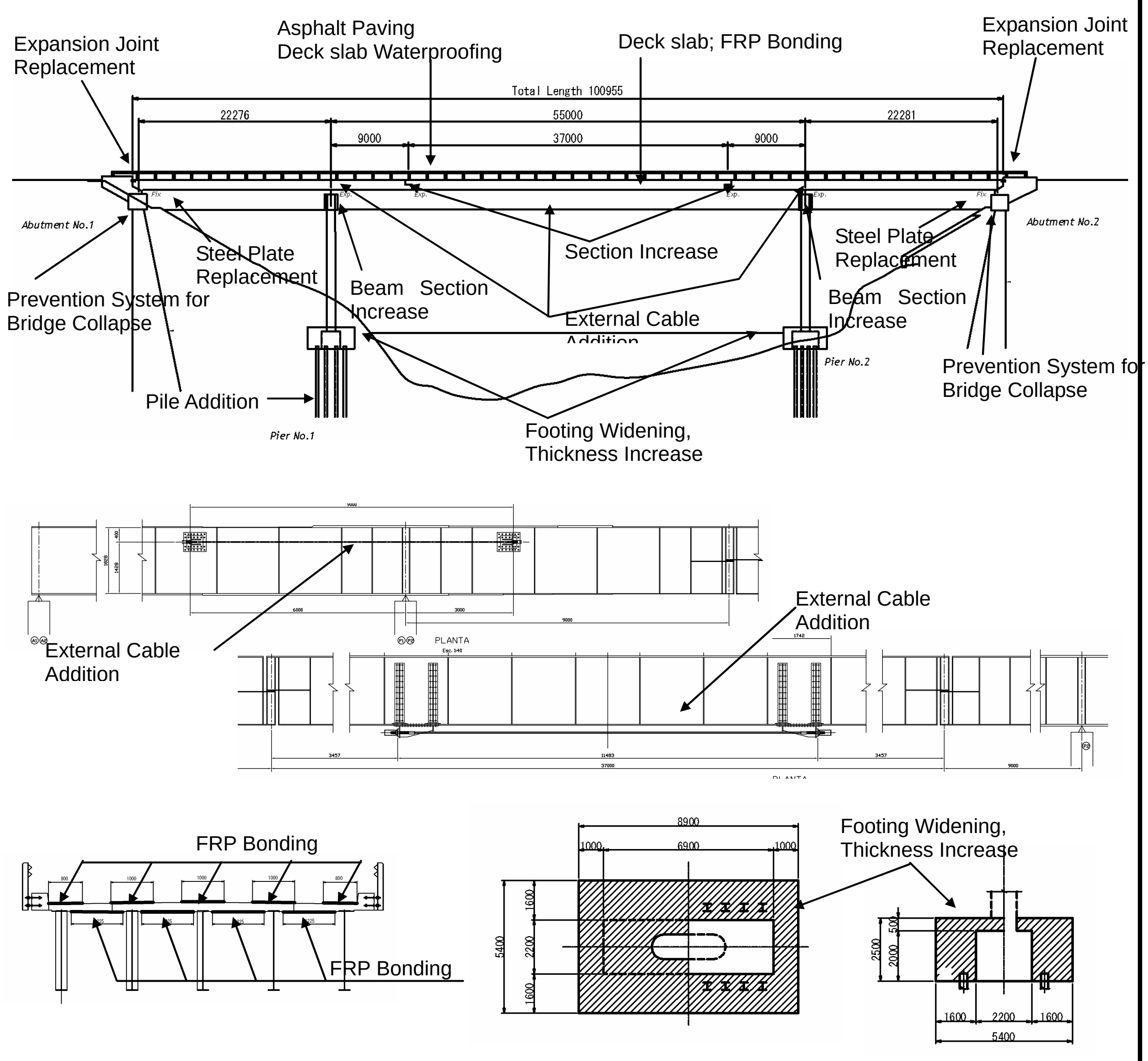
| | | | | |
|---|---|---|---|---|
| Bridge Name: | Rio Chirripo | | Route | National Road Route4 |
| Bridge Type: | 3 Span Continuous PC Box Girder Bridge | | | |
| Bridge Length: | 175.800 m | Spans | 46.500 + 82.800 + 46.500 m | |
| | A1Abutment | P1Pier | P2Pier | A2Abutment |
| Substructure Type | Rigid Frame | Wall | Wall | Rigid Frame |
| Foundation Type | Spread | Spread | Spread | Spread |
| Design Live Load: | HS-20 | | | |




| | | | |
|---|---|---|---|
| Superstructure | - | | |
| Substructure | Pier Column | Concrete Protection: P1,P2（25cmThickness, 5m Height Area near riverbed） | |
| Foundation | Footing | Widening,<br>Thickness Increase | P1 (9.50 x 10.50 x 2.50 m → 11,0 x 11.3 x 2.50 m)<br>P2 (9.50 x 10.50 x 2.50 m → 11,0 x 11.3 x 2.50 m) |
| Accessory | Expansion Joint | Replacement:A1, A2 | |
| Paving | | Asphalt Paving: t=5cm, Waterproofing: Deck slab (Whole Area) | |

# Table.11.22 Summary of Repair and Reinforcement Design for No.19 Sarapiqui Bridge

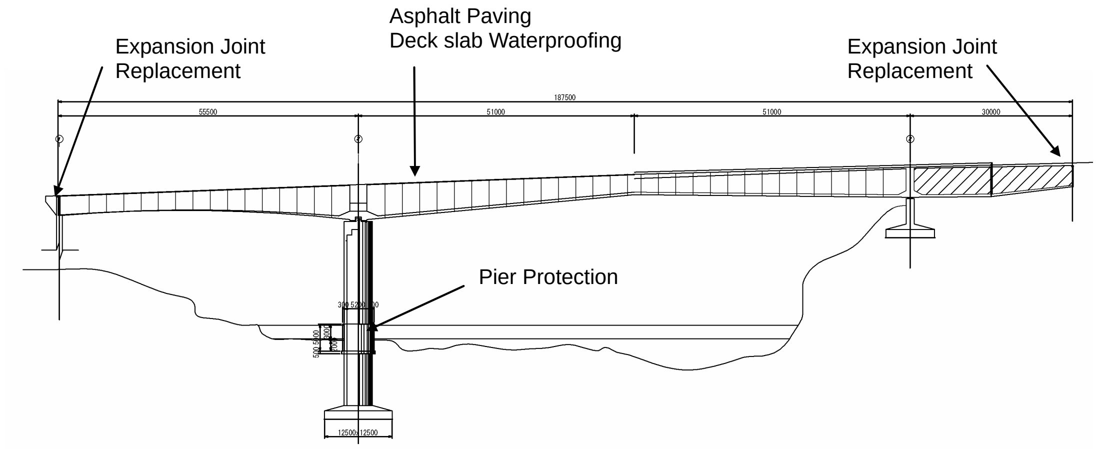
| | | | | |
|---|---|---|---|---|
| Bridge Name: | Rio Sarapiqui | Route | National Road Route4 | |
| Bridge Type: | 3 Span Gerber Type Steel I Beam | | | |
| Bridge Length: | 100.955 m | Spans: 22.276 + 55.000 22.281 m | | |
| | A1Abutment | P1Pier | P2Pier | A2Abutment |
| Substructure Type | Reversed T | Column with Beam | Column with Beam | Reversed T |
| Foundation Type | Pile Foundation (H Shape Steel) | Pile Foundation (H Shape Steel) | Pile Foundation (H Shape Steel) | Pile Foundation (H Shape Steel) |
| Design Live Load: | HS15-S12 | | | |

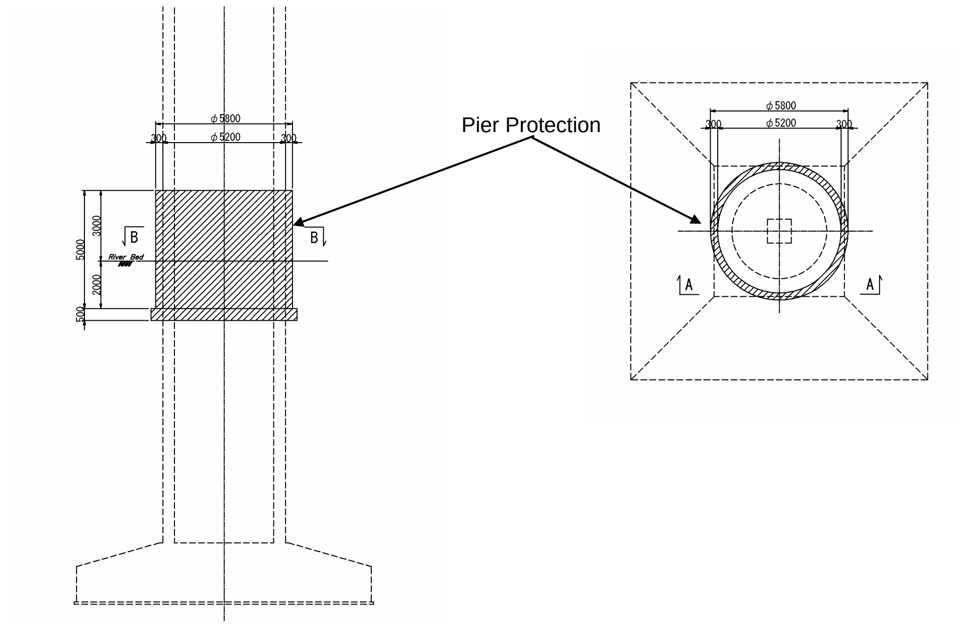



| | | | |
|---|---|---|---|
| Super-structure | Deck slab | FRP Bonding (Upper and Bottom Side, 2 Layers each) | |
| | Main Beam | External Cable Addition: Center of Center Span; 260 kNx5,<br>At Middle Piers; 260kNx10 x 2 points | |
| Sub-structure | Bridge Seat | Prevention System for Bridge Collapse: A1,P1,P2 | |
| | Pier Beam | Section Increase: P1,P2 (b=0.9m → 1.50m) | |
| Foundation | Footing | Widening,<br>Thickness Increase | P1 (2.20 x 6.90 x 2.00 m → 5.40 x 8.90 x 2.50 m)<br>P2 (3.05 x 9.80 x 2.00 m→ 5.05 x 11.80 x 2.50 m) |
| | Pile | Pile Addition: P1Pier, H-shaped Steel Pile (12BP53 L=13.3mx 16No.) | |
| Accessory | Prevention System for Bridge Collapse | Anti-seismic Girder Connection: Chain Type (200kN, A1,A2) | |
| | Expansion Joint | Replacement: A1, A2 | |
| Paving | | Asphalt Paving: t=5cm, Waterproofing: Deck slab (Whole Area) | |

## Table.11.23 Summary of Repair and Reinforcement Design for No.20 Sucio Bridge

| | | | | |
|---|---|---|---|---|
| Bridge Name: | Rio Sucio | | Route | National Road Route32 |
| Bridge Type: | 3 Span Continuous PC Box Girder | | | |
| Bridge Length: | 187.500 m | Spans | 55.500 + 102.000 + 30.000 m | |
| | A1Abutment | P1 Pier | P2 Pier | |
| Substructure Type | Rigid Frame | Column | Wall | |
| Foundation Type | Spread | Spread | Spread | |
| Design Live Load: | HS-20 | | | |

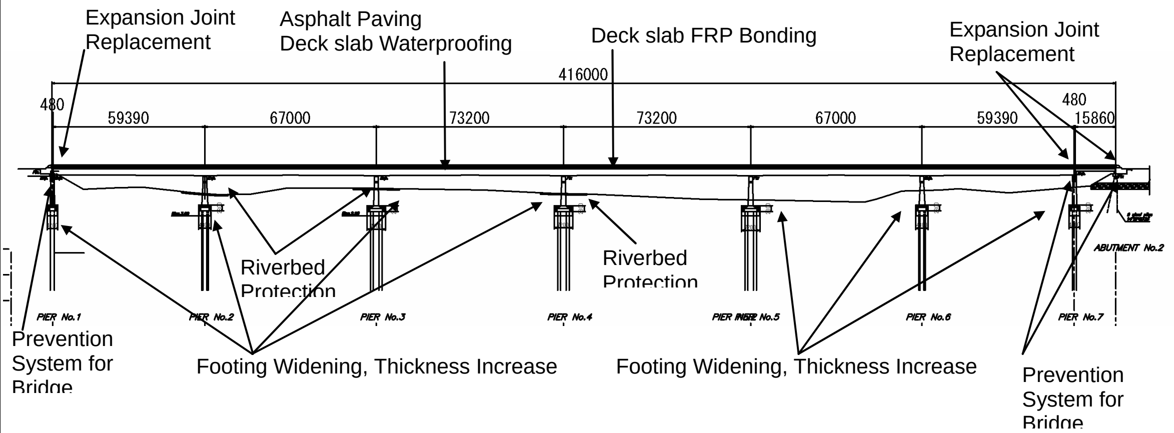


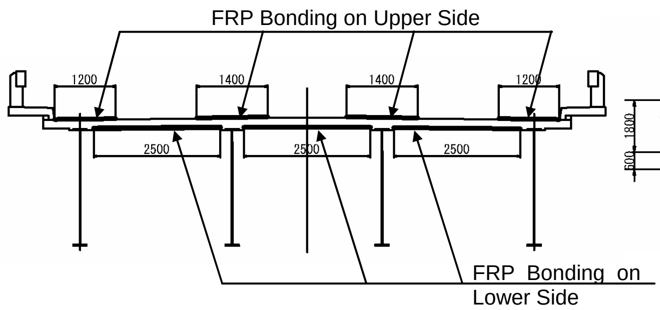



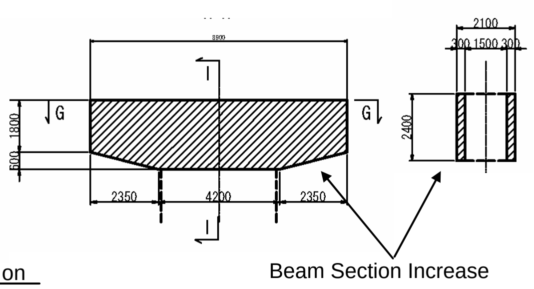

| | | |
|---|---|---|
| Superstructure | - | |
| Substructure | Pier Column | Concrete Protection: P1,P2（25cmThickness, 5m Height Area near riverbed） |
| Foundation | - | |
| Accessory | Expansion Joint | Replacement: A1, A2 |
| Paving | | Asphalt Paving : t=5cm,　Waterproofing: Deck slab (Whole Area) |

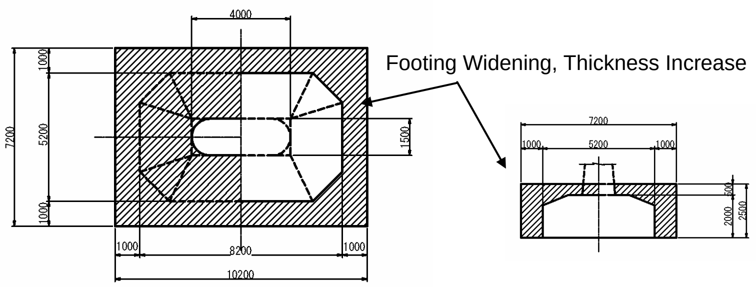
## Table.11.24 Summary of Repair and Reinforcement Design for No.26 Chirripo Bridge

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Bridge Name: | Rio Chirripo | | | Route | National Road Route32 | | | |
| Bridge Type: | 6 Span Continuous Steel I Beam + Simple Steel I Beam | | | | | | | |
| Bridge Length: | 416.000 m | | Spans | 59.5+67.0+73.0x2+67.0+59.5+16.23 m | | | | |
| | P1 Pier | P2 Pier | P3 Pier | P4 Pier | P5 Pier | P6 Pier | P7 Pier | A2 Abutment |
| Substructure Type | Column with Beam | Ditto | Ditto | Ditto | Ditto | Ditto | Ditto | Rigid Frame |
| Foundation Type | Pile Foundation (H-Steel Pile) | Ditto | Ditto | Ditto | Ditto | Ditto | Ditto | Pile Foundation (H-Steel Pile) |
| Design Live Load: | HS20 | | | | | | | |



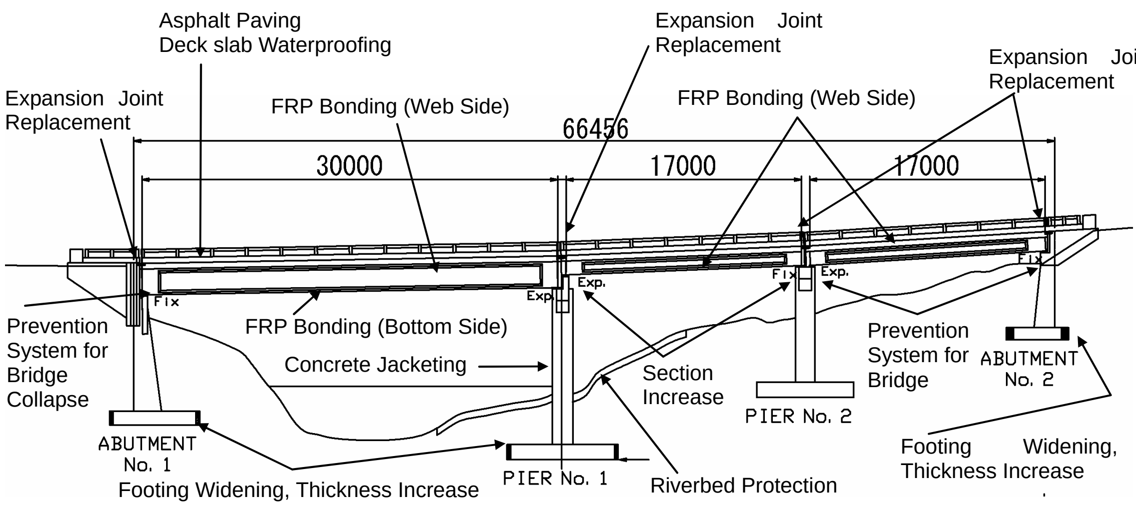



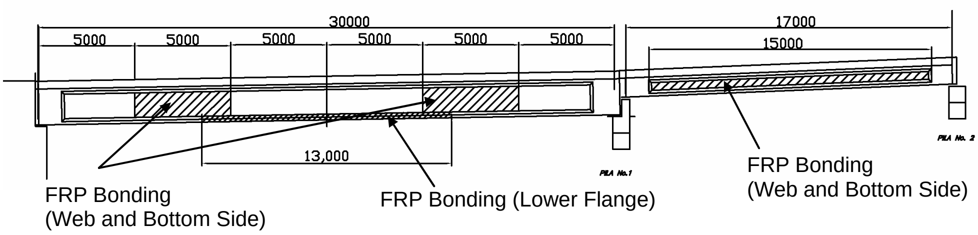



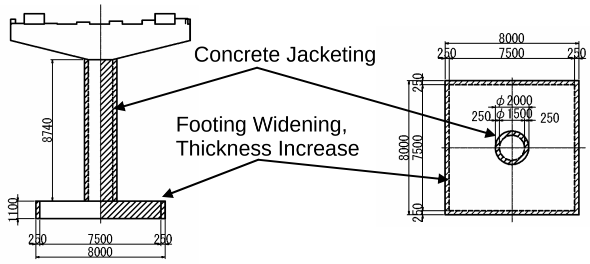

| | | | |
|---|---|---|---|
| Super-structure | Deck slab | FRP Bonding (Upper and Lower sides, 2 Layers each) | |
| Sub-structure | Bridge Seat | Prevention System for Bridge Collapse: P1,P7 ,A2 | |
| | Pier Beam | Section Increase : P4 (1.50 x 2.40 m → 2.10 x 2.40 m) | |
| Foundation | Footing | Widening, Thickness Increase | P1,P7 (2.20 x 7.30 x 1.80 m → 4.20 x 9.30 x 2.30 m)<br>P2,P6 (2.80 x 7.70 x 2.00 m → 4.80 x 9.70 x 2.50 m)<br>P3,P4,P5 (5.20 x 8.20 x 2.00 m → 7.20 x 10.20 x 2.50 m) |
| Accessory | Prevention System for Bridge Collapse | Anti-seismic Girder Connection: Chain (A1, P7, A2) | |
| | Expansion Joint | Replacement:P1, P7, A2 | |
| Paving | | Asphalt Paving: t=5cm, Waterproofing: Deck slab (Whole Area) | |
| Protection | | Riverbed Protection : Gabion Mat (P2, P3, P4) | |

## Table.11.25 Summary of Repair and Reinforcement Design for No.29 Torres Bridge

| | | | | |
|---|---|---|---|---|
| Bridge Name: | Rio Torres | | Route | National Road Route216 |
| Bridge Type: | PC I Beam x 3 Spans | | | |
| Bridge Length: | 66.456 m | Spans | 30.000 +17.000m x 2 | |
| | A1Abutment | P1 Pier | P2 Pier | A2Abutment |
| Substructure Type | Column with Beam | Column with Beam | Column with Beam | Rigid Frame |
| Foundation Type | Spread | Spread | Spread | Spread |
| Design Live Load: | HS20 | | | |




| | | | |
|---|---|---|---|
| Super-structure | Main Beam | Bending Moment: FRP Bonding 30mBeam, Center 13.0m)<br>Shear Force: FRP bonding<br>(30mBeam, Near both ends 5.0m each,<br>17mBeam Near whole length 15.0m) | |
| Sub-structure | Bridge Seat | Prevention System for Bridge Collapse: A1,P1,P2,A2 | |
| | Pier Beam | Section Increase : P1, P2 (1.10 x 2.25 m → 1.90 x 2.25 m) | |
| | Pier Column | Concrete Jacketing: P1 (D=1.50m → 2.00m) | |
| Foundation | Footing | Widening,<br>Thickness Increase | A1: (6.00 x 3.50 x 1.00 m → 6.50 x 4.00 x 1.00 m)<br>P1: (7.50 x 7.50 x 1.10 m → 8.00 x 8.00 x 1.10 m)<br>A2: (3.50 x 2.00 x 0.90 m → 4.50 x 3.00 x 0.90 m) |
| Accessory | Expansion Joint | Replacement:A1, P1, P2, A2 | |
| Paving | - | Asphalt Paving: t=5cm, Waterproofing :Deck slab (Whole Area) | |
| Protection | | Riverbed Protection: Gabion Mat (P1) | |

# Chaper. 12 Preliminary Construction Planning and Cost Estimate

## 12.1 Construction Planning

It is crucial to carry out the works without a complete traffic closure as the bridges are located on very important trunk roads in Costa Rica and full closure would have a significant social and economic impact. Therefore, the construction works shall be carried out on one side of the bridge in order to maintain one-way traffic on the other side at all times. As a result of using one-way working, an extension to the construction period will be required.

## 12.2 Cost Estimate

The Cost Estimate for the Project consists of the following items:

**Direct Costs**

- Construction Cost
    - Preparation and removal of temporary site facilities
    - Traffic control during the construction period
    - Works execution cost
- Transportation cost of equipment and materials: 5% of total construction cost

**Indirect Costs**

(a) Contingency Cost: 5% of total direct cost
(b) Administration Cost: 10% of {total direct cost + (a)}
(c) Contractor's Profit: 10% of {total direct cost + (a) + (b)}

The estimated construction periods and project costs are shown in Table.12.1.

**Table.12.1. Construction Period and Project Cost for 10 Bridges**

| Rt. | No. | Name | Period (days) | Project Cost (USD) |
|---|---|---|---|---|
| 1 | 2 | Rio Aranjuez | 120 | 1,291,000 |
| | 3 | Rio Abangares | 140 | 1,372,000 |
| | 7 | Rio Azufrado | 100 | 432,000 |
| 2 | 12 | Rio Puerto Nuevo | 190 | 1,371,000 |
| | 16 | Rio Nuevo | 140 | 661,000 |
| 4 | 17 | Rio Chirripo | 80 | 485,000 |
| | 19 | Rio Sarapiqui | 160 | 1,108,000 |
| 32 | 20 | Rio Sucio | 60 | 360,000 |
| | 26 | Rio Chirripo | 145 | 3,270,000 |
| 218 | 29 | Rio Torres | 140 | 557,000 |
| | | Total Cost | | 10,907,000 |

# Chapter. 13 Economic Analysis

## 13.1 The Concept of Economic Analysis for Bridge Rehabilitation and Reinforcement

The aims of this economic analysis include: 1) consideration of a suitable economic analysis method for bridge rehabilitation & reinforcement, 2) trial this analysis against the 10 selected bridges, and 3) customize this method to enable it to be used on other bridges. In order to achieve the above objectives, the concept of the economic analysis has been set-up as stated below.

- To review the methods of economic analysis for infrastructure construction, especially for roads, and to make proposals for a suitable method of economic analysis for bridge rehabilitation and reinforcement.

- To consider whether it will be possible to use the results in information given to the public to make society and road users understand and become more aware of the importance of bridge maintenance. This might help module project 5 in the context of capacity development.

- To conduct an economic analysis to show the costs and benefits achieved when a set of rehabilitation and reinforcement works is implemented for each selected bridge.

During the study period, two feasibility study reports have been collected for reference to economic parameters.

Based on the "with case" and "without case" for bridge rehabilitation & reinforcement, project costs and benefits are as the table below. The project benefits are evaluated as the reduction in costs over the 30-year period between the "With Case" and the "Without Case". Note that the costs in the without case are estimated for when the bridge will not have any future rehabilitation or reinforcement.

**Table.13.1. Basic Concepts of Costs and Benefits**

| | With Case | Without Case |
|---|---|---|
| Scenario | To conduct Rehabilitation and Reinforcement<br>-> To extend the life of the bridge<br>-> to introduce anti-seismic measures | No Rehabilitation or Reinforcement<br>-> Becomes unusable when the bridge has reached the limit of its serviceable life<br>-> The bridge collapses if an earthquake occurs |
| Cost | Cost 1: Work Cost for Rehabilitation and Reinforcement<br><br>Cost 2: Social Cost due to Detours due to traffic closures or Waiting at one-way traffic restrictions | Type A: Scenario caused by Bridge Life<br>Cost 1: Works Cost for Reconstruction<br>Cost 2: Social Cost<br>Detour Cost due to traffic closure during construction period<br>Type B: Scenario caused by Earthquake<br>Cost 1: Works Cost for Emergency Recovery and Reconstruction<br>Cost 2: Social Cost<br>Detour Cost due to traffic closure during construction period |
| Benefit | Reduction of Costs in Without Case | |

Based on the above concept, the Cost and Benefit characteristics are shown below. It is clear that benefits only appear when an event occurs under the scenarios due to bridge life and earthquake. These benefits have the following characteristics:

- Benefits due to the bridge's life will appear "once" when the scenario occurs.

- Benefits due to earthquakes will appear "each year" because there is a probability of earthquake occurrence.

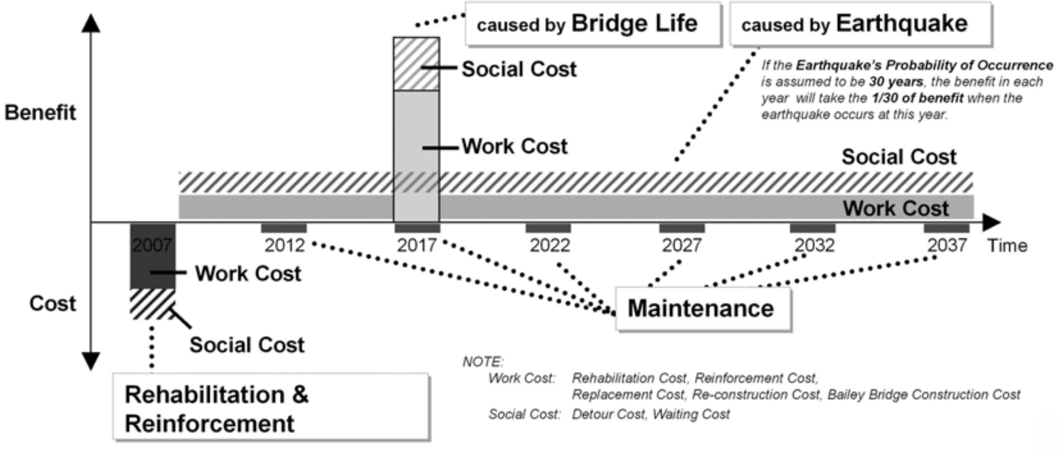
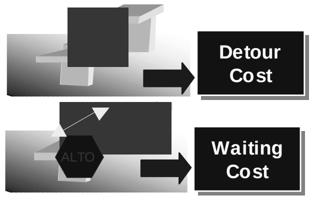



**Figure.13.1. Cost and Benefit Occurrence**

Economic Evaluations are generally carried out on the basis of a 30-year evaluation period. This allows for several cycles of maintenance and for several natural phenomena such as earthquakes to occur during the evaluation period thus normalizing the cost patterns over this time period.

## 13.2 Social Costs and Benefits

In order to estimate the Social Costs and Benefits for bridge rehabilitation and reinforcement, it is necessary to decide on what items should be included. This study takes the Social Costs as the "Detour Cost" and the "Waiting Cost" as costs due to traffic closures and one-way traffic restrictions. Detour Costs occur when the bridge collapses and extra time and distance are involved for the traffic to use the detour route. Waiting Costs occur when there are traffic restrictions due to one-way traffic operation during the construction works.




In order to estimate the Social Costs and Benefits due to both detours and waiting, it is necessary to estimate the future traffic volume and to identify the unit values for VOC & TTC. Both of these have already been researched by the MOPT Planificacion Dept., therefore, after reviewing them, they have been applied to this study. Note that the time value for Asset (Goods) is referred to in a similar feasibility study report for road concession projects. The details for each parameter taken from this study are as follows:

| | |
|---|---|
| **Estimation of Traffic Volume** | The study team has collected historical traffic data from the MOPT Planificacion. The traffic volume estimation method used is "Trend Method (External Estimation Method)". |

| | |
|---|---|
| **Unit Value for VOC and TTC** | The MOPT Planificacion Dept. has researched the unit values for VOC andTTC. |
| **Detour Condition** | Detour routes are identified using the existing road network for each bridge. |
| **Waiting Costs** | Waiting costs are calculated using the average waiting time, traffic volume and time value in the case of 1-direction traffic restrictions during the construction works. |

The social loss in the case of a "one day traffic closure" is estimated for each bridge. For the 10 selected bridges, the social loss has different values according to the detour conditions and traffic volume. Note that R32 has the characteristics of the mass weight of 5-axles and TTC means the time value of goods. The results are shown in below.

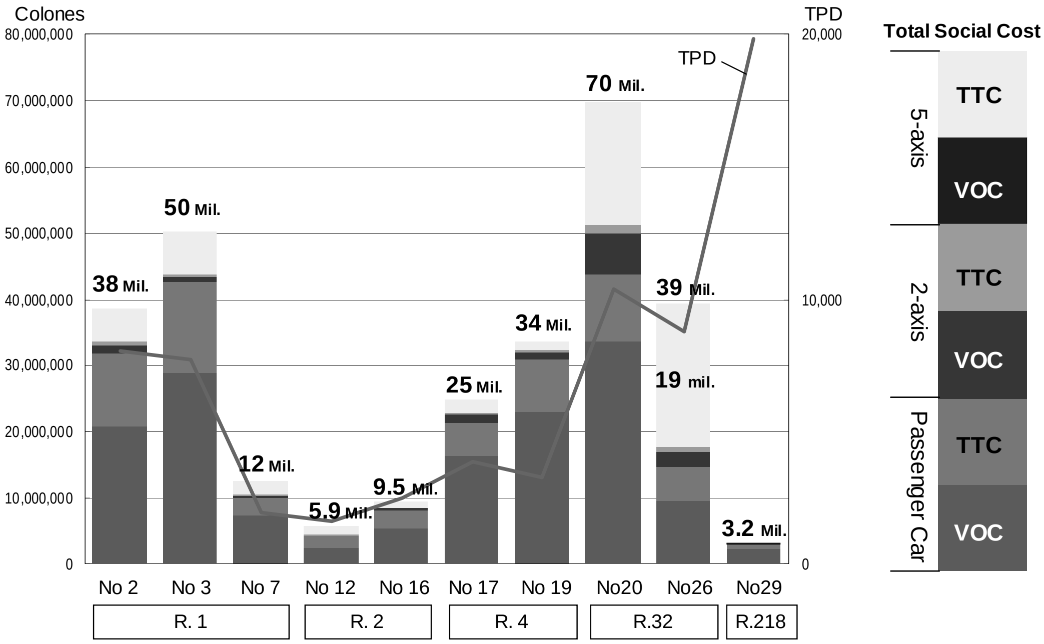



**Figure.13.2. Social Loss of 1 day Traffic Closure for 10 Bridges**

## 13.3 Scenario Setting

In the without case, each bridge has its own unserviceable scenario. The study team decided on each scenario using engineering judgment based on the inspection results of the existing condition and age of the bridge.

There are two scenarios; one is the scenario caused by " Bridge Life", the other is by "Earthquake".

The scenario caused by "Bridge Life" means that the bridge would be unusable when a part of the bridge has reached its serviceable life because of deterioration. The bridge life is thought to be predictable. On the other hand, for the scenario caused by "Earthquake" it is assumed that the bridge will collapse if an earthquake occurs. Therefore, it is not predictable and has the probability of occurring in each year. Both scenarios will affect the traffic due to road closures or traffic restrictions for one-way working depending on the damage to the bridges. The elements of these scenarios are shown in the figure below.

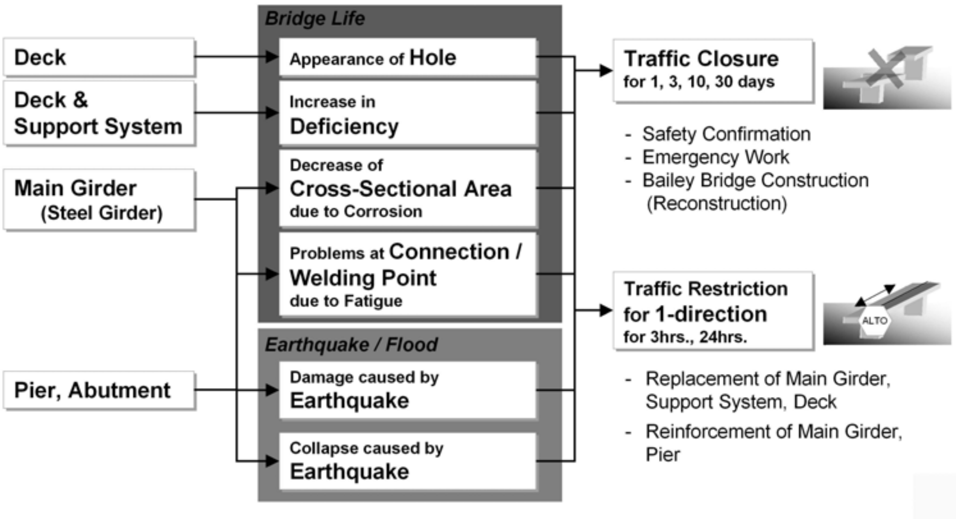



**Figure.13.3. Structural Elements and Bridge Scenarios**

## 13.4 Results of Social Cost and Benefits for each Bridge

The results of the net social benefit for the 10 selected bridge are summarized in figure S.13.4. The Rio Abangares (Bridge No3) and Rio Chirripo (Bridge No26) have the highest social benefit value for rehabilitation and reinforcement. These two bridges are on the Routes 1 and 32, which are the most important for international transportation and have not enough redundancy for the road network. The next section deals with the economic evaluation for rehabilitation and reinforcement using the works cost and benefit added to the social costs and benefit, in order to find the EIRR and B/C.

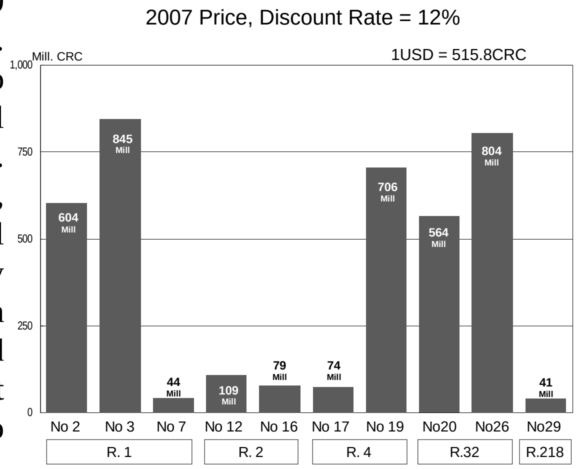



**Figure S.13.4. Results of Net Social Benefits**

## 13.5 Works Cost for each Bridge

The project costs for rehabilitation and reinforcement have been estimated in Chapter12. In the economic evaluation, costs should be converted from their financial cost to their economic cost. For project components purchased in Costa Rica, no conversion factor is needed, since it is assumed that the market is competitive for these resources and also because they do not impact on imports/exports. For tradable resources, the standard conversion factor of 0.83 is used for the prices in Costa Rican colones (Cs). Note that all taxes/duties are excluded from the economic costs. Because the project cost includes 13% sales tax, this cost is multiplied by 0.87 to make the tax deduction.

Operation and maintenance costs are taken into consideration in the "with case", and works costs such as emergent recovery, rehabilitation, reinforcement, preparation of Bailey Bridge and re-construction costs for each scenario in the "without case".

The currency exchange rates used are "1USD=515.8CRC, 1USD = 116.91JPY and 1JPY = 4.41CRC" estimated in 12.2.2 (1). CRC is used in the economic evaluation.

## 13.6 Economic Evaluation

The results of the Economic Internal Rate of Return (EIRR) for the selected 10 bridges are shown to the right. There are 8 bridges whose EIRR is more than 20% and so are feasible projects for rehabilitation and reinforcement within the national economic context. Although two bridges (Azufurado Bridge (No.7) and Chirripo Bridge (No.12) have less than 20% EIRR, it is dangerous to say that these bridge are not worth rehabilitating and reinforcing because their EIRRs have been calculated under this particular set of assumptions.

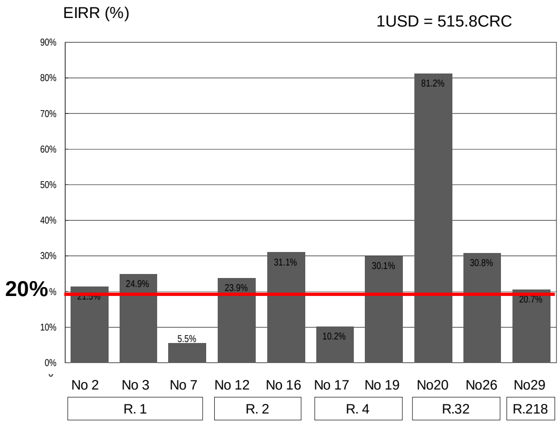
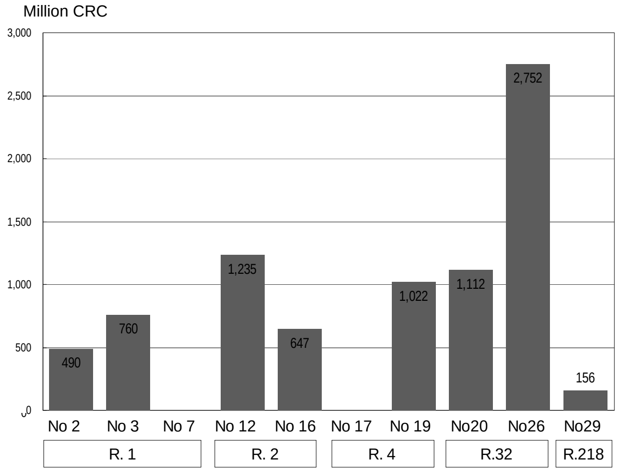



**Figure.13.5. Results of EIRR**

The Net Present Value (NPV) has been calculated for the 8 bridges using 12% of discount rate, having an EIRR greater than 20% and the results are shown below. The results of the NPV calculations show that Chirripo Bridge (No.26), Puerto Nuevo Bridge (No.12) and Sucio Bridge (No.20) have the highest values of NPV. The results also show the order of importance/beneficial rank for rehabilitation and reinforcement from the national economic point of view.




Beneficial Rank by NPV (EIRR>20%)

| | | |
|---|---|---|
| 1. Chirripo Bridge | No.26 | R.32 |
| 2. Puerto Nuevo Bridge | No.12 | R.2 |
| 3. Sucio Bridge | No.20 | R.32 |
| 4. Sarapiqui Bridge | No.19 | R.4 |
| 5. Abangares Bridge | No.3 | R.1 |
| 6. Nuevo Bridge | No.16 | R.2 |
| 7. Aranjuez Brige | No.2 | R.1 |
| 8. Torres Bridge | No.29 | R.218 |

**Figure.13.6. Results of NPV, Beneficial Rank for Rehabilitation and Reinforcement**

The scenario for Chirripo Bridge (No.26), which has highest NPV, is shown in Table S.13.2. and its cost/benefit table is shown in Table.13.4.

**Table.13.2. Scenario for Chirripo Bridge (No.26)**

| | | |
|---|---|---|
| Cost | Rehabilitation and Reinforcement | Slab Deck (FRP Bonding), Prevention System for Unseating (Bridge Seat Widening, Connection System), Expansion Joint (New Installation), Asphalt Paving and Waterproofing, Pier (Increase Height of Transverse Beam), Foundation (Footing Widening) (Social: 1-dir. Traffic Closure 100days) |
| | Maintenance | Routine Inspection (every 5 years), Detailed Inspection (every 10 years)<br>Repair for Support System (Injection), Pavement Overlay, Replacement of Expansion Joint, Asphalt Paving and Waterproofing, Pier Protection |
| Benefit | Scenario 1 | After 15years, Not Passable due to Increase in Deficiency (Deck Slab)<br>Social Cost: Traffic Closure 30 days<br>Works Cost: Bailey Bridge Construction, Slab Replacement |
| | Scenario 2 | After 20 years, Lack of Cross-sectional Area due to Deterioration of Paint and Corrosion (Main Girder)<br>Social Cost: 1-dir. Traffic Closure 3hrs. 7days<br>Works Cost: Steel Plate Replacement |
| | Scenario 3 | After 30 years, Damaged Cracks around Connections due to Fatigue (Main Girder)<br>Social Cost: Traffic Suspension 24hrs. and : 1-dir. Traffic Closure 3hrs. 7days<br>Work Cost: Cover Plate Fixing |
| | Scenario 4 | Within 30 years, Collapse of Main Girder of Side Span due to Earthquake<br>Social Cost: Traffic Closure 30 days<br>Works Cost: Bailey Bridge Construction and Re-Construction |

The Results of the Sensitivity Analysis are shown below. It shows that the sensitivity to an increase in cost or decrease in benefit is not so high, therefore, the switching value of cost is 2.8 times the base value, and the switching value of benefit is 0.3 times the base value. Note that the EIRR will be reduced from 30.8% to 27.0% if social costs/benefits are not taken into consideration in this evaluation. In this context, the NPV will be also reduced from 2,752 million CRC to 1,948 million CRC.

**Table.13.3. Result of Sensitivity Analysis for Chirripo Bridge (No.26)**

| Scenario | | EIRR | NPV （million CRC） | Switching Value |
|---|---|---|---|---|
| Cost | +10% | 28.4% | 2,607 | Base * 2.8877 |
| | +20% | 26.4% | 2,461 | |
| Benefit | -10% | 28.2% | 2,331 | Base * 0.3463 |
| | -20% | 25.2% | 1,910 | |

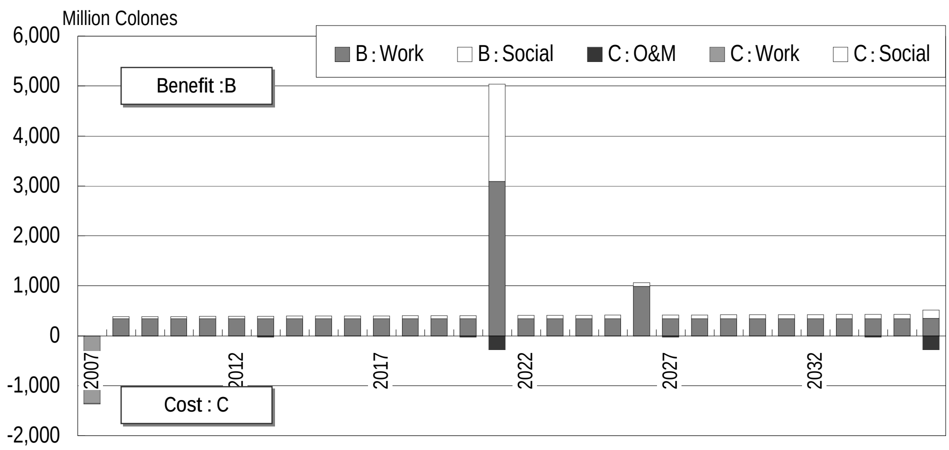
# Table.13.4. Cost/Benefit Table for Chirripo Bridge (No.26)

Unit: CRC, 1USD = 515.8CRC

| | year | Costs | | | | Benefits | | | Results |
|---|---|---|---|---|---|---|---|---|---|
| | | Work | | Social | Total Cost | Work | Social | Total Benefit | Net Benefit |
| | | Rehabli. & Reinf. | Maintenance | Traffic Rest. | (A) | Scenario 1 to 5 | Scenario 1 to 5 | (B) | (B-A) |
| 1 | 2007 | 1,355,277,221 | | 11,437,992 | 1,366,715,214 | | | | -1,366,715,214 |
| 2 | 2008 | | | | 0 | 343,814,571 | 41,049,885 | 384,864,456 | 384,864,456 |
| 3 | 2009 | | | | 0 | 343,814,571 | 42,732,137 | 386,546,708 | 386,546,708 |
| 4 | 2010 | | | | 0 | 343,814,571 | 44,414,388 | 388,228,959 | 388,228,959 |
| 5 | 2011 | | 31,000 | | 31,000 | 343,814,571 | 46,096,640 | 389,911,211 | 389,880,211 |
| 6 | 2012 | | | | 0 | 343,814,571 | 47,778,891 | 391,593,462 | 391,593,462 |
| 7 | 2013 | | 25,619,012 | | 25,619,012 | 343,814,571 | 49,461,142 | 393,275,713 | 367,656,701 |
| 8 | 2014 | | | | 0 | 343,814,571 | 51,143,394 | 394,957,965 | 394,957,965 |
| 9 | 2015 | | | | 0 | 343,814,571 | 52,825,645 | 396,640,216 | 396,640,216 |
| 10 | 2016 | | 168,000 | | 168,000 | 343,814,571 | 54,507,897 | 398,322,468 | 398,154,468 |
| 11 | 2017 | | | | 0 | 343,814,571 | 56,190,148 | 400,004,719 | 400,004,719 |
| 12 | 2018 | | | | 0 | 343,814,571 | 57,872,399 | 401,686,970 | 401,686,970 |
| 13 | 2019 | | | | 0 | 343,814,571 | 59,554,651 | 403,369,222 | 403,369,222 |
| 14 | 2020 | | 25,619,012 | | 25,619,012 | 343,814,571 | 61,236,902 | 405,051,473 | 379,432,461 |
| 15 | 2021 | | 283,132,225 | | 283,132,225 | 3,088,479,607 | 1,950,493,762 | 5,038,973,369 | 4,755,841,145 |
| 16 | 2022 | | | | 0 | 343,814,571 | 64,601,405 | 408,415,976 | 408,415,976 |
| 17 | 2023 | | | | 0 | 343,814,571 | 66,283,656 | 410,098,227 | 410,098,227 |
| 18 | 2024 | | | | 0 | 343,814,571 | 67,965,908 | 411,780,479 | 411,780,479 |
| 19 | 2025 | | | | 0 | 343,814,571 | 69,648,159 | 413,462,730 | 413,462,730 |
| 20 | 2026 | | 168,000 | | 168,000 | 989,167,656 | 71,331,369 | 1,060,499,024 | 1,060,331,024 |
| 21 | 2027 | | 25,619,012 | | 25,619,012 | 343,814,571 | 73,012,662 | 416,827,233 | 391,208,221 |
| 22 | 2028 | | | | 0 | 343,814,571 | 74,694,913 | 418,509,484 | 418,509,484 |
| 23 | 2029 | | | | 0 | 343,814,571 | 76,377,165 | 420,191,736 | 420,191,736 |
| 24 | 2030 | | | | 0 | 343,814,571 | 78,059,416 | 421,873,987 | 421,873,987 |
| 25 | 2031 | | 31,000 | | 31,000 | 343,814,571 | 79,741,668 | 423,556,238 | 423,525,238 |
| 26 | 2032 | | | | 0 | 343,814,571 | 81,423,919 | 425,238,490 | 425,238,490 |
| 27 | 2033 | | | | 0 | 343,814,571 | 83,106,170 | 426,920,741 | 426,920,741 |
| 28 | 2034 | | 25,619,012 | | 25,619,012 | 343,814,571 | 84,788,422 | 428,602,993 | 402,983,980 |
| 29 | 2035 | | | | 0 | 343,814,571 | 86,470,673 | 430,285,244 | 430,285,244 |
| 30 | 2036 | | 283,269,225 | | 283,269,225 | 348,540,475 | 167,148,694 | 515,689,169 | 232,419,945 |

EIRR = 30.8%

NPV at 12% = 2,752,424,784 Colones



# Chapter. 14 Bridge Management System

## 14.1 Existing Information System for Roads and Bridges and its Issues

### 1) Existing Information System

The study team has researched and gained an understanding of the existing information system for roads and bridges to assist in the discussions about the implementation of a bridge management system.

The administration for roads and bridges is carried out by the Planning Department of MOPT. The data is used for the planning of an annual budget and for the selection of the roads and locations for maintenance. In CONAVI, there is an inventory display system using GIS (ArcInfo) for the administration of the roads and bridges.

**Table.14.1. Information Administered by each Organization/Section**

| Organization/Section | Information |
|---|---|
| Planning Div. of MOPT | Information on national highways, regional roads, bridges and marine ports |
| Bridge Dept. of MOPT | Information on inventory data (EXCEL) prepared by the Planning Div. of MOPT and drawings (Materials) |
| CONAVI | Information on the selected location of roads to be repaired and the construction contracts based on an annual action plan prepared by the Planning Dept. of MOPT |

The following table shows the computer network environment in MOPT and between MOPT, CONAVI and regional offices.

**Table.14.2. Network Environment**

| Area | Network Environment |
|---|---|
| LAN ( in MOPT) | The personal computers in the Public Works Division are connected by fiber optic cables through the switch principal from the server and are connected with the category 5 100 BASE-TX (100Mbbps) through the Ethernet. |
| WAN (External Network) | The network connections between the MOPT, CONAVI and the Local Government are by exclusive lines and the other Local Governments are connected by Modems through general lines. |

The existing road management system in the MOPT is shown in table below.

**Table.14.3. Existing System for Road Management**

| System | Description |
|---|---|
| SPEM (Pavement) | The SPEM was developed by German engineers in 1993 for the management of local roads. A German engineer still supports the system and the system is being well managed. Utilization of the system is limited solely to MOPT staff. |
| HDM4 (Pavement) (DESYROUTE, DESYSEMI, DESYVISAGI) | The annual action plan for road maintenance is produced using the economic analysis, the prioritization of the roads to be maintained, and the prediction of deterioration using HDM4. The locations for maintenance are finally selected by CONAVI considering the annual action plan and political decisions. |
| Bridge Management System (BMS) | Bridges inspections are carried out based on the inspection manual by inspectors from the Planning Department. However, the information is not used by the Bridge Department since the inspectors are not bridge engineers. The Bridge Department maintains drawings of bridges and answers requests for information from other departments. |

The overall picture of the existing road and bridge management system and the flow of information are illustrated in the Figure below.

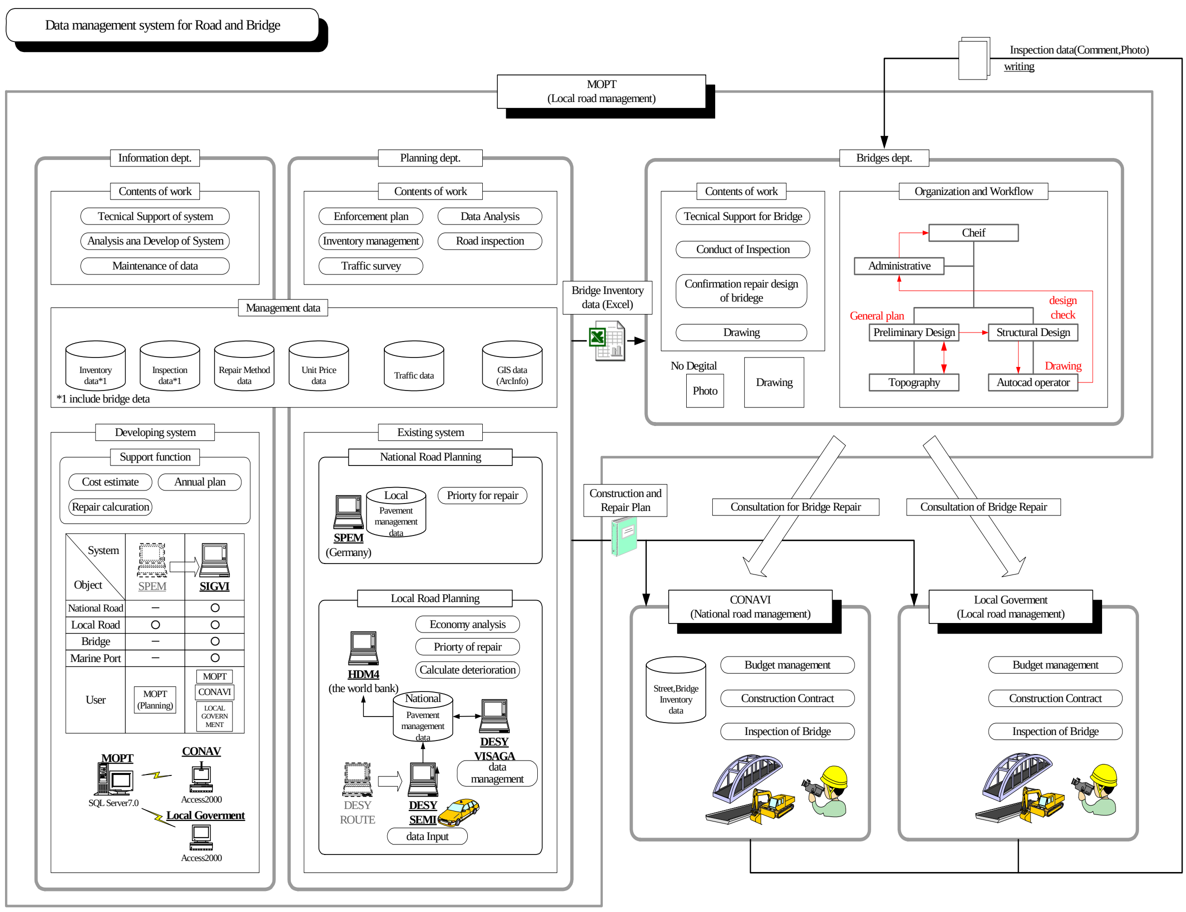



**Figure.14.1. Existing System for Road and Bridge Management/Maintenance**

## 2) Existing Issues

The issues for the existing information systems for the roads and the bridges in the MOPT are as follows:

- The number of computers and the skills of the staff for the system in the Local Governments are not sufficient.
- The information is not unified within the MOPT, CONAVI and the Local governments.
- Each department develops the systems separately and as a result, the systems are not compatible between departments.
- When each department develops their own system, the exchange of information is insufficient, and so some essential information and functions for bridge management do not exist in the systems.
- Drawings and photos of bridges are not registered in the database and and as a result are not often used.
- The bridge inspectors are not trained and the bridge inspections are not carried out properly. The criteria for prioritization of the bridge repairs are not clear.
- The systems offered from abroad cannot be continuously maintained and the systems are utilized in ad hoc fashion.

## 14.2 Bridge Management System (BMS)

### 1) System Development

The total road management system (SIGVI) is now under development and will be the future system for the Public Works Division in the MOPT. This system is intended to be a total management system for roads and bridges, but it is still under development. In this context, the study team proposed that the Bridge Management System (BMS) should be developed independently to SIGVI. Note that it is necessary that SIGVI should be able to take the BMS module into its system in order to develop it as a totally integrated road and bridge management system in future.

### 2) Outline of the System

The Bridge Management System (BMS) is the decision support tool responsible for managing the inspection, analysis and maintenance for the numerous components that make up a bridge. The bridge inventory, the bridge deficiency and the records of maintenance activities are all stored in the BMS and analysis for the evaluation of this data is done within the BMS.

The concept of the BMS is shown in figure below.

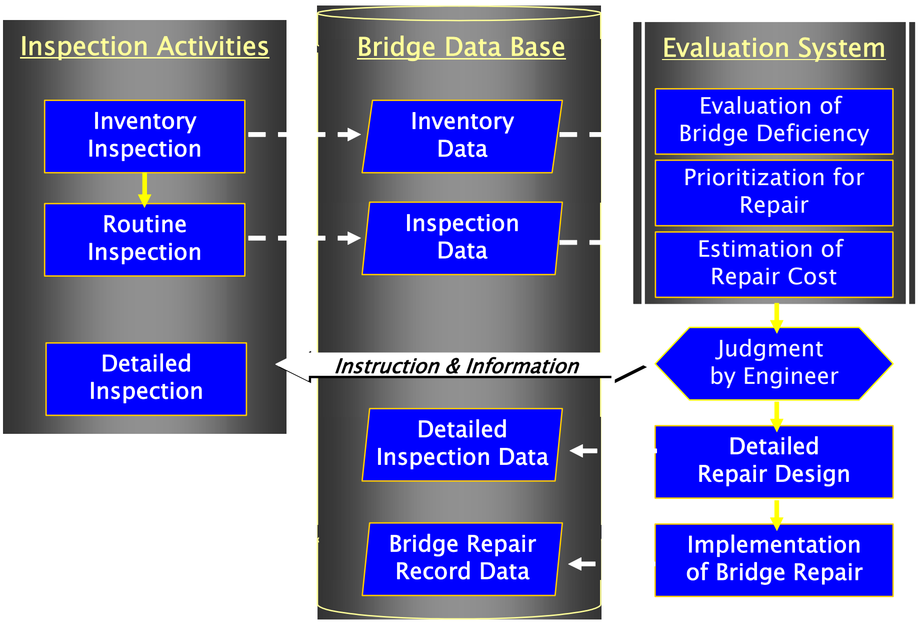



**Figure.14.2. Concept of the BMS**

### 3) Functions of the System

The functions of the system are as follows:

1. Function for the registration and renewal of the data
2. Function for the administration of data such as evaluation of deficiency,

prioritization of repairs and cost estimation

3. Function for the retrieval of data including bridge inventory and bridge inspection data and for the display of data for any bridge location.
4. Function for output of the bridge inventory

### 4) System Components

The system consists of a server and clients (C/S type system) and all data are administered by the server. The system components, the environment of the operation and the data stored in the system are shown in the figure below. When the file server is not available, all data shall be stored on the database server.

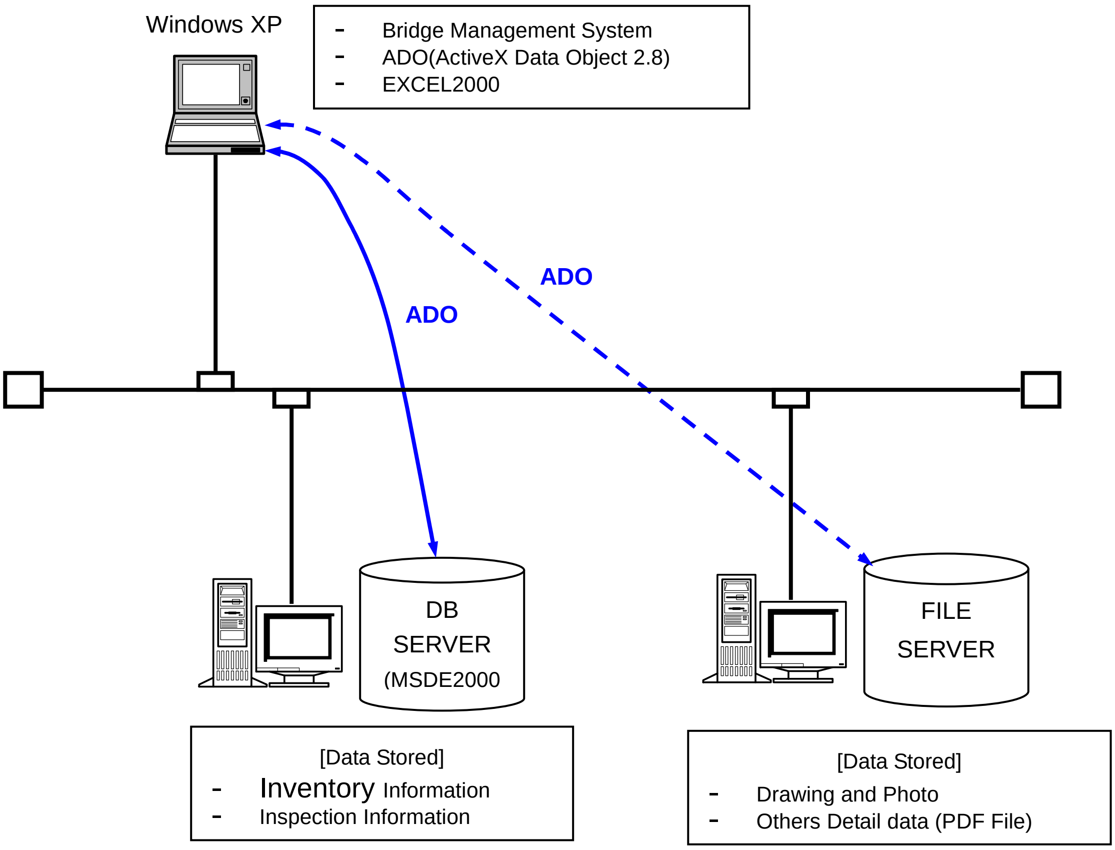



**Figure.14.3. Hardware Components of the System**

### 5) Display and Graphics

The display and the graphics of the BMS are shown in figure below.

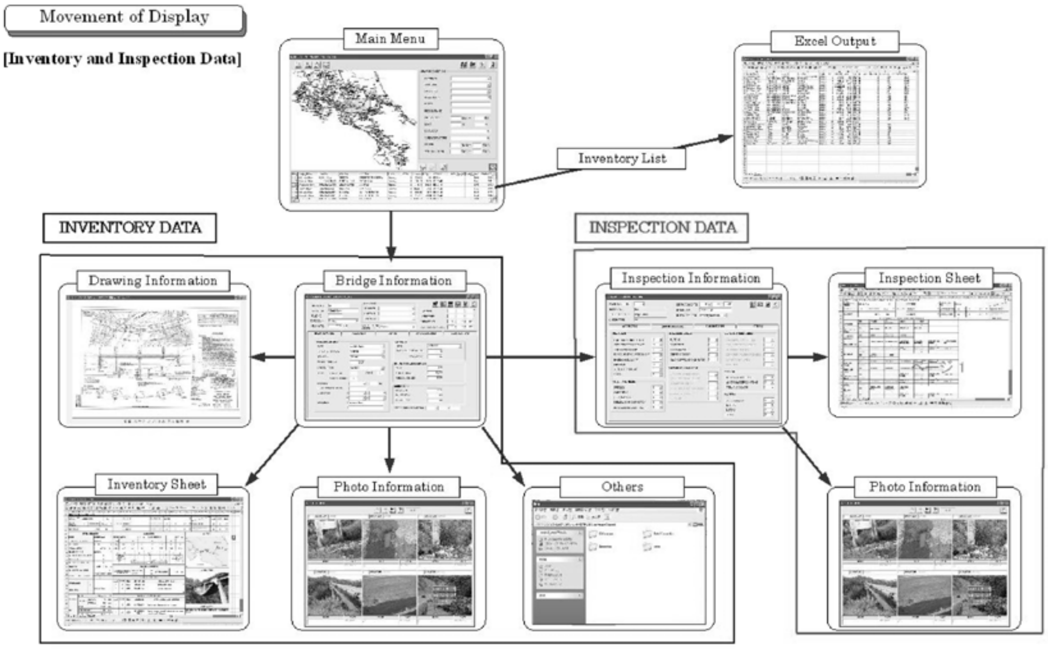



**Figure S.14.4. Display and Graphics**

### 6) Bridge Reporting System

The data and information required in Costa Rica is listed in Form-1 to Form-7. The forms and necessary information are to be completed for each bridge and placed in each file of the Bridge Folder. Specific forms and other information used to record the necessary bridge data are as follows.

1. Form-1 General Information of the Bridge Inventory Record
2. Form-2 Dimensions of the Superstructure
3. Form-3 Dimensions of the Substructure
4. Form-4 Bridge Plans
5. Form-5 Bridge Photos
6. Form-6 Condition Rating of the Bridge Elements
7. Form-7 Photos of the Condition of the Elements of the Bridge

Form-1, Form-5 and Form-6 are shown below as an example.

## Form-1 General Information of the Bridge Inventory

INVENTARIO BASICO DE PUENTES

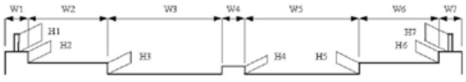
| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| NOMBRE DEL PUENTE | Colorado River 001 | LOCALIDAD | PROVINCIA | * | ADMINISTRADO POR | Colorado * | | DIA / MES / AÑO |
| No. DE LA RUTA | 1 | CLASIFICACION: Primary * | CANTON | * | LATITUD NORTE | 12 ' 34 " 56.7 "' | FECHA DE DISEÑO | 31 / 3 / 1968 |
| KILOMETRO | 35.756 km | | DISTRITO | * | LONGITUD ESTE | 12 ' 34 " 56.7 "' | FECHA DE CONCLUCION DE CONSTRUCCION | 31 / 3 / 1970 |

**ELEMENTOS BASICOS**

| | |
|---|---|
| DIRECCION DE LA VIA HACI | SAN JOSE * |
| TIPO DE ESTRUCTURA | PUENTE * |
| CARGA VIVA | H15-44 * |
| LONGITUD TOTAL | 204.00 m |
| ESPECIFICACION | AASHTO * |
| No. DE SUPER ESTRUCTURA | 1 |
| No.DE TRAMOS | 3 |
| No. DE SUB ESTRUCTURA | 3 |
| LONGITUD DE DESVIO | SI 50 km |
| PENDIENTE LONGITUDINAL | % |
| FECHA DE ULT. PINTURA (DIA / MES / AÑO) | |
| SERVICIOS PUBLICOS | 1 / 2 / 3 / 4 |
| CRUZA SOBRE | 1 Colorado River; 2 |
| PAVIMENTO – TIPO | ASFALTO * |
| PAVIMENTO – ESPESOR – ORIGINAL | 75 mm |
| PAVIMENTO – ESPESOR – SOBRECAPA | 120 mm |
| CONTEO DE TRAFICO – AÑO | 1,940 Year |
| CONTEO DE TRAFICO – TOTAL DE VEHICULOS | 15,355 Car |
| CONTEO DE TRAFICO – % DE VEHICULOS PESADOS | 13.00 % |
| RESTRICCIONES – POR CARGA | 15.0 t |
| RESTRICCIONES – POR ALTURA | 4.5 m |
| RESTRICCIONES – POR ANCHO | 6.0 m |

**DIMENSIONES**

| ANCHO TOTAL | 11.3 m | CALZADA | 10.7 m | | | | |
|---|---|---|---|---|---|---|---|
| ITEMS | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| W(m) | 0.3 | 0.6 | 4.25 | 0 | 4.25 | 0.6 | 0.3 |
| H(m) | 0.49 | 0.35 | 0.24 | 0 | 0.24 | 0.35 | 0.49 |




**CLARO LIBRE**

| ALTURA LIBRE VERTICAL | SUPERIOR | m | WAPROX | 10.0 m |
|---|---|---|---|---|
| | INFERIOR | m | | |

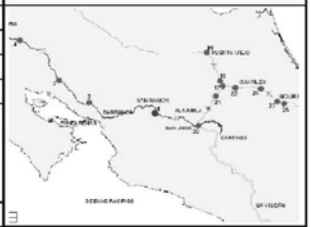
**ANTECEDENTES DE INSPECCION**

| DIA | MES | AÑO | INSPECTOR | TIPO DE INSPECCION |
|---|---|---|---|---|
| 4 | 10 | 2005 | Gabriela Jorge | Routine Inspection * |
| 4 | 10 | 2000 | Gabriela Jorge | Inventory Inspection * |
| | | | | * |

**ANTECEDENTES DE REHABILITACION**

| DIA | MES | AÑO | ELEMENTOS | RESUMEN DE CONTRAMEDIDAS |
|---|---|---|---|---|
| 4 | 10 | 2005 | PAVIMENTO | Debido al daño severo, Pavimentar sobrecapa |
| 4 | 10 | 2000 | JUNTA DE EXPANSION | Cambiar debido al mucho desnivel de la junta de expansión |
| | | | | |
| | | | | |

**UBICACION**



**VISTA PANORAMICA**

**OBSERVACIONES**

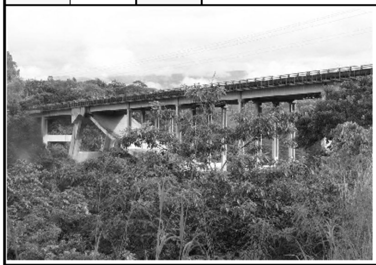
dificultar la inspección de sub estructura debido a la ubicación montañosa

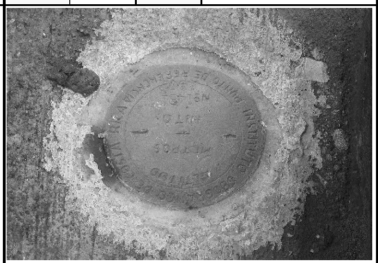
## Form-5 Bridge Photos

INVENTARIO BASICO DE PUENTES(FOTOS) NO. 2 / 10

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| NOMBRE DEL PUENTE | Colorado River 01 | LOCALIDAD | PROVINCIA | ALAJUELA * | ADMINISTRADO POR | Region CONAVI * | | DIA / MES / AÑO |
| No. DE LA RUTA | 1 | CLASIFICACION: Primary * | CANTON | GRECIA * | LATITUD NORTE | 0 ' 0 " 0 "' | FECHA DE DISEÑO | 1 / 7 / 1968 |
| KILOMETRO | 36.605 km | | DISTRITO | PUENTE DE PIEDF * | LONGITUD ESTE | 0 ' 0 " 0 "' | FECHA DE CONCLUCION DE CONSTRUCCION | / / 1974 |

| No. | UBICACION | NOTA | DIA | MES | AÑO |
|---|---|---|---|---|---|
| 7 | Damage | 77 | 7 | 9 | 2005 |
| 8 | Damage | 88 | 8 | 9 | 2005 |
| 9 | Damage | 99 | 9 | 9 | 2005 |
| 10 | Damage | 11 | 10 | 9 | 2005 |
| 11 | Damage | 22 | 11 | 9 | 2005 |
| 12 | Damage | 33 | 12 | 9 | 2005 |





## Form-6 Condition Rating of the Elements of the Bridge

INSPECTION DE PUENTES (GRADO DE DAÑO)

| No. DE ESTUCTURA | 1 |
|---|---|

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NOMBRE DEL PUENTE | Colorado River 01 | | | LOCALIDAD | PROVINCIA | ALAJUELA * | ADMINISTRADO POR | Region CONAVI * | | | | |
| | | | | | | | | | | DIA | MES | AÑO |
| No. DE LA RUTA | 1 | CLASIFICACION | Primary * | | CANTON | GRECIA * | LATITUD NORTE | ° | ' | " | FECHA DE DISEÑO | 1 | 7 | 1968 |
| KILOMETRO | 36.605 km | | | | DISTRITO | PUENTE DE PIEDRA * | LONGITUD ESTE | ° | ' | " | FECHA DE CONCLUCION DE CONSTRUCCION | | | 1974 |

TIPO DE DAÑO Y EVALUACIÓN DEL GRADO DEL DAÑO

| Elemento | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1. PAVIMENTO | ITEM | 1. ONDULACIÓN | 2. ZURCOS | 3. AGRIETAMIENTO | 4. BACHES | 5. SOBRECAPAS DE ASFALTO | | |
| | EVALUACIÓN | 1 | 1 | 3 | 2 | 1 | | |
| 2. BARANDA (ACERO) | ITEM | 1. DEFORMACIÓN | 2. OXIDACIÓN | 3. CORROSIÓN | 4. FALTANTE | | | |
| | EVALUACIÓN | | | | | | | |
| 3. BARANDA (CONCRETO) | ITEM | 1. AGRIETAMIENTO | 2. ACERO DE REFUERZO EXPUESTO | 3. FALTANTE | | | | |
| | EVALUACIÓN | 1 | 1 | 1 | | | | |
| 4. JUNTA DE EXPANSIÓN | ITEM | 1. SONIDOS EXTRAÑOS | 2. FILTRACION DE AGUAS | 3. FALTANTE O DEFORMACIÓN | 4. MOVIMIENTO VERTICAL | 5. JUNTAS OBSTRUÍDAS | 6. ACERO DE REFUERZO | |
| | EVALUACIÓN | 1 | 5 | 1 | 1 | 5 | 1 | |
| 5. LOSA | ITEM | 1. GRIETAS EN UNA DIRECCIÓN | 2. GRIETAS EN DOS | 3. DESCASCARAMIENTO | 4. ACERO DE REFUERZO | 5. NIDOS DE PIEDRA | 6. EFLORESCENCIA | 7. AGUJEROS |
| | EVALUACIÓN | 1 | 1 | 2 | 2 | 1 | 3 | 1 |
| 6. VIGA PRINCIPAL DE ACERO | ITEM | 1. OXIDACIÓN | 2. CORROSIÓN | 3. DEFORMACIÓN | 4. PÉRDIDA DE PERNOS | 5. GRIETAS EN SOLDADURA O PLACA | | |
| | EVALUACIÓN | | | | | | | |
| 7. SISTEMA DE ARRIOSTRAMIENTO | ITEM | 1. OXIDACIÓN | 2. CORROSIÓN | 3. DEFORMACIÓN | 4. ROTURA DE UNIONES | 5. ROTURA DE ELEMENTOS | | |
| | EVALUACIÓN | | | | | | | |
| 8. PINTURA | ITEM | 1. DECOLORACIÓN | 2. AMPOLLAS | 3. DESCASCARAMIENTO | | | | |
| | EVALUACIÓN | | | | | | | |
| 9. VIGA PRINCIPAL DE CONCRETO | ITEM | 1. GRIETAS EN UNA DIRECCIÓN | 2. GRIETAS EN DOS | 3. DESCASCARAMIENTO | 4. ACERO DE REFUERZO | 5. NIDOS DE PIEDRA | 6. EFLORESCENCIA | |
| | EVALUACIÓN | 1 | 1 | 1 | 1 | 1 | 1 | |
| 10. VIGA DIAFRAGMA | ITEM | 1. GRIETAS EN UNA DIRECCIÓN | 2. GRIETAS EN DOS | 3. DESCASCARAMIENTO | 4. ACERO DE REFUERZO | 5. NIDOS DE PIEDRA | 6. EFLORESCENCIA | |
| | EVALUACIÓN | 1 | 1 | 1 | 1 | 1 | 1 | |
| 11. APOYOS | ITEM | 1. ROTURA DE APOYOS | 2. DEFORMACION EXTRANA | 3. INCLINACION | 4. DESPLAZAMIENTO | | | |
| | EVALUACIÓN | 1 | 1 | 3 | | | | |
| 12. PARED CABEZAL Y ALETONES (BASTIÓN) | ITEM | 1. GRIETAS EN UNA DIRECCIÓN | 2. GRIETAS EN DOS | 3. DESCASCARAMIENTO | 4. ACERO DE REFUERZO | 5. NIDOS DE PIEDRA | 6. EFLORESCENCIA | 7. PROTECCION DE TERRAPLÉN |
| | EVALUACIÓN | 1 | 1 | 1 | 1 | 1 | 1 | |
| 13. CUERPO PRINCIPAL (BASTIÓN) | ITEM | 1. GRIETAS EN UNA DIRECCIÓN | 2. GRIETAS EN DOS | 3. DESCASCARAMIENTO | 4. ACERO DE REFUERZO | 5. NIDOS DE PIEDRA | 6. EFLORESCENCIA | 7. PENDIENTE EN TALUDES |
| | EVALUACIÓN | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | ITEM | 8. INCLINACIÓN | 9. SOCAVACIÓN | | | | | |
| | EVALUACIÓN | 1 | 1 | | | | | |
| 14. MARTILLO (PILA) | ITEM | 1. GRIETAS EN UNA DIRECCIÓN | 2. GRIETAS EN DOS | 3. DESCASCARAMIENTO | 4. ACERO DE REFUERZO | 5. NIDOS DE PIEDRA | 6. EFLORESCENCIA | |
| | EVALUACIÓN | 1 | 1 | 1 | 1 | 1 | 1 | |
| 15. CUERPO PRINCIPAL (PILA) | ITEM | 1. GRIETAS EN UNA DIRECCIÓN | 2. GRIETAS EN DOS | 3. DESCASCARAMIENTO | 4. ACERO DE REFUERZO | 5. NIDOS DE PIEDRA | 6. EFLORESCENCIA | 7. INCLINACION |
| | EVALUACIÓN | 3 | 1 | 1 | 1 | 1 | 1 | 1 |
| | ITEM | 8. SOCAVACIÓN | | | | | | |
| | EVALUACIÓN | 1 | | | | | | |

COMENTARIOS

test

| EVALUACIÓN | GRADO DEL DAÑO | SOCAVACION |
|---|---|---|
| 1 | Ningún daño visible | Sin Socavación |
| 2 | En pocos lugares | Tendencia a socavarse |
| 3 | En muchos Lugares | Socavación no peligroso |
| 4 | En menos de la mitad | Socavación peligroso |
| 5 | En la mayoría de las partes | Condición de Emergencia |

| FECHA INSPECCION | | | NOMBRE DE INSPECTOR | FIRMA |
|---|---|---|---|---|
| 1 | 10 | 2005 | Gabriela Jorge | |

# Chapter. 15 Tools for Bridge Maintenance Management

A guideline and two manuals were prepared during this study as tools to support the Bridge Maintenance activities. They are the Guideline for Bridge Maintenance, the Bridge Inspection Manual and the Manual for Bridge Management System and the outlines of each of these tools are as follows:

## 1) Bridge Inspection Manual

This manual is prepared mainly for the bridge inspectors and bridge engineers. The manual provides instructions on how to implement the inventory survey, the procedures for the routine inspection and the methods to evaluate the bridge deterioration.

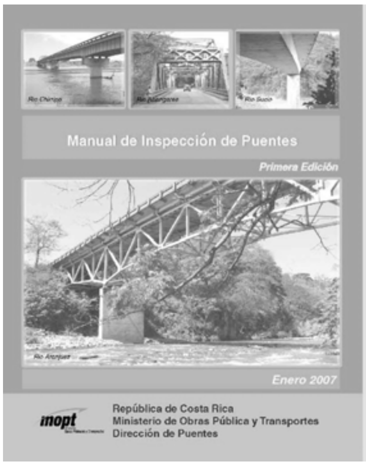
## 2) Manual for Bridge Management System

This manual is prepared mainly for the system administrator and bridge engineers. The manual provides instructions in the methods to operate and maintain the Bridge Management System.

## 3) Guideline for Bridge Maintenance

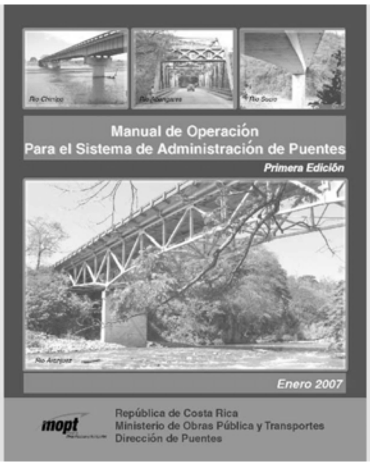
This guideline is prepared mainly for the bridge engineers who engage in bridge maintenance activities. The guideline gives instructions on the concept of bridge maintenance, the causes of the deterioration of a bridge, the method for detailed inspection, the method for carrying out the loading test and the bridge repair methods.

Bridge Inspection Manual




Chap 1 Introduction
Chap 2 Responsibilities of the Bridge Inspector
Chap 3 Inventory Survey and Periodical Inspection for Bridges
Chap 4 Bridge Report System
Chap 5 Coding Guide for Bridge Inventory Data
Chap 6 Coding Guide for Condition Rating for Bridge Elements
Pavement, Steel Railing & Curb, Concrete Railing, Expansion Joints, Deck Slab, Steel Main Girder, Elements of the Bridge, Painting, Concrete Main Girder, Concrete Cross Beam, Bridge Bearing, Parapet and Wing Wall of Abutment, Main Part of the Abutment, Beam of the Pier, Column of the Pier

Operation Manual for BMS




Chap 1 Introduction
1.1 Objective of the System
1.2 Concept of the System
1.3 System Component
1.4 Tools for System Development
1.5 Environment for the System Operation
1.6 System Operation
1.7 Relevant Information
1.8 Process of Data Registration
Chap 2 Operation of the System
2.1 Display and Graphics
2.2 Flow of the System Operation
2.3 Instructions for the System Operation
Chap 3 Administration of the System Data
3.1 Introduction
3.2 Structure of the Data
3.3 Registration and Renewal of Data
3.4 Administration of other Data

Guideline for Bridge Management


Chap 1 Introduction
Chap 2 Outline of the Guideline
Chap 3 Bridge Management System
Chap 4 Identification of Deterioration
Chap 5 Detailed Inspection
Chap 6 Investigation of Load Carrying Capacity
Chap 7 Design
General
Remedial Measures
Deck Slab, Deck Support System, RC-I Beam, PC-I Beam, PC Box Beam, Steel-I Beam, Steel Truss, Substructure, Foundation, Accessories, Prevention System for Bridge Collapse
Chap 8 Safety Measures

# Chapter. 16 Technical Support for Environmental and Social Considerations

## 16.1 Initial Environmental Examination (IEE)

This study summarizes the results of IEE which assesses the potential impacts associated with the bridge rehabilitation planning, maintenance and management of selected 10 existing bridges. Within this study, the field investigation is carried out while the information collection such as literature reviews and interviews with competent environmental agencies/or organizations such as SETENA are conducted. From this IEE study, it is found that no significant potential environmental impacts are recognized since the proposed project is a rehabilitation/maintenance-oriented project and would not have any large-scale construction works of new bridges nor approach roads. However, potential environmental impacts of following environmental factors such as the temporal water quality degradation, traffic jams, noise/vibration, the treatment of the construction waste, the set-up of the construction yards, infectious diseases such as dengue and malaria to the construction workers during the construction period would not be negligible. Several bridge sites may be located in adjacent areas of the important ecological and/or cultural sites or inside of the national parks. Also, it is likely that several illegal squatters stay at two bridge sites. So, it is essential to establish appropriate environmental management program that would lessen or avoid those identified negative environmental impacts.

## 16.2 Technical Support for ToR Development of Environmental Study

First of all, suitable ways of the environmental license approach abiding by both Costa Rican EIA Law and JICA Guideline are discussed. Then, based on both engineering features of the proposed bridge rehabilitation plans and the significance of potential negative impacts to be associated with this rehabilitation plan, the comprehensive list of relevant environmental subtasks are presented. These subtasks are key components of entire EIA study, and covers from, for example, field surveys to impact assessment studies. Several key directions and concepts of ToR development of the relevant environmental studies are summarized. Preliminary results of the project categorization of each bridge rehabilitation plan, one of important steps in the entire license application process, are presented, too.

Selected mitigative measures to be associated with the protection of roadside air quality, noise, water resources, soil and biological environment, would-be crucial environmental factors within the license application process, are summarized. Key directions and concepts of the formulation of the environmental management program and relevant environmental monitoring activities are summarized.

It can be said that all selected 10 rehabilitation plans are categorized into “Category B1” by Costa Rican EIA Law while “Category B” by JICA Guideline.

## 16.3 Stakeholder Meeting

According to the minutes of meeting exchanged between both Governments of Costa Rica and Japan, it is agreed that four JICA Guideline-based stakeholder meetings are to be held throughout this study in order to be put into the public domain for the information disclosure purpose.

Within this study, following information are put at the MOPT's homepage and can be downloaded for any parties and/or individuals who are interested in this proposed study from this website (www.mopt.go.cr/jica-mopt/index.html).

**Table.16.1. Abstract for Stakeholder Meeting**

| | Date | Place | Main Topics |
|---|---|---|---|
| 1 | Feb/21/06 (Thu)<br>9:00 am - 0:00 pm | MOPT | - Project Outline<br>- Environmental and Social Consideration<br>Costa Rica EIA Law & JICA EIA Guideline |
| 2 | Jun/08/06 (Thu)<br>9:00 am - 0:00 pm | CIC | - Results (major findings) of IEE<br>- Miscellaneous |
| 3 | Oct/11/06 (Wed)<br>1:30 pm – 3:00 pm | CIC | - Progress of Bridge Rehabilitation/Improvement Plan<br>- Review of Q/A session of previous stakeholder meetings.<br>- Explanation of Project Homepage (JICA Guideline-based stakeholder meeting)<br>- Major environmental issues to be associated with each bridge rehabilitation plan.<br>- Key Directions and Concepts of ToR Development<br>- Preliminary Project Categorization Results<br>- Miscellaneous |
| 4 | Dec/07/06 (Thu)<br>(Steering Committee)<br>8:30 am – 11:30 am | CONAVI | - Outline of Study Results<br>- Preliminary Project Categorization Results<br>- Miscellaneous |

MOPT: Ministry of Public Works and Transport, CIC: Civil Engineer's Association of CFIA


# Chapter. 17 Conclusions & Recommendations

## 17.1 Conclusions

### 1) Attainments

Consequently that capacity gaps and major issues on the bridge maintenance are minutely assessed and screened out during the study period, an synthetic program for bridge maintenance improvement has been concretely formulated and set about launching under the concept of the Program-Project-Management.

The bridge maintenance program is undertaken by the Bridge Maintenance Consulting Group (BMCG) as described thoroughly in Chapter 6, and is expected to render total efficacy to the Organizational level as well as the social/institutional level in need of the improvement. Simultaneously, diverse training activities have been duly experienced as trial inputs throughout the Technical Training Program stated in Chapter 7.

In particular mentions over those trial inputs, the loading test enforced on 2 bridges as well as the detailed design provided for rehabilitation, reinforcement and improvement work of 10 bridges deserve to be largely featured herewith. These two activities are completed with successful outputs grounded on consistent technical efforts of the mutual collaboration between the Counterpart and the Study team, which are described in detail in Chapter 10 and 11 respectively.

It is a significant attainment that considerable technical and administrative competences for the Counterparts have reached a worthwhile enhancement especially on the individual level.

### 2) Tasks Remaining

As results of the monitoring and evaluations specify in detail at Chapter 6, however, it is not that a desirable level of the capacity development has been embodied on all of three targeted levels.

**(1) Individual capacity level,** which results satisfactory at the early stage of the capacity development in terms of the technical competences, is expected to be further enhanced shifting to rather practical, hands-on stages of technical aspects based on trial inputs that the training program earlier described has widely rendered.

It is generally recognized that technical competences on the bridge engineering are neither to be piled up nor to gain the summit one day for another. There are still tasks remained on the transition which basic skills, acknowledge and tools outputted such as the comprehensive Manuals & Guideline are allowed to take root in engineers and to infiltrate into the far advanced level of the capacity for this particular country and/or regions.

**(2) Organizational, institutional and social capacity levels** are just set on a starting line to elaborate and roll-play their implementation plans formulated by BMCG under the bridge maintenance program.

Since it is crucial for the BMCG to be formed with members sector-widely and inter-institutionally summoned due to roles and tasks specified on the modular projects, there might be uncertain factors on managerial aspects to enforce the program plans. Close enlacement and coordination among the members, budgetary arrangements are indispensable factors to be secured.

### 3) Conclusions

As stated over previous chapters, the “Capacity Development in Bridge Rehabilitation Planning, Maintenance and Management Based on 29 Bridges of National Highway Network” has commenced and efficaciously expanded on strengthening capability of the maintenance of bridge in Costa Rica. Along with a technical examination for the rehabilitation of 29 bridges inclusively the design for repair works of the 10 selected bridges, which represent structural features of totality, as well as multiple advocacy activities for the Asset Management, awareness and comprehension on the concept of Capacity Development have been extensively rewarded with positive results and efficacy.

Now that the Capacity Development for the Bridge Maintenance has indeed commenced to deepen understandings amongst governmental agencies, academic and/or non-governmental institutions, it shall be high time that the Government of Costa Rica squarely persists in facing this significant issue with firm political visions and commitments.

The sustainability of the capacity development is a key word. It shall be essential that outcomes/outputs from the study are to be initiatively taken over by the Counterparts afterwards withdrawal of the external technical assistance, and that necessary follow-up cares are to be fed strategically into not long but short-mid term perspectives.

## 17.2 Recommendations

### 1) Follow-Up Cares of the Study Outputs

#### (1) Implementation of Comprehensive Bridge Maintenance Program via Formulation of Full-scale Work Breakdown Structures & Operation Plans for 5 Integrated Modular Projects

Based on the proposed preliminary work breakdown structures (WBS) and plan of operations (PO) for 5 integrated modular projects which are integral components of the bridge maintenance improvement program, MOPT and CONAVI, under the assistance of the members of 5 working groups of the Bridge Maintenance Consulting Group (BMCG), are required to formulate the full-scale and detailed WBS and PO for each modular project, thereby providing the clear-cut road map to achieve the ideal bridge maintenance program. These full-scale and detailed WBS and PO will be utilized as basis of the budget request for the financial year 2008 to 2012.

#### (2) Smooth Continuous Operation of BMCG & 5 Working Groups

While the BMCG acts as an advisory and consulting body to strengthen the institutional capacity of the newly established direction of bridges of MOPT and the planned department of bridge conservation of CONAVI, 5 working groups of the BMCG are responsible for the implementation of 5 integrated modular projects. The smooth and regular operation of the

BMCG as well as 5 working groups is absolutely required for the actual implementation of 5 integrated modular projects. Strong commitment by each member, protocols for procedures, and clear-cut demarcation of responsibilities among members are essential ingredients for the success of the smooth operation of the BMCG and 5 working groups. Especially, since the members of the BMCG are normally engaged in the original works of the organizations which they belong to, those organizations will be required to provide necessary back-stop services to the members.

**(3) Individual Capacity Improvement of MOPT & CONAVI Officials (Implementation of Modular Project 1)**

Individual capacities of MOPT and CONAVI officials should be steadily improved by a series of seminars as well as on-the-job training opportunities in the following fields so as to meet the demand of the institutional strengthening of MOPT and CONAVI.

**i) Individual capacity improvement in the field of inspection & diagnosis**

Appropriate periodical inspection and diagnosis of the existing bridges are basic and integral capacities for the bridge maintenance. The collected and diagnosed data of the existing bridges are obtained from the periodical inspections by the proper inspection manual which was drafted during the study period.

**ii) Individual capacity improvement in the field of BMS operation & prioritization**

A Bridge Management System (BMS) is a cardinal tool for the bridge maintenance practices. The BMS allows MOPT and CONAVI to analyze the priority selection of the bridges to be repaired and reinforced based on the database formatted by the BMS operation manual. The BMS itself should be flexibly and continuously updated in response to the identified operational problems, and the operation of the BMS should be linked with the improvement of inspection and diagnosis practices.

**iii) Individual capacity improvement in the field of planning & bridge maintenance**

In response to the results of the priority selection of bridges, the planning, designing, and implementation of repairs and reinforcement after the detailed inspections should be implemented. A series of these bridge maintenance practices should be implemented in compliance with the drafted guideline for the bridge maintenance. Since the bridge maintenance technologies can be acquired by ***learning by doing*** process, ample opportunities for on-the-job basis training should be continuously provided so as to generate sufficient qualified staff.

**(4) Strengthen New Strategy for MOPT Bridges & Create Proposed Bridge Conservation Department for CONAVI (Implementation of Modular Project 2)**

**i) Demarcation of responsibilities between MOPT & CONAVI Bridge Conservation Department**

In accordance with the proposed demarcation of responsibilities between MOPT and CONAVI, MOPT and CONAVI are required to jointly work for streamlining the workflows of both new bridge-related organizations.

**ii) Strengthen new strategy for MOPT bridges & create CONAVI Bridge Conservation Department**

Since the current bridge design department of MOPT is being upgraded to the new direction of bridges from the financial year 2007, this strong momentum for the institutional reform should be utilized at maximum to obtain ample financial and human resources for the bridge maintenance. In addition, the new department of bridge conservation of CONAVI is being proposed together with the ideal organizational structure, while CONAVI has not been specifying the details of the new department. Although the required number of staff, the proposed organizational structure, the required budget for the new direction of bridges of MOPT as well as the proposed department of bridge conservation of CONAVI are estimated, there are sizable gaps between the required scale of budgets and the requested amounts of budgets. The detailed organizational structures, the number of staff by expertise, the step-by-step enlargement of the total number of staff, and the budgetary arrangement for the operational and personnel costs should be finalized in close relations with planning and financial authorities.

**(5) Long-term Human Resources Development & Technical Information Exchanges (Implementation of Modular Project 3)**

The long-term human resources development which provides ample candidates for staff of MOPT and CONAVI officials as well as the private sector in the field of bridge maintenance is a key to the sustainable bridge maintenance. A couple of universities such as the University of Costa Rica can be regarded as candidate academic institutions to supply qualified graduates for the required engineers through relevant new courses in the field of bridge engineering and maintenance. The scale, schedule and budgetary plan for new courses at these universities should be designed taking into account the domestic demand and market size of the bridge construction and maintenance. At the same time, by using opportunities on the technical commission of PPP on the highway network, a series of technical information exchanges in the field of bridge maintenance should be promoted among the PPP member countries as the follow-up activities after the PPP regional seminar held in December 2006. Furthermore, the periodical domestic technical information exchanges among the public sector, the academic institutions and the private sector in the field of bridge engineering and maintenance should be also implemented.

**(6) Improvement of Regulations & Standards (Implementation of Modular Project 4)**

Relevant regulations and standards in the field of bridge designing and procurement procedures under the both public and concessionaire projects should be significantly improved by reviewing existing regulations and standards. Although the inspection manual, the BMS operation manuals and the guideline for the bridge maintenance are all drafted during the study period, relevant regulations and standards are not sufficiently improved. Especially, special attentions must be paid on the bridges which have been and will be constructed under the concession projects so as to make those concessionaires appropriately make use of the drafted inspection manual as well as the guideline for the bridge maintenance, thereby these bridge maintenance practices by concessionaires being complied with those of the regular public investment projects.

**(7) Promotion of Advocacy of Government Officials & Public Relations (Implementation of Modular Project 5)**

Since the budgetary arrangement is a key to the implementation of 5 integrated modular projects, especially, the individual capacity improvement (the modular project 1) and the institutional reform of MOPT and CONAVI (the modular project 2), the understanding on the importance of asset management by top government officials as well as the strong political commitment to the resource allocation for the bridge maintenance is essential for the sustainable bridge maintenance. At the same time, in an attempt to promote the understanding by taxpayers as well as bridge users on the importance of the bridge maintenance, various domestic public relations activities should be implemented by using available media and channels. The well-balanced budget allocation between the constructions of new bridges and the maintenance of existing bridges should be recognized by both government officials and taxpayers through these advocacy and public relations activities.

#### (8) Continuous Monitoring & Evaluation on Outcomes for Capacity Development Process

The outcomes of the capacity development through the implementation of 5 integrated modular projects are required to be periodically monitored and evaluated to ensure that the capacity development process is on the right truck in accordance with the proposed monitoring and evaluation procedures. Benchmarks as performance indicators for monitoring and evaluation will be continuously updated for the feedbacks to the capacity development activities. A couple of officials who are proficient in project management framework tools such as PDM, WBS and PO should be stationed in the monitoring unit of the secretariat of the BMCG.

### 2) Deflection of Pre-stressed Concrete Box Girder Bridges

Abnormal deflection can be observed at the central span of two pre-stressed concrete box girder bridges: Bridge No.17 (Rio Chirripo, about 20cm) and Bridge No.20 (Rio Sucio, about 27cm). The above analyses indicate that Bridge No.17 and No.20 satisfy the necessary structural requirements, except for the deflections observed at the central spans, and will therefore be able to serve traffic safely. It is thought that the observed deflections are due to insufficient quality control during construction. However, this is an assumption as there are no original construction plans and construction records available. Note that the load carrying capacity of the bridges for HS20+25% was checked in the structural analysis using a model based on original design drawings.

Given the preceding, the Study Team is of the opinion that Bridge No.17 and No.20 can serve the public safely in the future. However, it is recommended that the deflections of these bridges be measured for change at least once every year.

### 3) Ensuring Sufficient Funding for Bridge Rehabilitation and Reinforcement

The Study Team has examined and compiled concepts and methodologies on the proper rehabilitation and reinforcement of the Study bridges that will produce substantial benefits for the public. It is recommended that the public be made conscious of this via an awareness campaign to ensure sufficient future funding for these structures.

### 4) Environmental and Social Considerations

Throughout this IEE study, it was found that potential impacts to be caused by the proposed bridge rehabilitation program such as the impacts on the water quality would not be negligible at the construction phase. Also, several bridge sites may be located in the adjacent of the important biological corridor (Figure 16.2.1), and thus, would become critical discussion points at both construction and operation phases. ToR of this further environmental study shall be developed based on Costa Rican EIA law as well as relevant laws/or regulations such as the biodiversity law, and then, relevant environmental studies shall be carried out based on the developed ToR.