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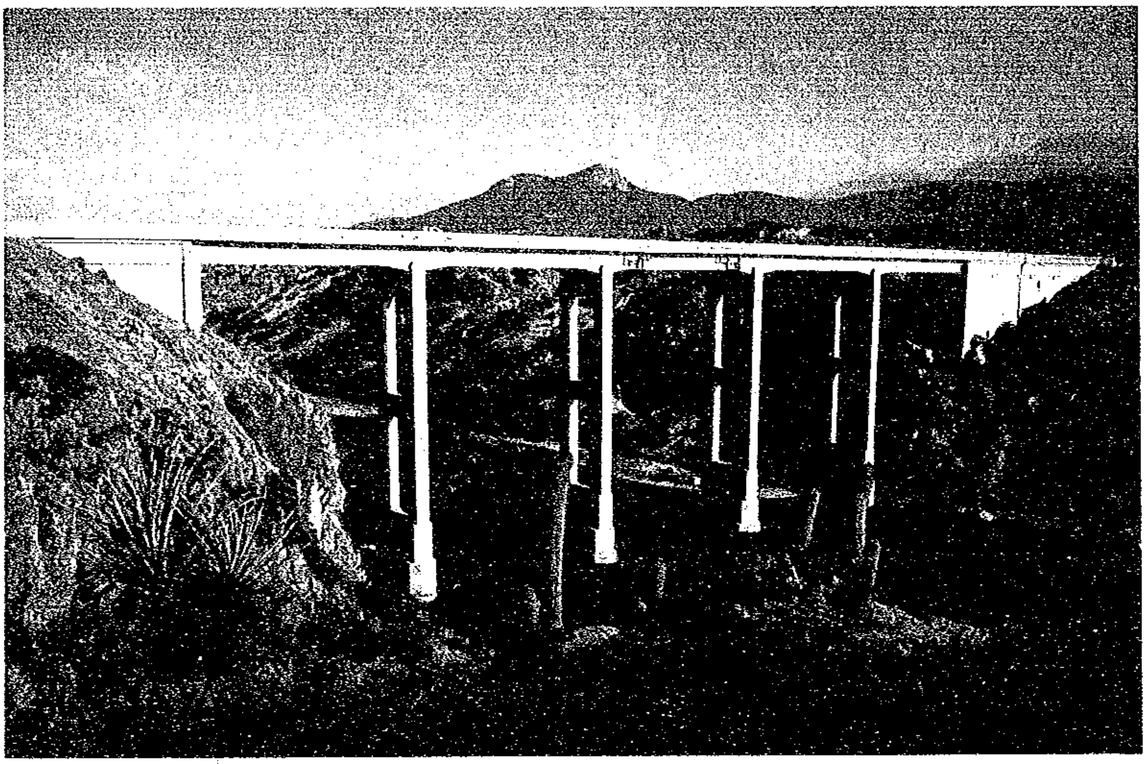
No. 22

The Study on the Rehabilitation and Conservation Program of Bridges in The Republic of Chile



Final Report (Summary)

March 1993

Japan International Cooperation Agency

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PREFACE

In response to a request from the Government of the Republic of Chile, the Government of Japan decided to conduct a Study on the Rehabilitation and Conservation Program of Bridges in the Republic of Chile and entrusted the Study to the Japan International Cooperation Agency (JICA).

JICA sent to Chile a study team headed by Mr. Katuyuki Hioki, Chodai Co.,Ltd , three times between October, 1991 and February 1993.

The team held discussion with the officials concerned of the Government of Chile, and conducted field surveys at the study area. After the team returned to Japan, further studies were made and the present report was prepared.

I hope that this report will contribute to the promotion of the project and to the enhancement of friendly relations between our two countries.

I wish to express my sincere appreciation to the officials concerned of the Government of the Republic of Chile for their close cooperation extended to the team.

March, 1993

Kensuke Yanagiya
President

Japan International Cooperation Agency

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Chapter 1 Introduction

1-1 Survey Background

The coast line of the Republic of Chile is long, running approximately 4,270km north and south. Mountain ranges parallel the coast line, with the Coast Ranges running down the Pacific coast, paralleled by the Andes to the east. Looking east and west, the country is very narrow, with a maximum width of 150km and a minimum width of 80km. 80% of the county is mountainous and high mountains are prominent especially in the northern and central regions.

In order to promote regional economic development and export business, the construction of traffic networks connecting production areas and consumption and shipping areas is urgent. Presently, Chile receives financing from international agencies such as the World Bank and IDB, for developing its road traffic network. The Pan America Highway, which extends north and south, and its adjacent roads are the core of Chile's transportation and traffic network. However, the bridges on these roads are old and present a major obstacle to the development of the road traffic network system.

The construction of bridges in Chile became active in the 1980s and there are now approximately 8,000 bridges. However, earthquakes frequently occur in this country which has more than 55 active volcanoes. In addition to the earthquakes, heavy deterioration of the existing bridges and erosion from fast-flowing rivers from high mountains, such as the Andes, present serious problems in maintaining and managing Chile's bridges.

MOP recently created an inventory of existing bridges on and in close proximity to the Pan America Highway, which is Chile's main road, in order to maintain the functioning of the highway. MOP is planning to establish a bridge maintenance, repair, and management system based on this inventory. In order to activate the efficient maintenance and management of these bridges, it is necessary to summarize and utilize the information which has already been collected individually. Therefore, the establishment of a bridge information system using a data base is also planned. Through this system, a bridge record, inspection record, and repair record, which are presently collected individually, will be systematized and prepared for common use as comprehensive bridge information. By utilizing this method, costs vs effects can be judged rationally.

Given these circumstances, MOP has asked Japan, which has similar topography and geology, and high-technological expertise in the field of bridge earthquake-proofing, for its cooperation and assistance with this plan.

1-2 Survey Outline

1-2-1 Survey Objective

At the request of the Chilean government, a field survey for bridges along the Pan American Highway and the major adjacent routes was conducted throughout Chile, except in the 11th and 12th states. From the field survey, a maintenance, inspection, and repair plan, and related guidelines were created. Additionally, a data base system was constructed using a computer in order to systematically manage all collected information and to perform effective bridge maintenance and management.

The objectives of the field survey can be summarized as follows.

1) To propose a bridge maintenance and management method which is appropriate for Chile.
2) To perform a field survey and collect data related to bridge maintenance and management, and to create a bridge repair plan.
3) To systematize the bridge records and construct a data base.
4) Through this survey, transfer technology related to bridge maintenance, inspection, and management operations to the counterpart engineers in Chile.

1-2-2 Survey Outline

The survey can be divided into the following three themes.

1) Survey of the present bridge situation and determination of a bridge repair plan.
2) Preparation of bridge maintenance and inspection guidelines.
3) The creation of a bridge maintenance and management system.

(1) Present Bridge Situation Survey and Determination of a Bridge Repair Plan

The survey of the present situation regarding bridges in Chile was performed by dividing the survey into a preliminary survey and a detailed survey.

1) Preliminary Survey

The following survey was performed targeting 256 bridges along Route 5 in the 4th to the 10th state, as well as, bridges along other adjacent main roads.

a. Visual observation inspection (deterioration, damage, deformation)
b. Measurement of basic bridge dimensions
c. Photographing bridges

Based on this survey, general bridge structural drawings were created, and a comment chart was created outlining the damage evaluation, structural characteristics, and problems related to bridge maintenance and management.

2) Detailed Inspection Survey

Based on the results of the preliminary survey and its analysis, 10 bridges were targeted for detailed survey. The following surveys were performed.

a. Survey of the deterioration of structural materials such as concrete and steel.
b. Measurement of bridges and related facilities, and a deformation survey.
c. Geological survey

With regard to bridges that traverse rivers, the influence of rivers on bridge structures was surveyed and countermeasures were discussed. A road test was performed for the Peuco Bridge. The purpose of this test was to clarify the characteristics of the Peuco Bridge, to collect data related to the possibility of fatigue failure, and to introduce the latest road test methods to Chilean bridge technicians.

3) Determination of Bridge Repair Plan

Based on the results of the detailed inspection survey, a method of repair was proposed. The proposed method of repair was created based on the following concepts.

a. Priority was given to the recovery of the original functions. Function enhancement was not considered.
b. Design repair based on each member's structural calculations was not performed.
c. Structural damage and the environment surrounding the bridges such as nature and traffic volume were considered.

(2) Creation of Bridge Maintenance and Inspection Guidelines

Bridge maintenance and management is a project to maintain bridge functions, from the completion of bridges to their replacement. In promoting maintenance and management activities, "Bridge Maintenance Repair Guidelines" was created for the technicians in charge of the project. This guideline consists of the following:

1) Definition of terminology used for bridge maintenance and management.
2) Visual inspection survey method
3) Method of evaluating inspection results and standards.
4) Standard repair methods
5) Detailed inspection survey methods
6) Examples of repair methods

(3) Creation of a Bridge Maintenance and Management System

Computers were essential in order to create repair plans scientifically and rationally. In this survey, a system was proposed to evaluate bridge soundness, repair priorities, and to calculate rough estimates for repair costs.

1-3 Survey Organization

The survey was performed in Chile and in Japan. The survey organization consisted of a delegation organized by JICA and its counterpart dispatched from the Chile National Government Agency. The survey was performed through the organization shown in Figure 1-1.

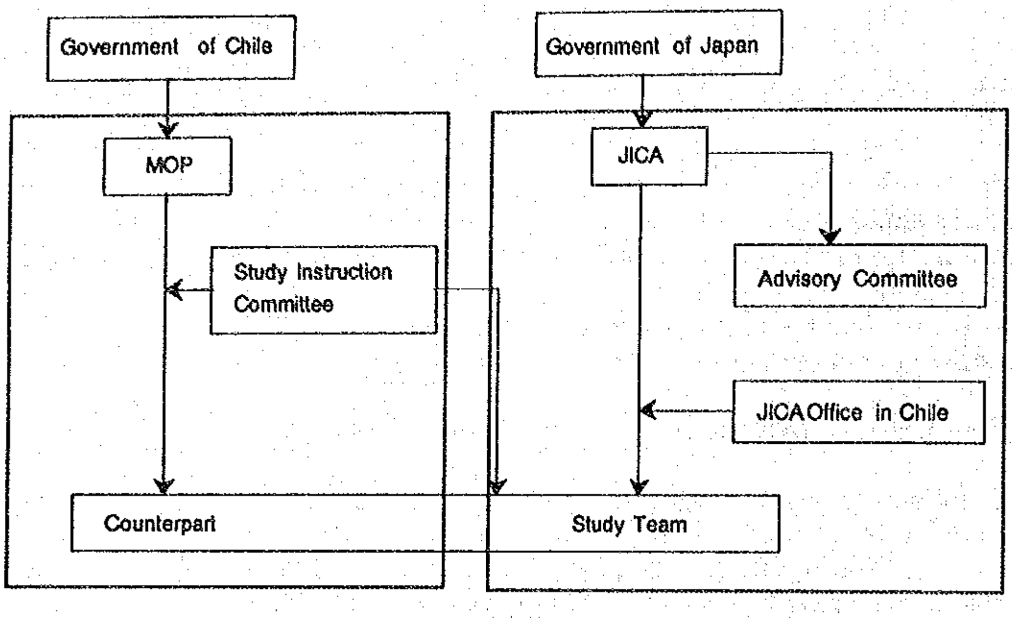


Figure 1-1 Survey Performance Organization

1-4 Survey Targeted Area

The survey was performed targeting bridges along the major highway Route 5 (Pan American Highway runs through every state) and the adjacent main highways in every state, except for the northern 1st, 2nd, and 3rd states and the southern 11th and 12th states. The survey area is shown in Figure 1-2.

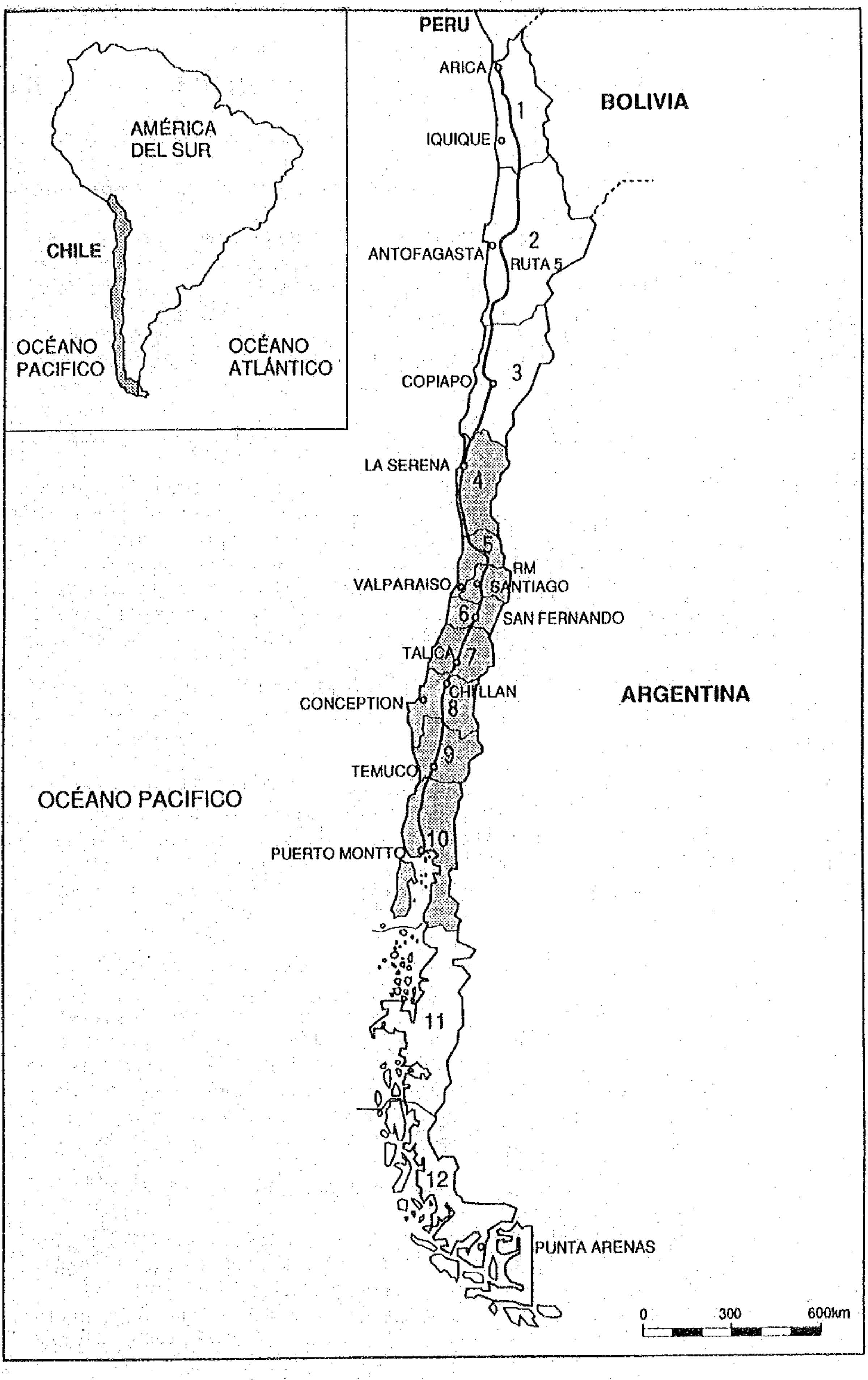


Figure 1-2 Survey Targeted Area

Chapter 2 Bridge Survey

2-1 Bridge Preliminary Survey

2-1-1 Outline of Preliminary Survey

Three teams conducted preliminary surveys targeting 240 bridges. As per agreement, survey bridges included those of a length 10 meters or greater located in the states numbered 4 to 10, and bridges especially required by MOP. Initially, there was a slight difference between the number of targeted bridges proposed by MOP and the actual bridges surveyed. In the end, the number of bridges surveyed by the delegation was 246 located along Route 5 (Figure2-1 to Figure 2-8), and 10 bridges located on routes other than Route 5.

2-1-2 Field Survey Method

In order to perform the survey along a 2,000 km route, extending north and south, the delegation was divided into 3 survey teams. A survey chart (Table 2-3) was created prior to operation in order to maintain consistency in the types of data obtained from each survey team. Data included estimation of bridge damage, basic bridge size, and specific bridge portions to be photographed. Furthermore, prior to the actual survey, a joint survey was conducted and opinions were exchanged in an effort to minimize differences in the evaluation values between each survey team.

The following survey sheet was prepared for the preliminary survey.

1) Inspection Record

An inspection record (Table 2-1) was created as a means to eliminate differences in inspection parts and evaluation items between surveying teams. The record lists the same items as in the inspection book; as well, these items are basically the same as the evaluation matrix which is used for evaluation of bridge soundness. The essential items were determined during an exchange of opinions after the joint survey.

2) Record of Basic Bridge Measurements

As was expected many old bridges did not have drawings or a record of basic information for input into the data base. In these cases, basic bridge measurements were performed. Measurement records (Figure 2-9) were created showing the elements that would be measured, such as, bridge width and length. Once again efforts were made to minimize inconsistencies in the measuring data, and general structural drawings were made based on this record.

3) Photographic Positioning Instructions

Photographs were an important feature of the inspection data. Reference drawings (Figure 2-10) such as overall structural drawings, bridge surface conditions, main girders, slab, crossbeams, abutments, bridge piers were created, along with drawings of the structures which required special attention and drawings which showed bridge damage.

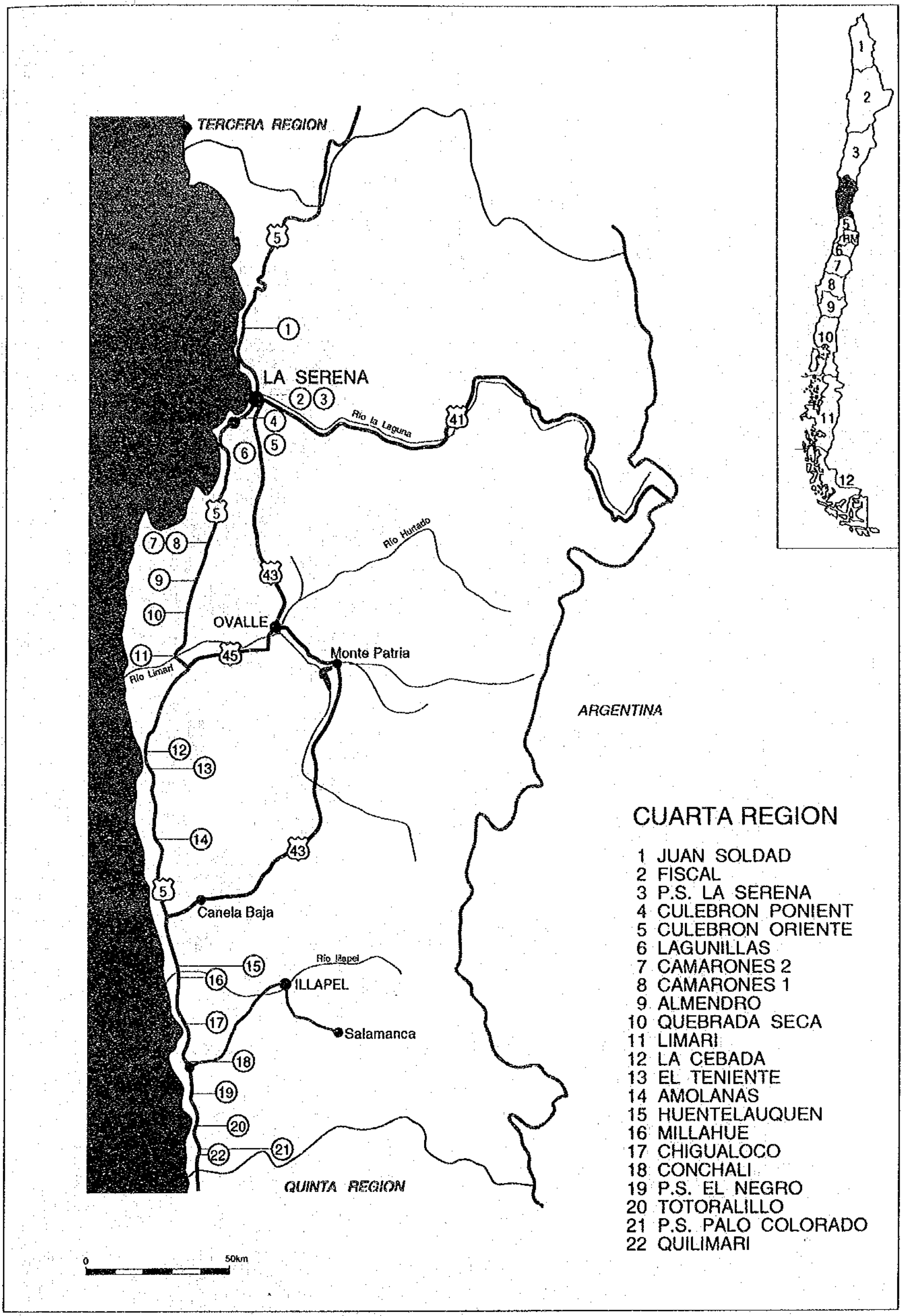


Figure 2-1 Survey Targeted Bridges in the 4th State

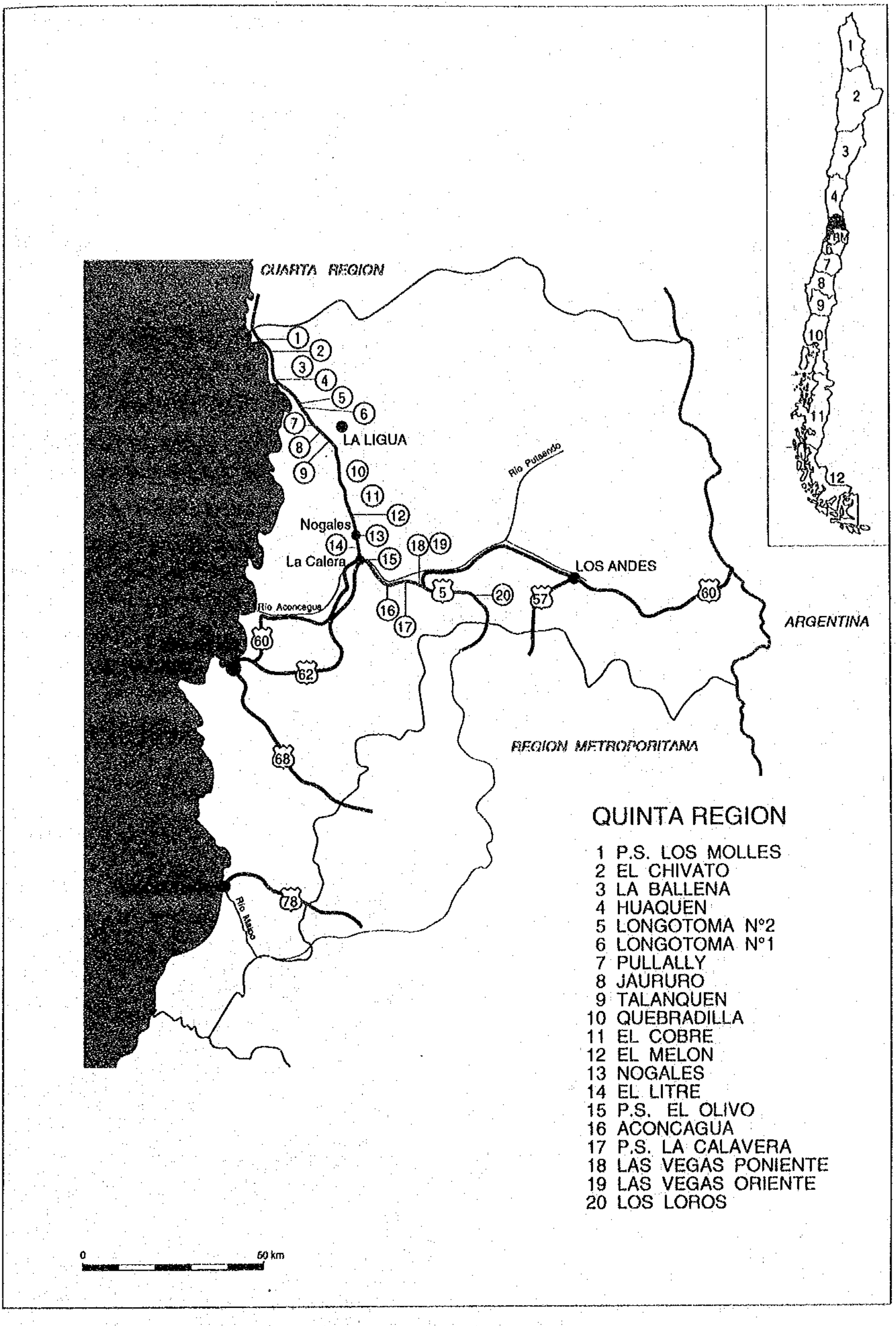
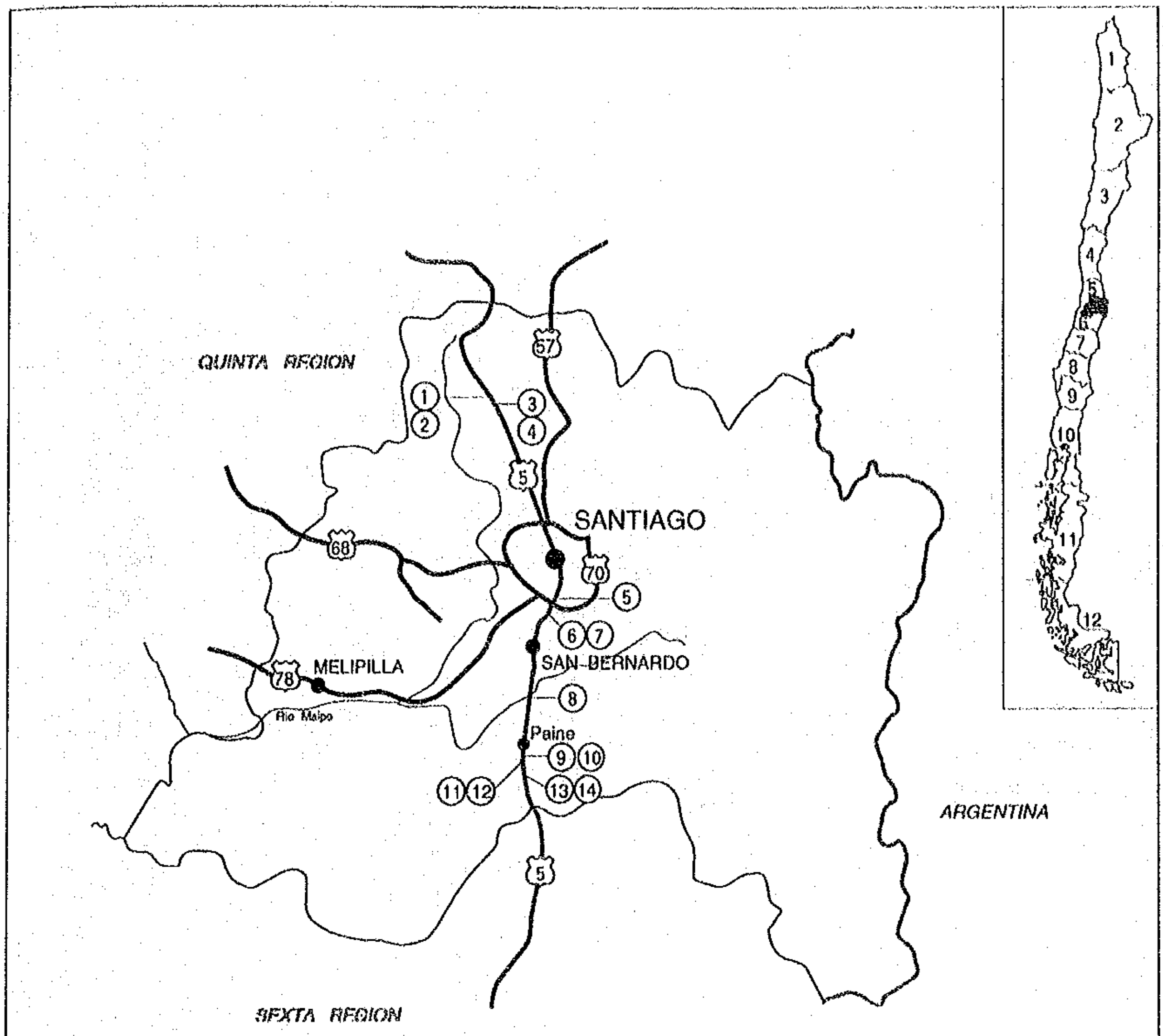


Figure 2-2 Survey Targeted Bridges in the 5th State

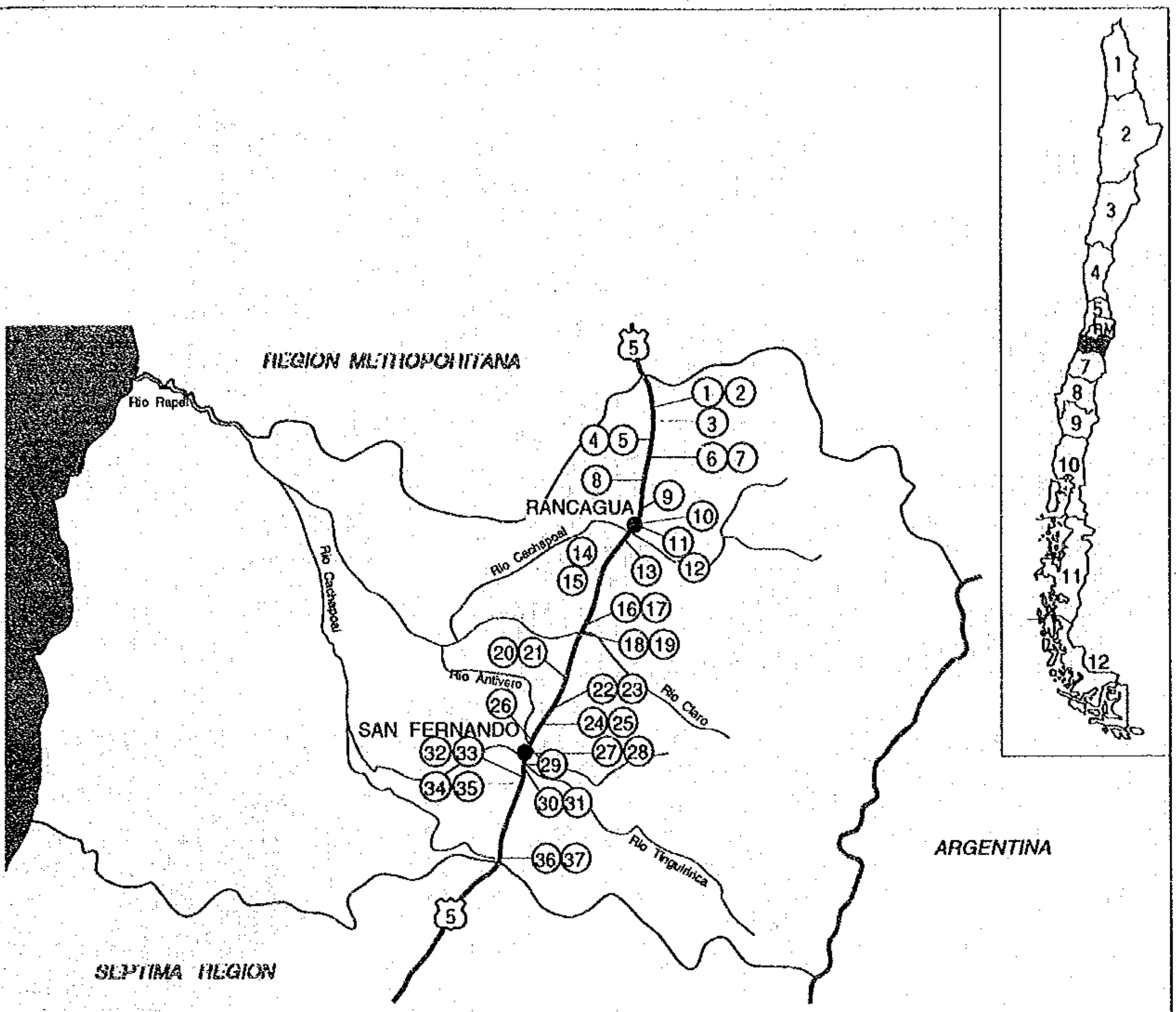


REGION METROPOLITANA

1 PEUCO ORIENTE
2 PEUCO PONIENTE
3 LO PINTO N°1
4 LO PINTO N°2
5 P.S. LO SIERRA
6 P.S. FF. CC. AL SUR N°1
7 P.S. FF. CC. AL SUR N°2
8 MAIPO
9 P.S. FF. CC. PAINE PONIENTE
10 P.S. FF. CC. PAINE ORIENTE
11 PAINE N°1
12 PAINE N°2
13 P.S. HOSPITAL ORIENTE
14 P.S. HOSPITAL PONIENTE

0 50 km

Figure 2-3 Survey Targeted Bridges in the Capital State



SEXTA REGION

1 PEUCO ORIENTE
2 PEUCO PONIENTE
3 TRONCO
4 STA BLANCA PONIENTE
5 STA BLANCA ORIENTE
6 BENITO N°1
7 BENITO N°2
8 CADENA
9 P.S. ALAMEDA
10 P.S. MACHALI
11 P.S. EL TTE. N°1
12 P.S. EL TTE. N°2
13 CACHAPOAL
14 P.S. LOS LIRIOS ORI.
15 P.S. LOS LIRIOS PON.
16 TIPAUME N°1
17 TIPAUME N°2
18 CLARO N°1
19 CLARO N°2
20 P.S. PELEQUEN PON.
21 P.S. PELEQUEN ORI.
22 RIGOLEMU ORI.
23 RIGOLEMU PON.
24 CHARQUICAN ORI.
25 CHARQUICAN PON.
26 P.S. SAN FERNANDO
27 ANTIVERO ORIENTE
28 ANTIVERO PONIENTE
29 P.S. TERMAS
30 TINGUIRIRICA ORI.
31 TINGUIRIRICA PON.
32 DESCARGA N°1 ORI.
33 DESCARGA N°1 PON.
34 DESCARGA N°2 ORI.
35 DESCARGA N°2 PON.
36 PEOR ES NADA ORI.
37 PEOR ES NADA PON.

0 50 km

Figure 2-4 Survey Targeted Bridges in the 6th State

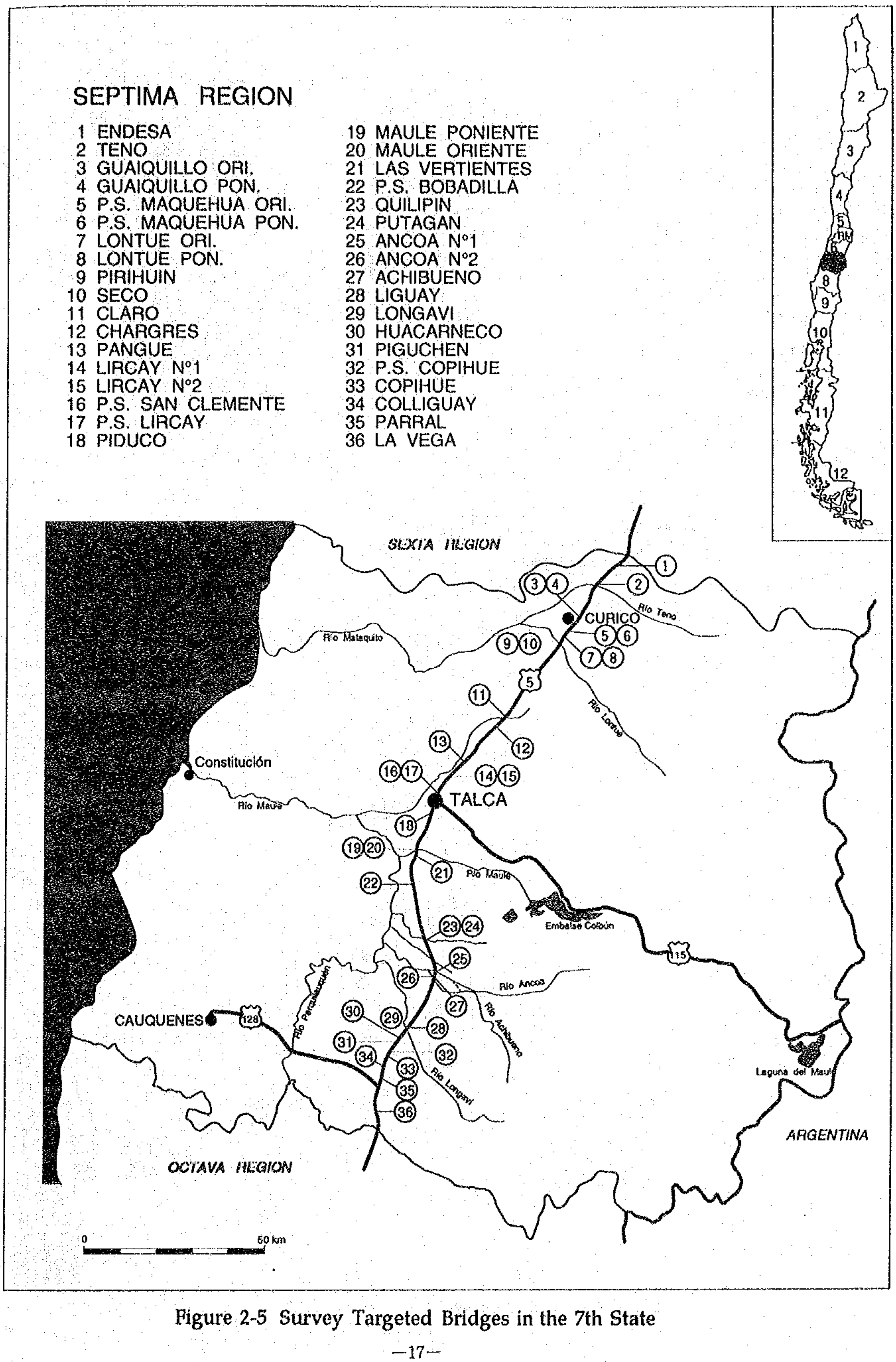


Figure 2-5 Survey Targeted Bridges in the 7th State

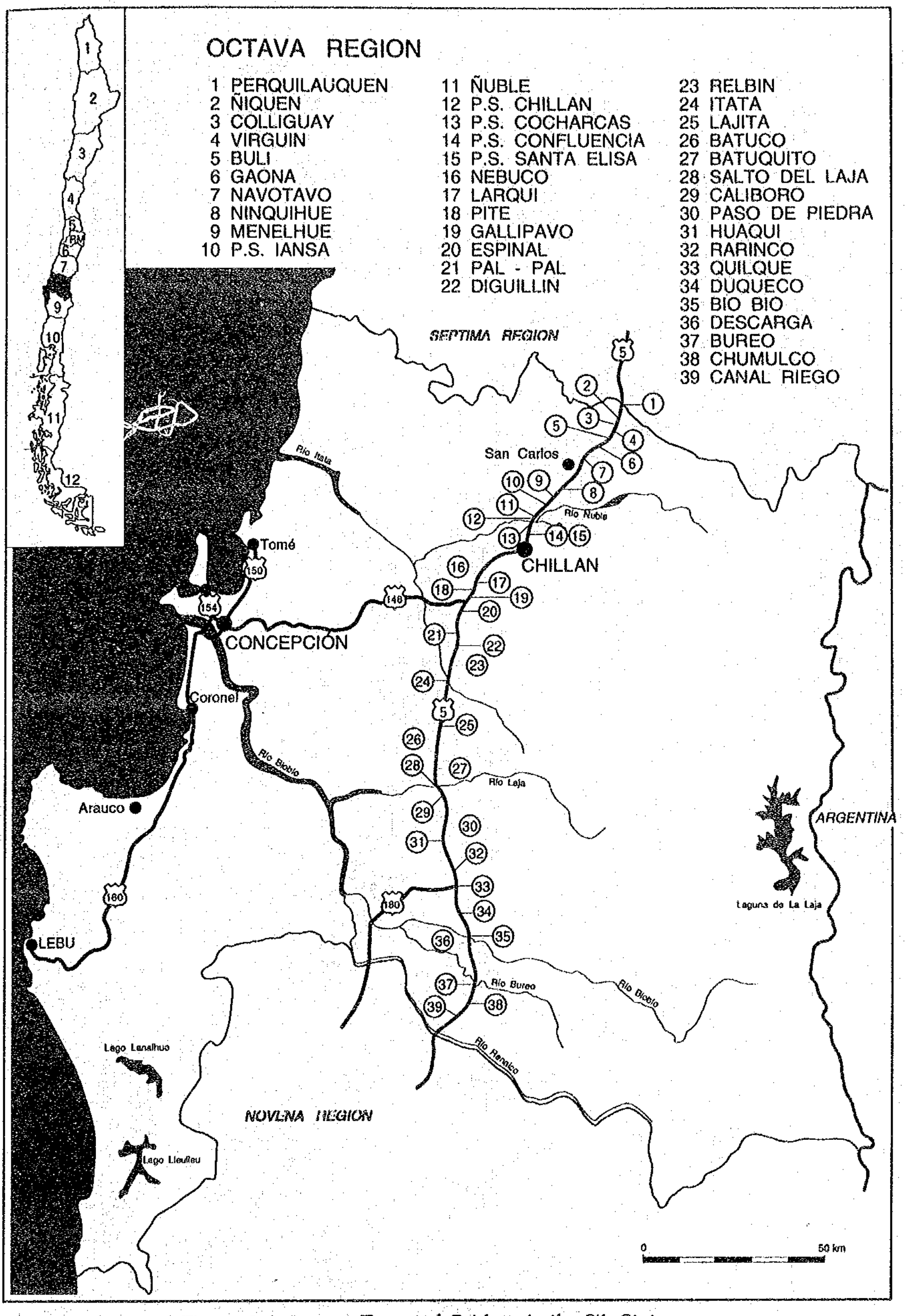


Figure 2-6 Survey Targeted Bridges in the 8th State

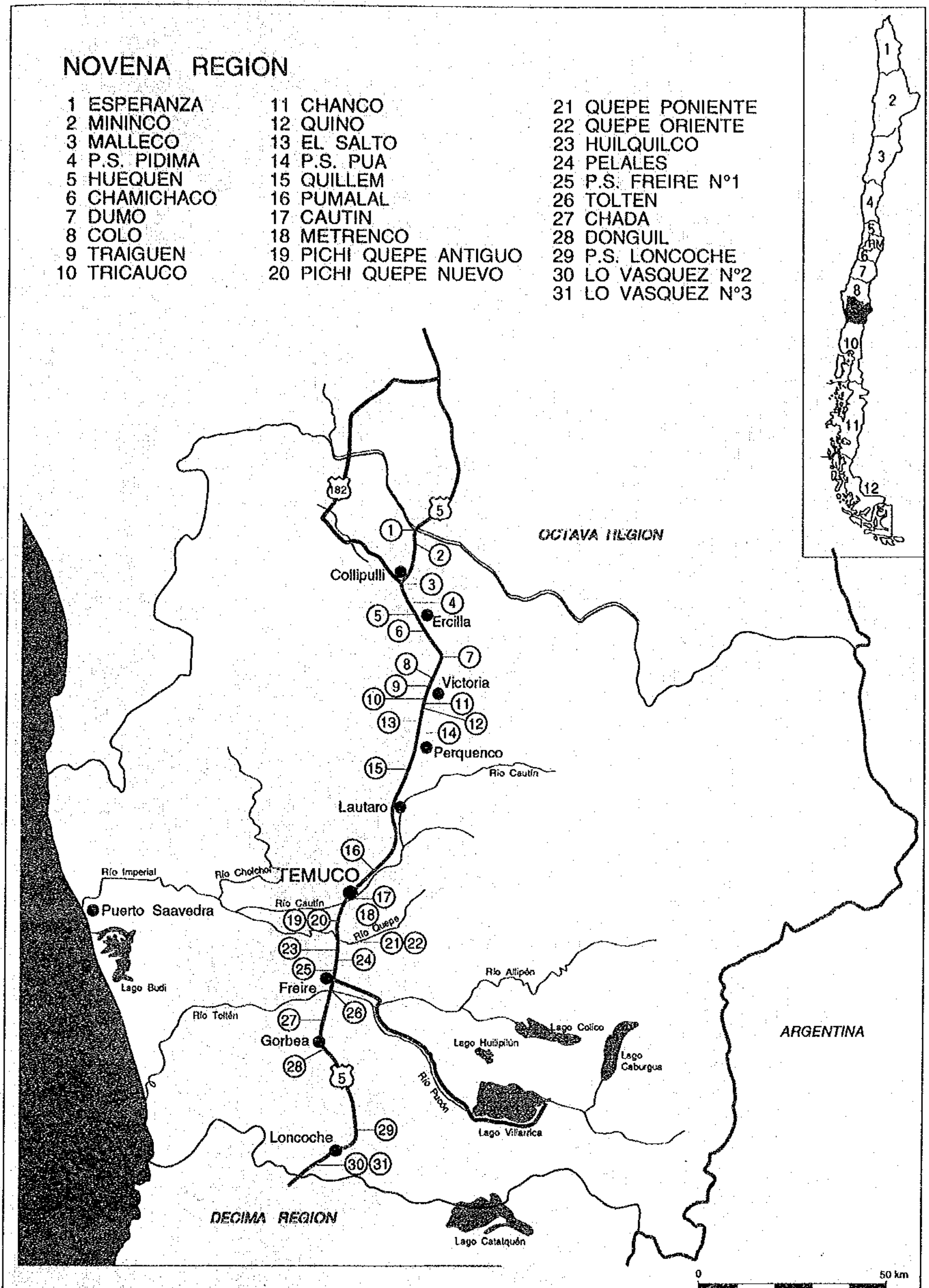


Figure 2-7 Survey Targeted Bridges in the 9th State

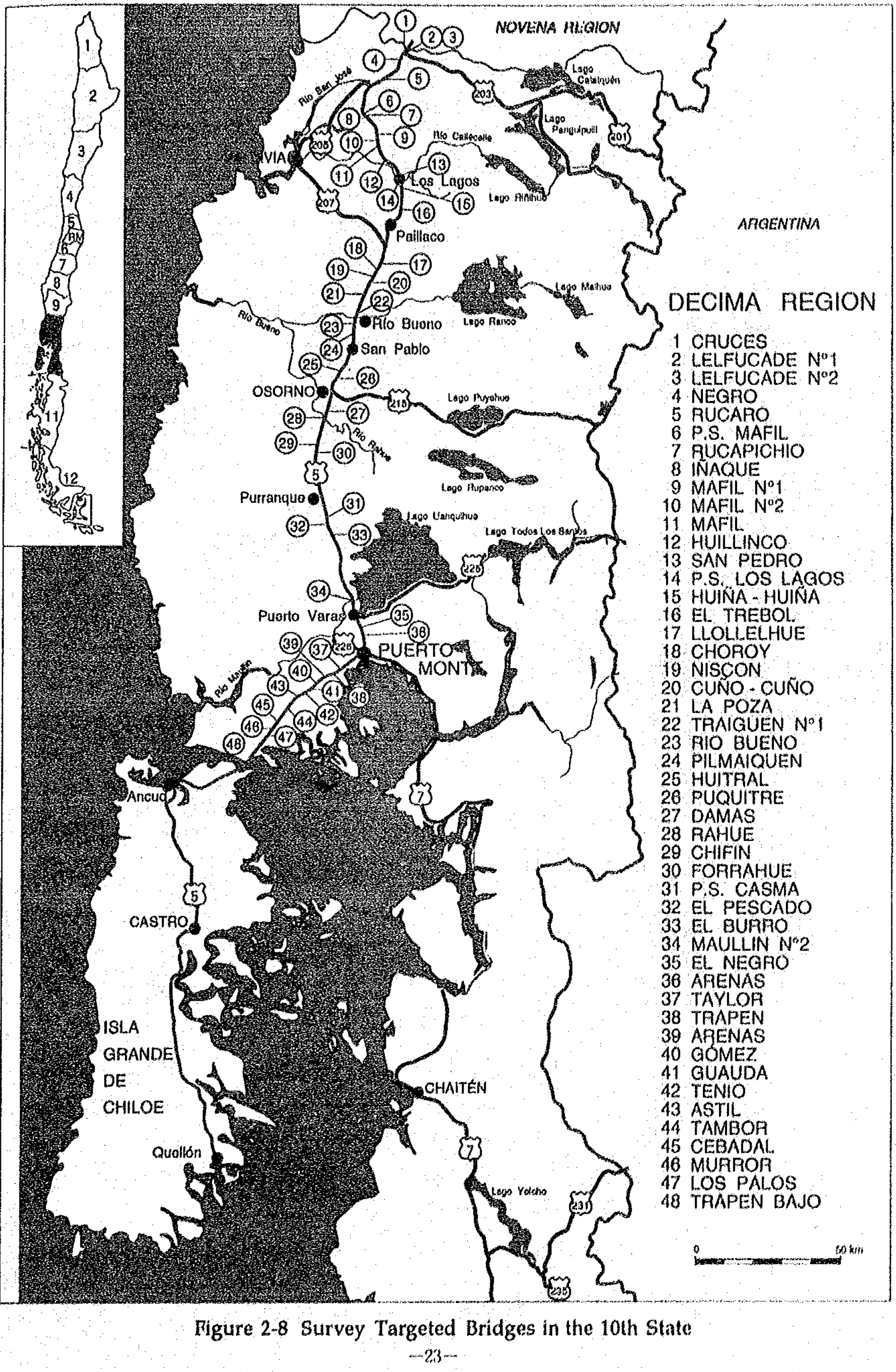


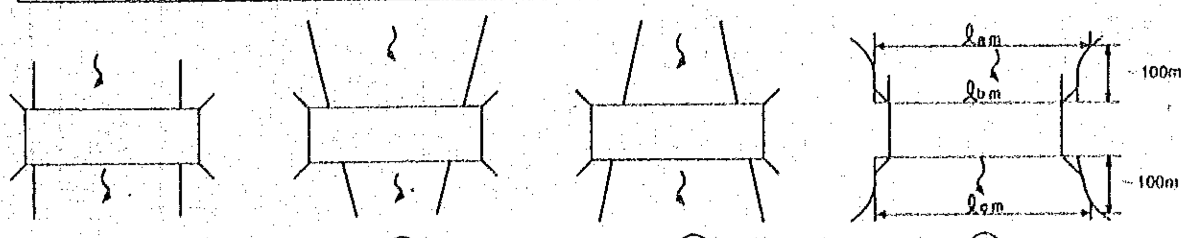
Figure 2-8 Survey Targeted Bridges in the 10th State

Table 2-1 Inspection Records

CODIGO DEL PUENTE		NOMBRE		NOMBRE DEL CRUCE		NOMBRE DEL RIO	

Lagar de inspección : Nombre del Inspector : Pagina No. de

		TIPO DE DAÑO O DETERIORO Y SU CANTIDAD					
PAVIMENTO	ITEM	1 ALABEO	2 ENSURCADO O CARRILES	3 FISURAMIENTO	4 ASENTAMIENTO	5 OTROS	
	GRADO O CANTID						
BARANDAS	ITEM	1 DEFORMACION	2 OXIDAMIENTO	3 CORROSION	4 FISURAMIENTO	5 ARMADURA AL AIRE	6 OTROS
	GRADO O CANTID						
JUNTAS DE EXPANSION	ITEM	1 SONIDOS EXTRAÑOS	2 FILTRACION DE AGUAS	3 DEFORMACION	4 MOVIMIENTOS VERTICALES	5 JUNTAS OBSTRUIDAS	6 OTROS
	GRADO O CANTID						
LOSA	ITEM	1 FISURAS EN UNA DIRECCION	2 FISURAMIENTO EN RED	3 DESCASCA RAMIENTO	4 ARMADURA AL AIRE	5 NIDOS DE PIEDRAS	6 EFLORES CENCIAS
	GRADO O CANTID						
RIOSTRAS (PTES. DE ACERO)	ITEM	1 OXIDAMIENTO	2 CORROSION	3 DEFORMACION	4 ROTURA DE LAS UNIONES	5 ROTURA DE ARRIOSTRAMIENTOS	6 OTROS
	GRADO O CANTID						
VIGAPRINCIPAL DE ACERO (EN CHERCHAS)	ITEM	1 OXIDAMIENTO	2 CORROSION	3 DEFORMACION	4 PERDIDA DE PERNOS	5 FISURAS EN SOLADURAS	6 OTROS
	GRADO O CANTID						
RIOSTRAS (PTES. CONCRETO)	ITEM	1 FISURAS EN UNA DIRECCION	2 FISURAMIENTO EN RED	3 DESCASCA RAMIENTO	4 ARMADURA AL AIRE	5 NIDOS DE PIEDRAS	6 EFLORES CENCIAS
	GRADO O CANTID						
VIGA PRINCIPAL DE CONCRETO	ITEM	1 FISURAS EN UNA DIRECCION	2 FISURAMIENTO EN RED	3 DESCASCA RAMIENTO	4 ARMADURA AL AIRE	5 NIDOS DE PIEDRAS	6 EFLORES CENCIAS
	GRADO O CANTID						
APOYOS	ITEM	1 ROTURA DEL APOYO	2 ROTURA DE ACCESORIOS	3 SALIDA DE ANCLAJES	4 ROTURA DEL DISCO	5 DEFORMACIONES RARAS	6 OTROS
	GRADO O CANTID						
ESTRIBOS	ITEM	1 GRIETAS O DESCASCARAM	2 FISURAS A PARTIR APOYO	3 ROTURA DEL PARAPETO	4 INCLINACIONES	5 SOCAVACIONES	6 OTROS
	GRADO O CANTID						
CEPAS	ITEM	1 GRIETAS O DESCASCARAM	2 FISURAS A PARTIR APOYO	3 DEFORM DE CANTILEVER	4 INCLINACIONES	5 SOCAVACIONES	6 OTROS
	GRADO O CANTID						
PINTURA	ITEM	1 DECOLORACION	2 OXIDAMIENTO	3 AMPOLLAMIENTO	4 DESCASCARAM	5 OTROS	
	GRADO O CANTID						
ARTICULACIONES DE VIGAS GERBER	ITEM	1 FISURAS EN UNA DIRECCION	2 FISURAMIENTO EN RED	3 AGRIETAMIENTO	4 ARMADURA AL AIRE	5 NIDOS DE PIEDRAS	6 EFLORES CENCIAS
	GRADO O CANTID						
OTROS	ITEM	1 DERRUMBE TALUD, ESTRIBO	2 DAÑOS POR IMPACTO ROCAS	3 DAÑOS EN CABO VIGAS	4 SE EFECTUO REPARACION?	5 OTROS	
	GRADO O CANTID						
COMENTARIOS ESPECIALES	1. EXISTIERON DESBORDAMIENTOS a. SI b. NO c. NO SE SABE				2. EXISTEN EMPRESTITOS DE MATERIAL a. SI b. NO		



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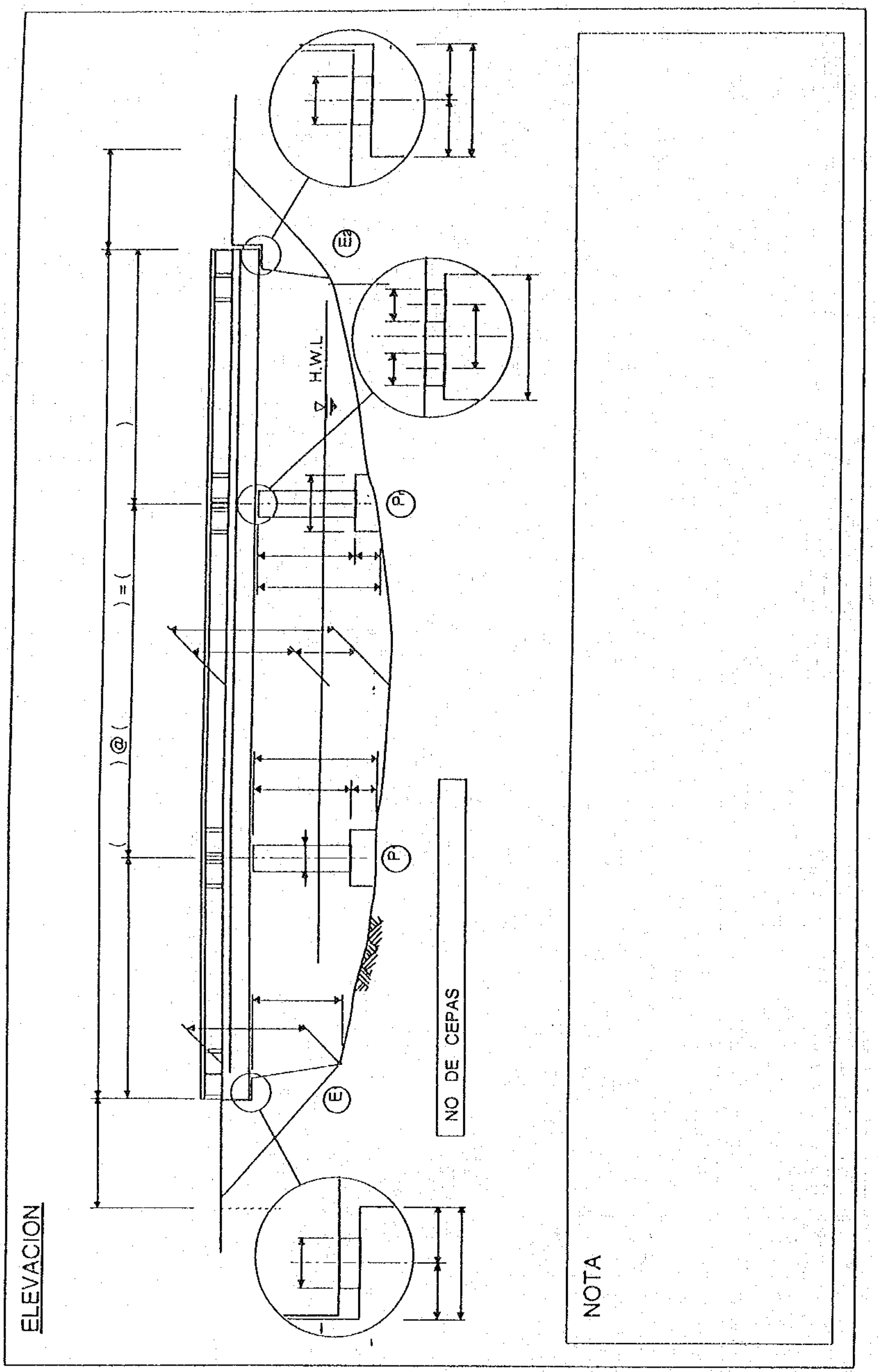

Figure 2-9 Form for Size Measurement

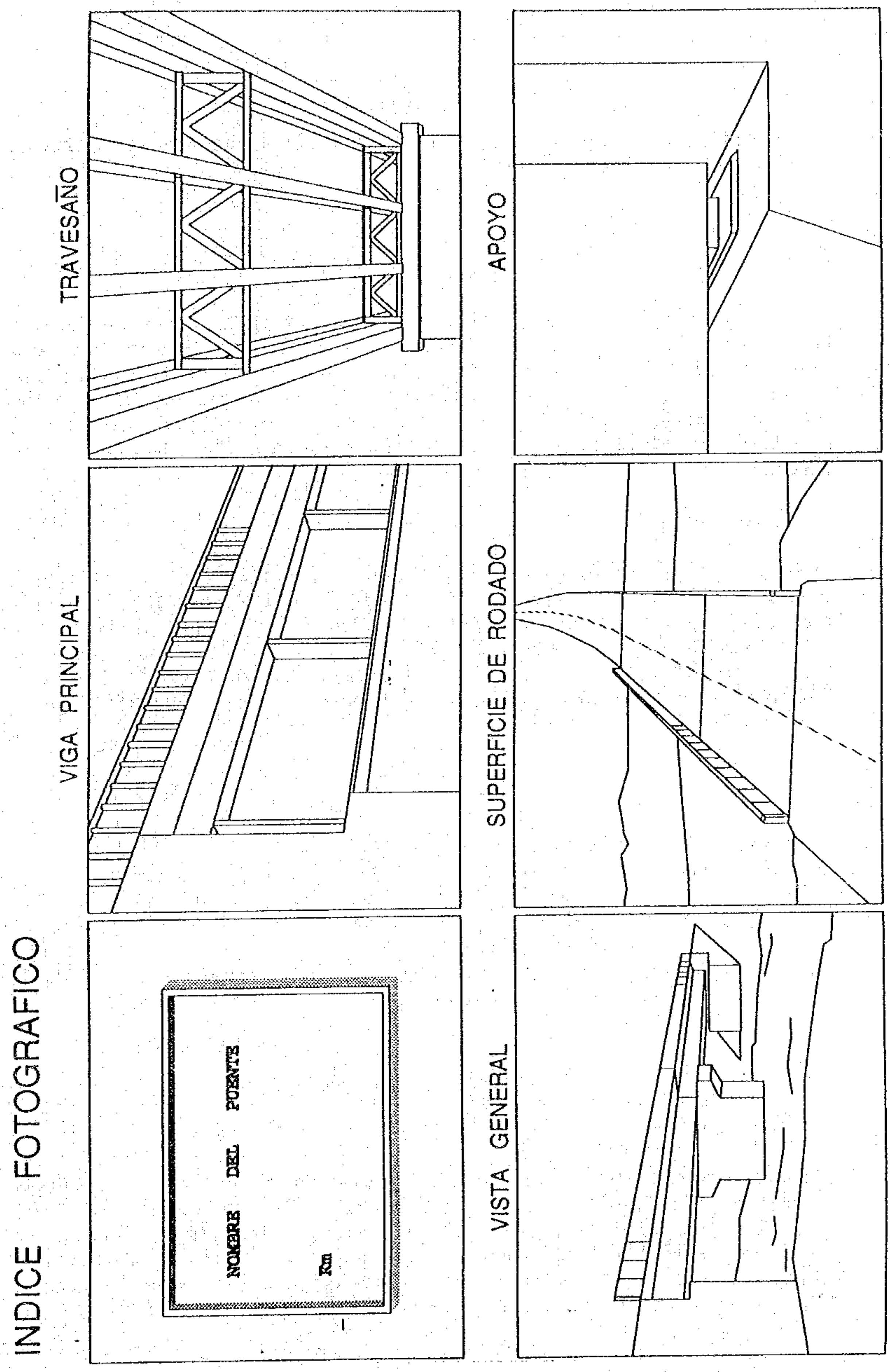

Figure 2-10- Photography Standards

2-1-3 Survey Results

(1) General Bridge Problems in Chile

As a result of visual observation inspections, the following general bridge problems were defined by the surveying teams.

1) Common Problems

a. Bearing

Rubber bearings are now used in the construction of bridges, and satisfactory bearing were almost non-existent for bridges constructed over 10 years ago. As a result, bridge deflection and impact are directly transferred to the substructure and many of the contact points (usually called the base of bearing) between the substructure and upper-structure are now damaged. Movable parts were judged to be immobile, and the Gerver hinge, which is often used in Chile, had an adverse effect on the main body of the bridge.

b. Expansion Joint

Cover plate expansion joints are used for most road bridges in Chile. The cover plate is welded at the construction site and its reliability is suspect. The joint's durability is questionable because most bridge joints were judged by the survey teams to have been damaged after only two years of use. As well, operation accuracy is poor and this has had an adverse affect on the main body of the bridge by creating abnormal sounds and increasing impact effect. (Refer to Figure 2-11)

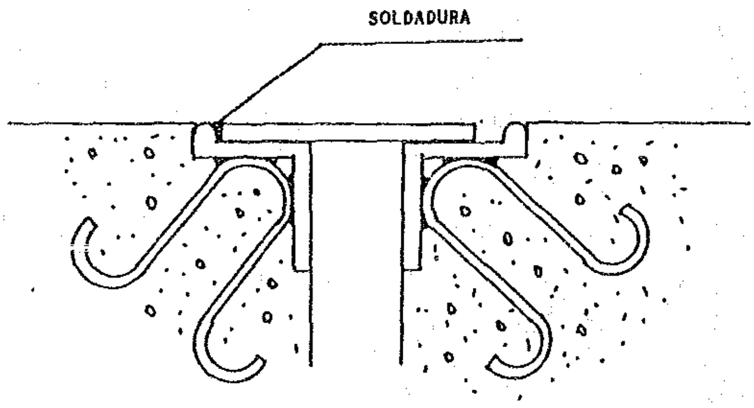

Figure 2-11 Expansion Joint

c. Filling

The protection of fill is extremely poor in the areas where fill touches the bridge. In order to reduce fill pressure, pier-abutment and pier-type abutment bridge bases have often been used. There is however is a high possibility that the fill on the backside of the abutment (approach) will sink as a result of poor compaction and lack of protection of the fill at the front. It is necessary to discuss protection methods for filling. (Refer to Figure 2-12)

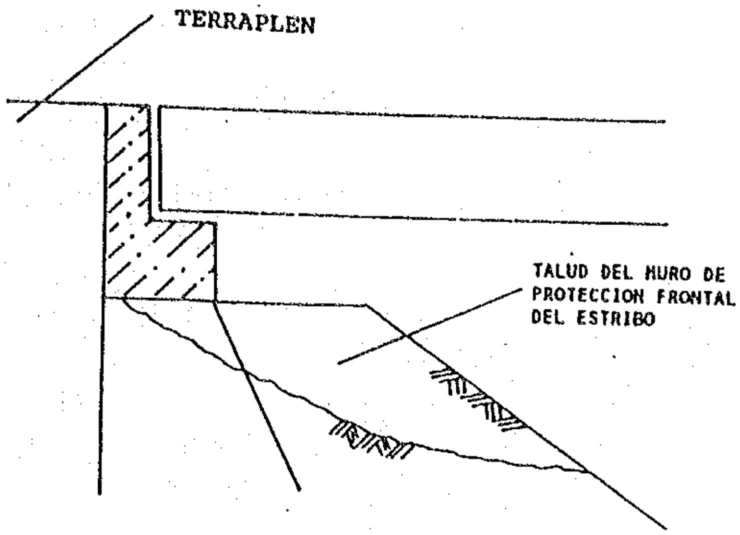

Figure 2-12 Filling

d. Foundation

Certain types of bridge foundations, such as the foundations at the Maipo and Malleco bridges, are often used in Chile even though they should not be used for bridge foundations in countries that experience frequent earthquakes. As was seen at Maule Bridge, problems of scouring were basically a result of the lack of foundation depth. Bridges in dry area tend to endure earthquakes better because of strong ground support. However, in the south, especially for problem bridges in the 10th state, the ground support is poor. Survey of the foundation ground when planning the construction of a bridge is very important.

e. Planning and Design

Bridge design is still analyzed by a bar structural analysis, even for bridges of great width. Grille structural analysis and multidimensional static indeterminate structural analysis are not widely used. This has resulted in the construction of bridge structures that ignore lateral sectional strength by not using supports such as crossbeams. As well, weak points in the structure have been created by using Gerver joints where continuous spans would be more appropriate. The Gerver structure is not being used for bridges currently under construction.

f. Alteration and Renovation Methods

An increase in traffic volume has resulted in a shortage of bridge width in Chile. There are two possibilities for expanding bridges from two lanes to four lanes. One possibility includes using the two old lanes exclusively for oncoming or ongoing traffic, while two lanes are added by constructing a totally separate bridge; the second possibility includes width expansion by creating a vertical joint to make the bridge seem as one. In both situations, the old and new bridge are always different. In the first situation, both bridges are constructed individually and there are few maintenance and control problems as long as the composition of the spans are the same. In the second situation, it is necessary to consider the influence of the new structure on the old structure, control of the expansion joint, and deformation of the vertical joint. (Refer to Figure 2-13)

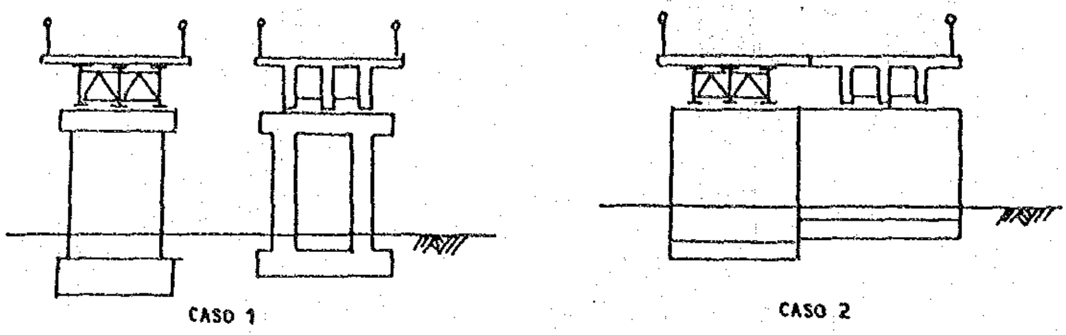

Figure 2-13 Bridge Widening Methods

2) Concrete Bridge Problems

a. Concrete Quality

In general, the quality of concrete was judged to be low. Problems were noticed in the construction of form work, and its resemblance to unfinished concrete. The finish of some bridges presents a problem, such as the treatment of wire for forms and the leaving of corner forms behind.

The curing of the concrete was poor, causing honeycombing and the exposure of reinforcement. This contributes to points of weakness in the structure.

b. Continuous Reinforced Concrete Beam Bridges

Gerver hinges have been frequency used on continuous reinforced concrete bridges. One of the problems however is the use of Gerver hinges where there is no necessity. For example, hinges have even been used for beams less than 20 meters in length which creates a major point of weakness. Another problem shown in the figure is the weakness of the hinge structure against shearing. Furthermore, large cracks at a right angle to the bridge axis on the concrete pavement side of the middle support point were observed. (refer to figure 2-14)

Effective Structures against Shear Destruction

Structures used in Chile

Figure 2-14 Problems using the Gerver Hinge

c. Pillars for Reinforced Concrete Arched Bridges

The pillars used for arched bridges are too thin. Rigidity of the pillars is questionable as they are 30 meters in length and only 70 centimeters in thickness, furthermore, there are no middle crossbeams. Pillar elastic deformation does not seem to have been considered and significant bridge damage as a result of pillar thinness was observed in the southern part of the country. (Refer to Figure 2-15)

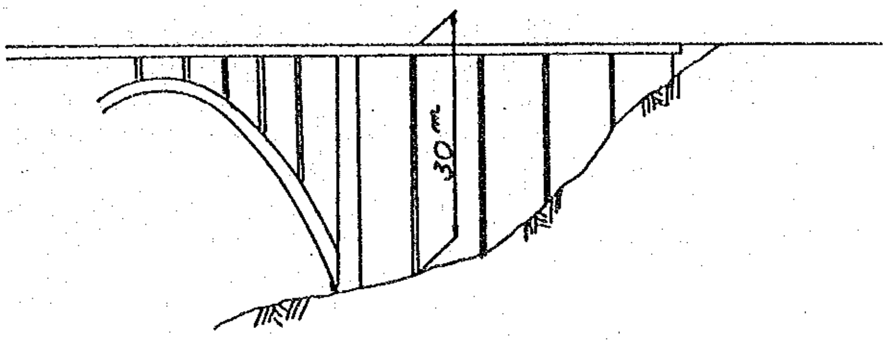

Figure 2-15 Pillars for Arched Bridges

d. Execution of Concrete Work

Treatment of new and old concrete work joints was not performed carefully and weak points in bridge structures were often seen.

3) Steel Bridge Problems

a. Crossbeam Structures

Floor framing was composed of the floor beam only and in rare case, both crossbeams and the floor beam are used. Connection with the main girders was done by on-site welding and was not carefully done. Breaks in the welding and repairs were seen at no less than 10 bridges. (Refer to Figure 2-16)

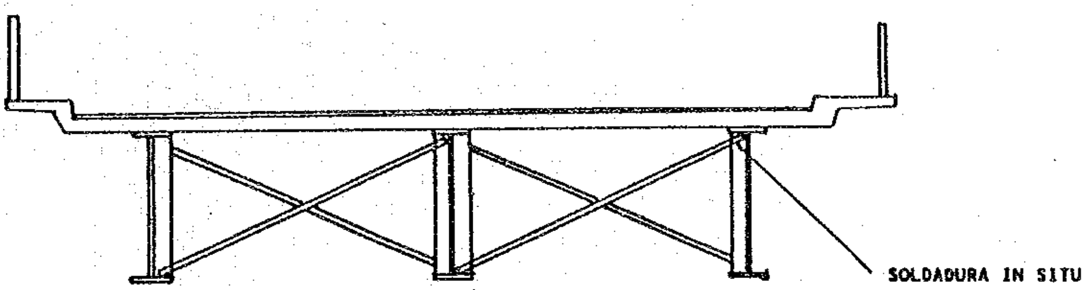

Figure 2-16 Crossbeam Structure

b. Main girders

Cross-section change of the main girders was sudden, which causes a structural problem in regard to fatigue. As well, many girders were loose because of a lack of camber adjustments.

(2) Evaluation of Bridge Damage

Evaluation of damage for bridge members was conducted based on the inspection record shown in Table 2-1. The Analytic Hierarchy Process was used in the evaluation method. The estimation was divided into three steps. In the first step, each member of bridge is evaluated, in the second step the superstructure, substructure and accessories such as expansion joint , pavement and handrail, etc. are evaluated. The comprehensive evaluation for bridge damage is conducted in the third step. The bridges evaluated as damage degree 4 and 5 are shown in Table 2-2.

Table 2-2(1) Bridges Evaluated as Damage Degree 4

No	Name	Type	Region	Deteriorale
122	NAVOTAVO	LOS	8	2.95
42	LOS LOROS	LOS	5	2.96
151	DESCARGA	LOS	8	2.96
100	LAS VERTIENTES	HAG	7	2.96
90	CLARO	ARS	7	2.96
149	DUQUECO	HPO	8	2.96
22	QUILIMARI	HAG	4	2.97
29	PULLALLY	ACE	5	2.98
88	PIRIHUIN	LOS	7	2.98
17	CHIGUALOCO	HAG	4	2.98
158	PS PIDIMA	ACE	9	2.99
106	ACHIBUENO	HAG	7	3.00
102	QUILIPIN	ACE	7	3.00
175	QUEPEANTIGUO	ACE	9	3.00
117	NIQUEN	LOS	8	3.01
31	TALAQUEN	LOS	5	3.01
44	PEUCOORIENTE	ACE	6	3.01
25	LA BALLENA	LOS	5	3.02
155	ESPERANZA	HAG	9	3.02
72	TINGUIRIRICAP	HAG	6	3.04
171	CAUTIN	HAG	9	3.05
172	METRENCO	HA-	9	3.06
176	QUEPENUEVO	MIX	9	3.06
157	MALLECO	ACE	9	3.09
116	PERQUILAUQUEN	HAG	8	3.10
233	TRAPENBAJO	LOS	10	3.12
33	EL COBRE	LOS	5	3.13
178	PERALES	ACE	9	3.18
236	LO PINTO 1 ORI.	LOS	13	3.18
23	PS LOS MOLLES	LOS	5	3.19
124	MENELHUE	LOS	8	3.19
161	DUMO	ARS	9	3.20
188	LELFUCADE2	ACE	10	3.20
168	PS PUA	LOS	9	3.22
240	PS SURACERO	ACE	13	3.23
181	CHADA	LOS	9	3.23
140	LAJITA	ACE	8	3.23
34	EL MELON	LOS	5	3.23
14	AMOLANAS	ARN	4	3.24
160	CHAMICHACO	HA-	9	3.25
38	ACONCAGUA-OCOA	HAG	5	3.26
108	LONGAVI	ACE	7	3.26
70	ANTIVERO PONIEN	HAG	6	3.27
138	RELBUN	HAG	8	3.33
156	MININCO	HAG	9	3.37
134	GALLIPAVO	LOS	8	3.37
152	BUREO	HAG	8	3.42
110	PIGUCHEN	LOS	7	3.46
141	BATUCO	LOS	8	3.46
142	BATUQUITO	LOS	8	3.48

Table 2-2(2) Bridges Evaluated as Damage Degree 5

No	Name	Type	Region	Deteriorate
143	SALTO DEL LAJA	ACE	8	3.51
150	BIO-BIO	HAG	8	3.52
245	PAINE ORIENTE	ACE	13	3.60
123	NINQUIHUE	LOS	8	3.67
166	QUINO	ARN	9	3.71
97	PIDUCO	LOS	7	3.74
213	RAHUE	ARN	10	3.75
99	MAULE ORIENTE	ACE	7	3.81
159	HUEQUEN	LOS	9	3.89
98	MAULE PONIENTE	MIX	7	3.95
137	DIGUILLIN	HA-	8	3.97

2-2 River Surveys

The following 4 problems can be pointed out from the results of our site surveys on the bridges on the National Highway No. 5.

1) Considerable scour at parts of piers and abutments

Rivers in Chile have steep slopes and rapid seasonal changes in discharge. The lengths of bridge spans are relatively short and the foundations are shallow. For these reasons, piers and abutments of many bridges are scoured to a considerable degree.

2) Shortage of opening of bridges

In order to make the spans shorter, many bridges have approach roads, which are banked at the same level as ground level of the bridges, protruded on the high-water channels. In addition, many bridges have short spans for the economic reasons, with a result that many rivers in the lower reaches have cross-sections much narrower than those in the upper reaches. For these reasons, the flow passage sections of the rivers are conspicuously insufficient.

As a result, in time of flood, the water levels at the bridges will rise higher than those upstream and downstream of the bridge and the flow velocities will increase. This will bring about the increases in the scour at the substructures and the lateral loads caused by the flowing water pressure. This will not only weaken the sustaining power of foundations but also incur the dangers such as subsidence, tilting and collapse.

Furthermore, in cases that the flowing water touch the superstructure, the water levels will rise further. This will bring about the further scouring of the piers and abutments and the deterioration of the superstructures.

3) Insufficient protection of revetment slopes

In many bridges, access roads are protruded on the high-water channels by embankment, and large natural stones are often used to protect the slopes of the approach banks and revetments. In these cases, only those stones which have size and thickness enough to bear the stream power of the rivers serve the purpose of protecting the slopes. Some of them, however, change artificially the stream direction from the upstream portion, resulting in centering the stream power at some parts of the substructures, causing or increasing scours.

At some revetments, which were unable to bear the stream power, slope collapses or erosions have occurred.

4) Insufficient embedding of the foundations of bridge substructures.

In Chile, spread foundations are used in many cases, as most river-bed grounds are made of gravel layers. Whether they use spread or pile foundations, footing depths of substructures are relatively shallow, with a result that the embedment of foundations are notably insufficient. This brings about the early lowering of support strata, tilting and collapse caused by the scour, and is one of the main reasons for insufficient life of functional bridges there.

Chapter 3 Bridge Detailed Survey

3-1 Bridge Detailed Survey

3-1-1 Outline of Detailed Survey

(1) Selection of Detailed Survey Targeted Bridges

Bridges were targeted for detailed survey based on the following selection standard policies.

1) Bridge for which the degree of damage is severe and repair is urgently required
2) Bridge showing the characteristic damage in Chile
3) Bridges for high economic and social importance
4) Bridge for preparing the typical bridge repair in the technology transfer

As a result of the above selection standards, discussion were held with MOP in regard to the 22 bridges selected by the Study team and the Operation Supervision Committee. Finally, 11 bridges selected, of which 10 bridges are selected for detailed bridge survey and the remaining 1 bridge is for load capacity test as shown in Table 3-1. Table 3-2 shows the situations for bridge damage. The locations of bridge are shown in Figure 3-1.

(2) Surveyed Bridges

Surveyed bridges are shown in Table 3-1.

Table 3-1 Outline of Surveyed Bridge

No.	State	Name of Bridge	Length (m)	Type of Bridge
1	4	AMOLANAS	235.2	3 Span Continuous Reinforced Concrete Arch
2	5	PULLALLY	148.5	3 Span Continuous Plate Girder
3	RM	MAIPO	460.6	Prestressed Concrete Girder
4	RM	PEUCO	99.0	Steel Girder
5	7	CLARO	117.7	7 Span Continuous Brick Arch
6	7	LONCOMILLA	150.0	Prestressed Concrete Girder
7	8	BIO-BIO ANTIGUO	1455.0	Steel Girder (104 continuous)
8	8	RAMADILLAS	210.0	Steel Girder (14 continuous)
9	9	MALLECO	344.1	9 Span Continuous Steel Girder
10	10	PICHOY	80.6	Reinforced Concrete Girder
11	10	CAYUMAPU	49.0	3 Span Continuous Reinforced Concrete Girder

Table 3-2 Situations for Bridge Damage

No	Bridge Name	Situation
1	Amolanas	Damage to the pavement and slab on the side span of the Santiago side was significant as a result of the impact of live loads.
2	Pullally	Deformation of the three continuous spans on the La Serena side was large. The ratio of beam depth to span was small (1/26), and vibration was heavy during vehicle crossing. According to MOP the bridge had a history of collapsing.
3	Maipo	There were no middle crossbeams. There were no lateral pre-stress at the end horizontal beams. The bridge piers were two individual pillars and their resistance to earthquakes was questionable. Part of the foundation was exposed by scouring.
4	Peuco	Two main steel girder bridge. No solid floor beam and damage at the welded parts
5	Claro	Being a monumental structure in Chile, a request was made to restore it. Scouring on the foundation was pronounced.
6	Loncomilla	The depth of the footings for the abutment and bridge pier was insufficient. Therefore, H-shaped steel was exposed to scouring and the bridge pillars were tilting.
7	Bio Bio Antiguo	The bridge collapsed during an earthquake in 1960. Vehicles over eight tons were prohibited from using the bridge. Traffic capacity was insufficient.
8	Ramadillas	The frequency of use by heavy trucks carrying timber was high. Serious cracks have appeared in the abutment concrete.
9	Malleco	The structure was constructed in 1973, but the grid buckled before the opening ceremony. Stiffening material was later added. Although this was a 3 main girder structure, there were no crossbeams to enhance load distribution and deflection was large.
10	Pichoy	The abutment shifted during an earthquake. The abutment width is very narrow and vulnerable to earthquakes. The Gerver hinge was also damaged.
11	Cayumapu	The abutment and bridge pier were significantly tilting as a result of earthquakes.

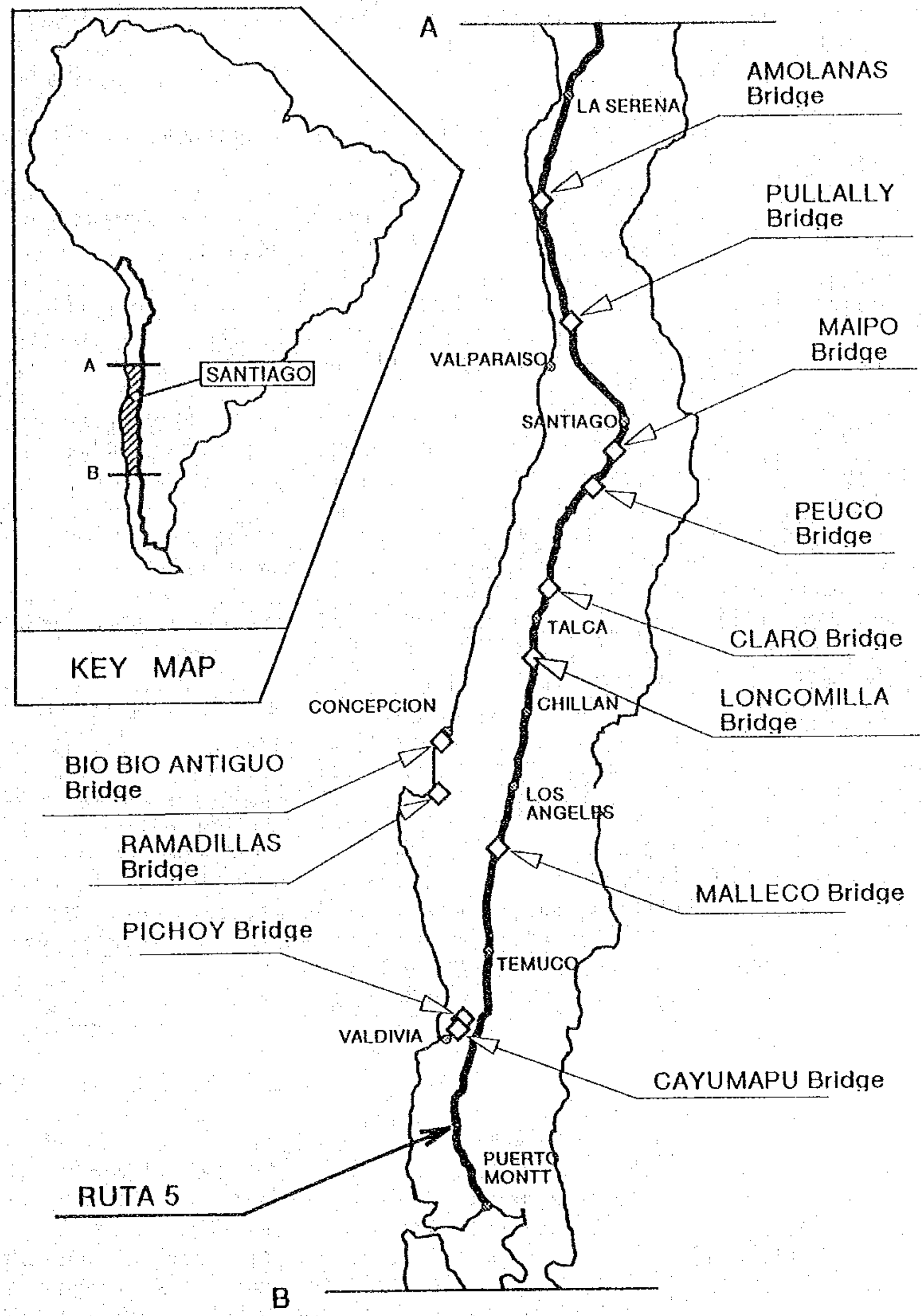

Figure 3-1 Location Map of Surveyed Bridges

3-1-2 Method of Detailed Survey

The following works were conducted in the detailed survey.

1) Measurement by Instrument

The following survey was conducted to measure conditions and deterioration of structure materials.

a. Non-destructive concrete hardness test by Schmidt Concrete Hammer Test
b. Non-Destructive Reinforced Concrete Survey by Profometer
c. Concrete Neutralization Test
d. Steel Hardness Test by Brinell Hardness

2) Survey of Deformation and Measurement of Dimension

Bridges deform by earthquakes, floods and scouring, etc. Differences between dimensions on design drawing and at completion sometimes occur. Therefore, the following surveys were conducted to obtain the present dimension of bridge.

a. Survey for horizontal and vertical displacement, vertical gradient and settlement. survey for vertical alignment of approach road.
b. Survey for scouring and degree of angle for pier
c. Confirmation for depth of foundation of substructure and survey for conditions of scouring on river bed
d. Survey for distribution of cracks in slabs

3) Geological Survey

At present, there is little geological data for bridges in Chile. The geological data is indispensable to conduct measurement against earthquake and scouring. Therefore, of 10 bridges for the detailed survey, 7 bridges exclusive of AMOLANAS, CLARO and RAMADILLAS bridges were surveyed. It is very important to obtain data from the standard penetration test. In this Study, the standard penetration test to find load resistance of foundation, and geological test in laboratory, to determine the type of soils in bridge construction site were conducted.

3-1-3 Survey Results and Examination

(1) Instrumentation Measurements

1) Measurement Results

a. Concrete Strength

The concrete strength of ten bridges, as measured by the Schimdt Hammer Test, has a maximum average of 330 kg/cm2 and a minimum average of 210 kg/cm2. Maipo and Loncomilla bridges, whose upper structures consist of pressed concrete girders, are beyond the maximum of 300 kg and their concrete strength was found to be higher compared with other bridges. The concrete strength at some locations was measured as low for the Bio-Bio, Lamadillas, Pichoy, and Cayumapu bridges; however, these strengths do not present an immediate problem in terms of structure failure.

b. Reinforcement Inspection

Reinforcement locations were confirmed by a profometer during nondestructive reinforcement inspections. For locations where neutralization testing was performed, the diameter of the reinforcement was confirmed by drilling into the concrete at locations where reinforcement is found. Even for the Loncomilla Bridge, which has the widest interval between reinforcement (the widest reinforcement interval being 260 cm), there are no problems concerning the reinforcement interval 1. The covering thickness of concrete varies from a maximum of 78 mm to a minimum of 3 mm: These values are within the range of location and construction error and do not present any particular problems. However, we could not confirm whether the reinforcement diameter is sufficient relative to stress as there were no design calculation results.

c. Steel Material Quality

A hardness measurement test was performed by echo tip to confirm the characteristics of the steel used for upper bridge structures. Brinell hardness of steel (SS40) used for bridges in Japan is HB=140-150. The value for the Pullally Bridge (average HB=125) and the Pichoy Bridge (average HB=128) was slightly lower in this survey.

d. Concrete Neutralization

Neutralization testing was performed at the same time as confirmation of reinforcement locations by profometer. This is performed because concrete neutralization is related to the progress of reinforcement bar rust. Concrete shows strong alkalinity (PH12) when first poured, however, concrete becomes neutralized and its alkalinity weakens with the passage of time. Reinforcement bar corrodes rapidly within concrete of less than PH9. For the Claro, Bio-Bio, Ramadillas, Pichoy, and Cayumapu bridges, the majority of locations are less than PH9 and the depth of neutralization is greater than 20 mm. This illustrates that neutralization is fairly advanced.

2) Examination

The objective of this survey is to analyze the characteristics of the bridge materials. As a result of this survey, the strength of some bridge materials indicate a slight problem. However, these problems are not directly related to the safety of the bridges that were examined. Concrete neutralization for several bridges is intense, as Table 3-3 shows, due to the fact that the survey targeted bridges are old. This means that the working life of these bridges is over and that repairment measures alone will not be sufficient. It is desirable in the near future to replace the bridges which have problems as indicated by concrete neutralization testing.

Table 3-3 Survey Results by Measuring Instrumentation

Bridge Name	Concrete Strength	Reinforcement Layout	Steel Strength	Neutralization
AMOLANAS			-	Δ
PULLALLY			Δ	Δ
MAIPO			-	
CLARO			-	©
LONCOMILLA			-	Δ
BIO-BIO	Δ			©
RAMADILLAS	Δ			©
MALLECO				
PICHOY	Δ		Δ	©
CAYUMAPU	Δ		-	©

Note)

© : shows problem

Δ : shows slight problem

Blank : no problem

- : test was not performed.

(2) Basic Structure and Deformation Survey

Measurement of bridge structures using survey equipment and the deformation survey shown below were performed at the same time as the various surveys using measuring instrumentation. The data is summarized in a separate collection of diagrams. Please refer to this information. In regard to the survey method refer to the bridge maintenance and repairment guidelines, 7-4 The problems of each bridge, as discovered from the deformation survey, are discussed in this section.

1) Survey Results

Table 3-4 shows a summary of the deformation causes of each bridge.

Table 3-4 Deformation Survey Result

Bridge Name	Major Deformation
AMOLANAS	Cracks in the pavement are obvious because of the vehicle wheel load. All of the pillars of the bridge pier on the Santiago -side span are deformed on the abutment side.
PULLALLY	Vibration is large when heavy vehicles cross. Deformation of the main girder is observed by visual observation. A difference of approximately 7 cm exists on the joints of the 3 and 4 continuous spans. Scouring of the bridge piers is advanced.
MAIPO	Scouring of the bridge piers on the Talca side (C11) is advanced. As well, settlement (approximately 10 cm) of the upper structure on the same bridge pier and lateral displacement (approximately 13 cm) are large.
CLARO	Scouring of C2 bridge pier foundation.
LONCOMILLA	Approximately 35 cm displacement is caused relative to the spans neighboring on the C5 bridge pier. At the same location, the left and right road surface height is displaced approximately 12 cm.
BIO-BIO	Scouring of the bridge piers is advanced and piles are exposed for a majority of the bridge piers. At the location of the C46 bridge pier, the left and right road surface height is displaced approximately 19 cm. Possible tilting of the same bridge piers is high. Road surface deformation is so advanced that the road is not adequate for high-speed driving.
RAMADILLAS	Road surface deformation is obvious because of settlement and tilting of the bridge piers. Deterioration of the bridge pier girder seat is at a dangerous level.
MALLECO	Deformation of the whole bridge is large when heavy vehicles cross. A displacement of approximately 8 cm is observed between the top and the base of the bridge piers. However, the cause is not clear as to whether this is a result of construction error or post-construction error.

PICHOY	Road surface deformation because of settlement and tilting of the C2 and C3 bridge piers is large. The maximum lateral displacement is 13 cm and the vertical displacement is 14 cm. Bridge piers on the Valdivia side are tilted and the bearings have come away.
CAYUMAPU	C1 bridge pier settlement (approximately 10 cm); C2 bridge pier tilt (approximately 4 degrees); E2 abutment tilt (approximately 11 degrees)

2) Examination

As a result of the deformation survey, the causes of deformation are considered as follows when the results are separated. Deformation does not occur due to any particular cause but is generated as a result of a combination of factors as shown in Table 3-14.

Table 3-5 Causes of Bridge Deformation

Bridge Name	Deformation Case			
	1	2	3	4
AMOLANAS	©			
PULLALLY	O	O	O	©
MAIPO		O		
CLARO		O		
LONCOMILLA		O	©	©
BIO-BIO			©	
RAMADILLAS	O		©	O
MALLECO	O			O
PICHOY		O	©	©
CAYUMAPU		O	©	©

1. Damage by heavy vehicle traffic.
2. Deformation caused by scouring from rivers.
3. Settlement deformation due to insufficient foundation support.
4. Deformation due to earthquakes.

© : major cause of deformation
O : secondary cause related to deformation

3-2 Load Test

3-2-1 Outline of Load Test

A load test and a stress frequency measurement of vehicles crossing were performed at the Peuco Bridge, located 60 kilometers south of Santiago City. Test measurements were performed using the latest instruments with the Chilean staff: the purpose being to introduce load testing to the Chilean staff. The results of the load test did not directly reflect the maintenance and repair plans which were the main purpose of this project. The principle objective was to clarify the basic characteristics of the bridge.

Peuco Bridge had 2 main composite plate girders and a relatively large slab span (3 continuous spans). All joints were welded. Based on these characteristics a load test was performed as described below.

Test Points are following:

(1) Confirmation of structural characteristics of a 2 main girder bridge.

1) deflection of the main girder and slab
2) load distribution effect by the floor beam
3) behavior of the composite girders

(2) Confirmation of fatigue characteristics

(3) Confirmation of the relationship between load and stress.

Measurements were performed using strain gauges attached to monitoring points on the main girders, floor beam, and vertical stiffener. Displacement gauges were also set on the main girders and slabs near the center of the span in order to act as sensors. The load test procedure is shown in Figure 3-2

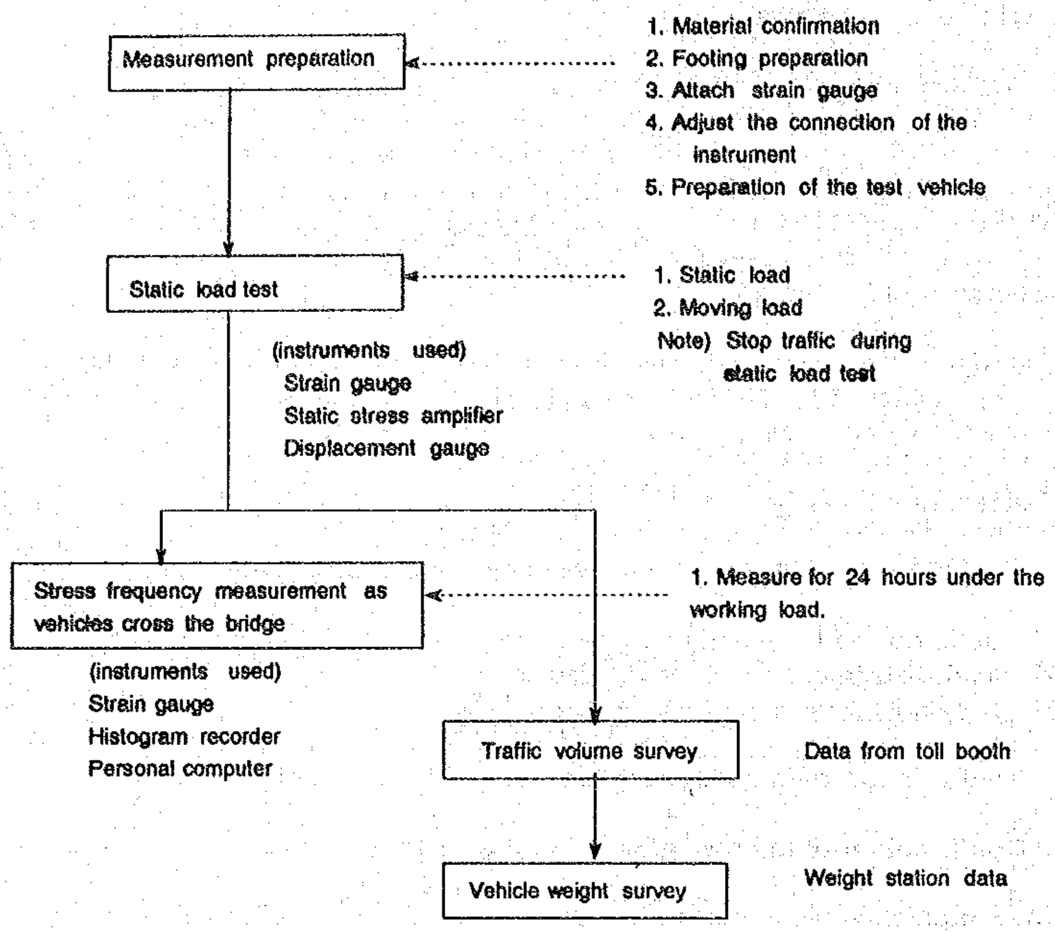

Figure 3- 2 Load Test Procedure

3-2-2 Summary of Measurement Results

(1) Static Load Test Results

The following tendencies were noted as a result of testing.

1) Stress occurred mainly in the main girders. Significant stress did not occur on the upper and lower members of the floor beams, diagonal members, and vertical stiffeners.

2) Comparing the stress in the bottom flange of the main girder where the load is at each measuring point, the stress at gauges No. 1 and No. 2 at the cross-section change point was 187 kg/sq cm and 178 kg/sq cm. The stress near the general center span was 92 kg/sq cm; the stress at the cross-section change point was approximately 2 times greater.

3) Comparing of gauges No. 14 and No. 101 (lower flange), which were located symmetrically to the bridge axis, when stress was loaded on the No. 14 side, the stresses for No. 14 and No.101 were 92 kg/sq cm and 18 kg/sq cm, respectively. This means that a large load distribution on the main girder did not occur.

4) A relatively large amount of stress was recorded on gauge No. 3, which monitored the stress on the welding end of the vertical stiffener lower end. The maximum was 120 kg/sq cm.

5) In regard to the floor beam member, 20 to 30kg/sq cm of stress was generated on the upper member; however, stresses on the lower member and diagonal member were almost nonexistent.

(2) Stress Frequency Measurement Results

Table 3-6 shows the calculation results of fatigue life.
The following points were determined based on the fatigue lives predictions.

1. Fatigue life of the main girder cross-section change point is 1 to 2 years. Severe stress for fatigue is occurring.

2. Life of the end of welding of the vertical stiffener is approximately 10 years and it is under severe stress conditions.

3. In regard to members of the floor beams, life of the welding of upper member gazette is short. However, a short life is not predicted for other points.

3-2-4 Summary and Recommendation

Replace of the PUECO bridge is recommendable by the following reason;

1) Fatigue life is less than two years at the cross-section change point of lower flange
2) Welding at the floor beam is cut several times.
3) The main girder is broken and repaired by weldment at the side.
4) There are some problems for the design concept of two main girder bridge under construction

Table 3-6 Fatigue Life Prediction Results

(unit: year)

Monitored location	Gauge number	Strength class					
		C	D	E	F	G	H
Lower flange cross-section change plate	1	21.5	6.4	* 1.8	* 0.7	0.2	0.1
Lower flange cross-section change plate	2	25.8	7.2	* 1.9	* 0.7	0.2	0.1
Web on the end of the welding part of the lower vertical stiffener	3	219.3	37.4	* 9.4	2.2	0.7	0.3
Lower member of the floor beam attached part	5	∞	∞	∞	∞	∞	* 59.6
Near the upper flange of the vertical stiffener upper part	7	∞	∞	* ∞	∞	233.6	88.9
Near the lower flange span center	14	∞	* 89.5	27.0	5.8	1.4	0.5
Upper member of the lower beam attached part	21	∞	∞	∞	∞	270.3	* 10.9
Upper flange and web welded part	102	∞	∞	* ∞	∞	∞	∞

Note)
- When fatigue life is greater that 274 days (more than 100,000 hours) life is showed as.
- The figure marked by an asterisk is the fatigue life and this corresponds to the stress class shown in Chart - .

Chapter 4 Bridge Repair Design

4-1 Basic Policies

The aim of this chapter is to present proposals for the methods to be used in the repair work of the ten bridges selected as a result of the First Field Survey, conducted between November and December 1992. The ten bridges were selected for the following reasons.

1) The bridges required urgent repair as the degree of damage was severe.
2) The type of damage observed on them was typical for bridges in Chile, as well as satisfying condition 1) above.
3) They were bridges that were of socioeconomic importance.

The ten bridges selected are therefore generally in unsatisfactory conditions and some of them will in fact require replacement with new bridges. Under the present project, however, replacement and upgrading of the bridges will not be considered. Proposals will be made here for methods of reinforcing the bridges so as to prevent collapse of the bridges that are in particularly dangerous conditions, and for methods of conducting repair work with a view to maintaining the existing bridges functional and removing the dangers.

Single reinforcement/repair methods are proposed and drawn up in principle for each bridge, but the proposals here do not go as far as the calculation of the details such as the thickness of the members and the quantities of reinforcement steel. Possible amelioration methods include a wide variety of choices from maintenance and repair to reinforcement and replacement and further studies will be required in many cases before the final decision is reached. Furthermore, the design for the repair work should deal not only with individual items of damage but should be based on an accurate assessment of the overall condition of each bridge. Various factors will therefore be taken into account in the design of the repair work, not only the conditions of the bridges themselves but factors relating to the topographical, geological, seismological and sociological conditions of the area where the bridges are located, as well their relation to the rivers which they cross and roads with which they are connected.

4-2 Results of Detailed Surveys and Conditions Relating to Selection of Repair Methods

(1) Results of Detailed Surveys

The detailed surveys were conducted using the instruments described in Chapter 3 and include tests on concrete strength, carbonation of concrete and hardness of the steel members, as well as measurement of the sectional dimensions of the bridges and their deformation. Soil surveys were also conducted around some of the bridges in question. The results of these surveys provide the basis for the selection of the repair methods. The items of the damage as observed in these surveys and visual inspection may be classified as follows.

(a) Appropriateness of the relationship between the road alignment and bridge position
(b) Topographical and geological problems at the bridge (landslides, soft ground, liquefaction)
(c) Problems relating to the river
(d) Traffic volume and bridge width
(e) Aging of the bridge
(f) Damage to structures
(g) Problems arising from the design and construction of the bridge
(h) Seismic structure of the bridge
(i) Deformation of the bridge
(j) Conditions relating to detour routes

The damage observed on each bridge may be summarized as shown in Table 4-1.

Table 4-1 Damage and Causes

Name of Bridge	A	B	C	D	E	F	G	H	I	J	Bridge Type
Amolanas	*	*		*	*	*	*	*	*	*	Reinforced concrete arch
Pullally		*	*				*			*	Steel-plate girder
Maipo			*				*	*		*	Prestressed concrete (post-tension)
Claro			*	*	*					*	Brick arch
Loncomilla			*			*			*	*	Prestressed concrete (pre-tension)
Bio Bio			*	*	*						Steel-plate girder
Ramadillas		*	*	*		*			*	*	Steel-plate girder
Malleco	*	*				*	*	*	*	*	Steel-plate girder
Pichoy		*			*	*			*		Steel-plate girder, T-shaped reinforced concrete girder
Cayumapu		*			*	*			*	*	T-shaped reinforced concrete girder

Note: Asterisks (*) show the applicable items of damage on each bridge.

(2) Conditions Relating to Repair Design

In addition to the examination of the damage and its causes on each bridge, certain conditions must be established for each item of damage in selecting the methods to be used in the repair work. The following conditions are used as the criteria in the design of the repair work.

1) Conditions for Road Alignment

Are the horizontal curve and longitudinal gradient on the bridge and in the sections immediately on either side appropriate for the design speed of the road? (Amolanas and Malleco Bridges)

2) Topographical and Geological Conditions

a. Landslides have been observed on the Temuco side of Malleco Bridge, and a drainage well (diameter: 25 m, depth: approx. 30) and approximately 50 landslide prevention piles (diameter: 1.0 m) have been constructed. The pier of this bridge, with a height of 77 m, penetrates only 6 m into the ground, a fact which gives rise to doubt as to whether account was taken of the location of the bridge in a landslide-risk area at the time of its construction. Geological surveys will need to be carried out to decide whether to implement landslide prevention works for protection of the bridge or to relocate it altogether.

b. On loose sandy ground liquefaction at times of earthquakes may result in the lowering of the bearing capacity. Investigations need to be carried out in such cases on the requirement for foundation works.

c. Where the penetration of the piles is inadequate on soft ground, this makes them prone to settlement and lateral movement. These piles should be reinforced with long additional piles or, where the conditions are not satisfactory, the substructure as a whole should be replaced. (Ramadillas, Pichoy and Cayumapu Bridges)

d. Foundation works are of importance where the abutments have been constructed on fill soil (Amolanas Bridge) or where there is a tall embankment nearby. Geological surveys should be carried out in such cases for investigation of the measures to be taken in such cases.

(3) Conditions Relating to Rivers

a. Where the bridge is too short in relation to the width of the river, the side spans will need to be lengthened in future. (Pichoy and Cayumapu Bridges)

b. Where the obstruction by the bridge in the cross-section of the river is large, effective spans will need to be enlarged in future. (Bio Bio Bridge)

c. Bridges whose clearance below the girders is inadequate in relation to the high water level should be replaced.

d. Where the bridge piers are not in line with the flow of water, the piers are subjected to high water pressure and this may also cause scouring. Construction of groynes and reinforcement of the foundation will be required in such cases. (Pullally, Maipo, Claro, Loncomilla, Bio Bio, Ramadillas and Cayumapu Bridges)

(4) Conditions Relating to Traffic Volume

Conditions relating to traffic volume include the bridge width, number of traffic lanes, and the problems in the structures for supporting the live load. These are summarized in Table 4-2.

Table 4-2 Traffic Volumes around Bridges to be Repaired

1988

Name of Bridge	Traffic Volume			Investigation Items	
	Small to Medium-Sized Vehicles	Large Vehicles	Total	Width	Live Load and Supporting Mechanism
Amolanas	1350	651	2001	*	(substructure)
Pullally	2235	1082	3317		(superstructure)
Maipo	11294	7400	18694		
Claro	4332	2867	7199	*	
Loncomilla	1199	684	1883		
Bio Bio	11700	2145	13845	*	(superstructure)
Ramadillas	1712	1501	3213		(substructure)
Malleco	2300	1444	3744		(superstructure)
Pichoy	1398	484	1882		(substructure)
Cayumapu	1398	484	1882		

Note: Those bridges marked with asterisks (*) in the table above do not have adequate widths and require widening or addition of new lanes. In the right-hand column, "superstructure" means that the bridge in question has problems supporting the live load for reasons arising out of the superstructure, such as damage to the floor slabs, while those marked "substructure" have problems such as the settlement of the substructure.

(5) Conditions Relating to Aging of Bridges

Of the bridges in question, Malleco and Maipo Bridges are relatively new. Serious symptoms of aging are observed on Amolanas, Claro and Bio Bio Bridges. These three should ideally be replaced. For reference, unsatisfactory results were also obtained in the carbonation test on Ramadillas, Pichoy and Cayumapu Bridges. Radical measures are required on Amolanas, Pullally and Bio Bio Bridges, where aging is observed in addition to the damage to the floor slabs, in view of the problems regarding the supporting mechanism for the floor slabs. On Ramadillas and Pichoy Bridges, where the widths of the bridge pier crowns are inadequate, the concrete has undergone carbonation and the sectional thickness is inadequate. It is thought best to carry out partial placement of new concrete on these two bridges.

(6) Conditions Relating to Damage to Structures

Considerations will be restricted here to damage to various components of the bridges. The positions where damage is observed are listed and given as conditions for devising countermeasures. Cases of slight damages have been omitted. Those cases listed below are also judged to require repair or reinforcement. (Refer to Table 4-3)

Table 4-3 Damage to Structures and Countermeasures

Name of Bridge	Floor Slabs	Main Girder	Cross Beam	Abutment	Pier	Foundation	Measures Required on
Amolanas	*	*		*	*		Floor slabs, pier
Pullally	*	*	*		*	*	Floor slabs, main girder
Maipo			*		*	*	Pier crown, foundation
Claro		*				*	Foundation, arch
Loncomilla				*	*	*	Repair of pier, foundation
Bio Bio	*	*	*	*	*	*	Floor slabs, fall-off prevention
Ramadillas		*	*		*	*	Pier crown, foundation
Malleco		*	*		*	*	Super- and substructures
Pichoy		*	*	*	*	*	Pier crown, foundation
Cayumapu		*		*	*	*	Gerber girder, substructure

Note: Asterisks (*) show the existence of damage in the relevant positions.

(7) Problems Arising out of Design and Construction of Bridges

Deficiencies that easily arise at the time of design include inadequate studies and inadequacy of the design standards used. Unsatisfactory execution, lack of satisfactory construction technology (machinery) and use of cheap materials and equipment for economic reasons will mean that the bridge thus constructed will suffer various problems on a semi-permanent basis. The problems arising out of such factors tend to run deep and usually require radical measures for amelioration. (Refer to Table 4-4)

Table 4-4 Problems Arising out of Design and Construction

Name of Bridge	Soil Surveys	Design Standards	Unsatisfactory Execution	Construction Technology	Economy	Remarks
Amolanas		*	*			Seismic design, floor slab camber
Pullally	*	*				Inadequate main girder section
Maipo		*				Seismic design
Claro						
Loncomilla	*			*		Inadequate pile penetration length
Bio Bio	*	*		*	*	Inadequate span
Ramadillas	*	*	*			Inadequate pile penetration length and pier crown width
Malleco	*	*				Landslide, seismic design
Pichoy	*	*				Inadequate pile penetration length and pier crown width
Cayumapu	*					Inadequate pile penetration length, Gerber girder

Note: Asterisks indicate problems arising out of design and execution.

(8) Conditions Relating to Seismic Design of Bridges

To determine the need for countermeasures, considerations are made on the overall structure of the bridge, as well as on the details of the structure, in relation to adequate strengths against earthquakes, and as to whether the bridges are located on ground easily affected by earthquakes. (See Table 4-5.)

(9) Conditions Relating to Deformation of Bridges

Deformation was observed on a number of bridges and in a number of cases the lack of bearing capacity was seen to have resulted in settlement and inclination, as well as deflection and torsion on the superstructure and tall bridge piers (see Table 4-6). The causes of such cases of deformation must be studied and appropriate measures taken accordingly.

Table 4-5 Parts Presenting Problems in Seismic Structure

Name of Bridge	Overall Structure	Details of Structure	Ground	Parts Presenting Problems
Amolanas	*	*		Column structure, girder support, longitudinal gradient
Pullally			*	Foundation
Maipo	*	*		Cross beams, independent piers
Claro				
Loncomilla				
Bio Bio		*	*	Girder support
Ramadillas		*	*	Girder support, soft ground
Malleco	*	*	*	Column structure, independent piers
Pichoy		*	*	Girder support, soft ground
Cayumapu		*	*	Girder support, soft ground

Table 4-6 Deformation of Bridge

Name of Bridge	Bridge Face			Superstructure		Substructure		
	Undulation	Settlement	Lateral Movement	Torsion	Deflexion	Settlement	Inclination	Deflexion
Amolanas	*	*	*		*		*	*
Pullally			*	*	*			
Maipo		*				*		
Claro								
Loncomilla		*	*				*	
Bio Bio	*	*	*					
Ramadillas	*	*	*	*	*	*		
Malleco				*	*	*	*	*
Pichoy	*	*	*			*		
Cayumapu							*	

(10) Detour Route Conditions

When a bridge faces major repairs, the execution methods will differ depending on whether or not the bridge can be closed to traffic. Even for work on the substructure, it may be easier to carry out the work with the superstructure removed, but if the traffic cannot be diverted this is not possible. The conditions relating to the detour routes are examined in this study.

4-3 Repair Design of Ten Bridges

Table 4-7 shows a summary of repair methods for bridge

Table 4-7 Repair and Reinforcement Methods for the Ten Bridges

Repair/Reinforcement Method		1	2	3	4	5	6	7	8	9	10
Floor Slabs	Placement in situ	#	#		#						
	Precast concrete slabs	#	#		*						
	Steel slabs		#								
	I-shaped steel grid slabs		#								
	Steel panel slabs		#								
	Attachment of steel plates		*				#				
	Attachment of FRP rods		#				#				
	Mortar spraying				#						
	Resin injection	*	*	#			*	#			
	Patching						*				
Floor System	Replacement of main girders	#	#								
	Overlapping beams				#						
	Addition of main girders		#				#	#	#	#	
	Addition of cross beams		#				#				
	Reinforcement of main girders	#	#		*				#	#	
	Span reduction		#								
	Introduction of prestress		#						#		
	Reinforcement of cross beams		#	#			#	#	#	#	#
	Repair of Gerber girders										*
Substructure	Widening of shoe seat	*	*	#			*	*		*	*
	Reinforcement/repair of piers	*		#	*	*	#	*	#	#	#
	Reinforcement of foundation		#		*	*		*		*	#
	Construction of new substructure	#				#		#	*	#	*
Others	Expansion joints	*		*		*	#	*		*	*
	Shoe					*	#	*	*	*	*
	Fall-off prevention	#	#	*			*	#		*	
	Painting		*				#	*	*	*	
	Railing				*	*	#				
	Approach slab	*								*	*
	Pavement	*	#		*					*	*
	Scouring prevention		*	*	*	*	#	#		#	*

Note) *: method adopted in outline repair design
#: method considered as alternative in outline repair design (excluding replacement of bridge)
Bridge names: 1 (Amolanas), 2 (Pullally), 3 (Maipo), 4 (Claro), 5 (Loncomilla), 6 (Bio Bio), 7 (Ramadillas), 8 (Malleco), 9 (Pichoy), 10 (Cayumapu)

Chapter 5 Bridge Rehabilitation Planning

5-1 Principle for the Planning of Bridge Rehabilitation

5-1-1 Present Situation of Bridge Rehabilitation Practice in Chile

One of the main objectives of this Study is to work out an optimum methodology which will contribute to the effective maintenance of bridges on the National Route 5 which is the most important trunk road in Chile, aiming to secure safe and smooth flow of traffic, from the engineering and socioeconomic standpoints, and then, to formulate a bridge rehabilitation plan. Through a series of bridge inspections carried out in the first and second phases of the Study, it was identified that there were many bridges which were in the latter stage of senility in their life cycles and had severe defects among those on this route.

A bridge is one of the components of a road network system, and therefore, when the function of a bridge is once lost, it will give a great adverse effect to the society and economy not only in the area where the road is running, but also of the whole country. Furthermore, because of the reason that the National Route 5 is the most important artery of this country whose traffic volume has been rapidly increasing in line with the development of economy, the loss of national benefits and interests will be unaccountable by the suspension or loss of bridge function. Therefore, implementation of the proper maintenance and rehabilitation activities to bridges on the National Route 5 is considered to be of great importance and urgent necessity in this country.

In parallel with the Study, the Government of Chile, with its own discretion and financial resources, has also been planning and implementing new construction, rehabilitation and replacement of those bridges which immediately require such measures, in order to comply with the rapid increase of traffic volumes. In particular, in Regions VI and VII, implementation of the large-scale highway improvement programs are underway, including construction of grade-separated intersections and widening of carriage ways. In line with the programs, Maule Bridge and Piduco Bridge which were identified to be of high priority for proposed replacement in this Study are now in the process of actual replacement works.

5-1-2 Bridge Rehabilitation Planning

Determination of the bridge rehabilitation priority consists of many factors and elements. The priority shall preferably be determined by the comprehensive evaluation based on the engineering and structural factors such as the degree of bridge defect and functional characteristics, as well as the political and socioeconomic factors like traffic volume, regional development plan and national development policy. However, formulation of a bridge rehabilitation plan in the Study was attempted with application of the Bridge Maintenance Management System developed for this Study, due to the following reasons. The process of plan formulation can be roughly described as the evaluation of bridge defective degree based on the results of periodic inspection as the first step, and then, the determination whether the inspected bridges require rehabilitation or not as the second step, which is followed as the final step by determination of the bridge rehabilitation priority and estimation of rehabilitation cost.

As a part of plan formulation, prioritization of bridge rehabilitation for all the inspected bridges on National Route 5 was worked out by the following conditions and methods.

1. All the inspected bridges on National Route 5 are to be compared with the same conditions, regardless of bridge status whether included in the existing rehabilitation plans with budget allocations or on-going rehabilitation works being undertaken.

2. Rehabilitation priority shall be determined from the viewpoint of engineering criteria such as degree of defect, function and type of the bridge.

3. The standard rehabilitation method and its cost for each bridge component shall be determined for those bridges which are rated as the defective degrees 4 and 5.

4. With an assumption that all the bridges rated as above on National Route 5 shall be rehabilitated with the aforesaid standard methods, calculation of each bridge rehabilitation cost will be made.

5. As the indicators for evaluation of rehabilitation priority, estimation of cost for bridge rehabilitation work and applicable traffic volume are to be worked out.

6. Above indicators shall be properly tabulated so that the bridge rehabilitation priority determined in item 2 can be evaluated.

5- 2 Bridge Rehabilitation Plan for the National Route 5

The priority of bridge rehabilitation decided by the integrated determination indicators (TE) is performed in the Study. The bridges which are necessary urgent repair are shown in Table 5-1, The bridges with the following conditions are not included in the Tables.

1. Bridges which already have plans for rehabilitation/replacement.
2. Bridges which are not the bridge deficiency rate 5 for the super- and sub-structure, though the TE indicator is higher
3. Bridges which are necessary to construct new bridge (replacement) due to severe damage occurred by problems of basic structure and of conditions for the bridge location.

Table 5-1 Bridges Necessary Urgent Repair

NO.	NO	NOMBRE	REG	COST (x1000 PS)	ADT	BA	COST/ ADT	COST/ BA*ADT	TE	L	S	I
1	29	PULLALLY	5	48916	4095	1552	11945	7.7	129	4	4	5
2	70	ANTIVERO PONIEN	6	26511	18182	1574	1458	0.9	120	5	4	3
3	53	PS TENIENTE PON	6	34990	15340	338	2281	6.7	130	4	4	5
1	137	DIGUILLIN	8	163725	12644	683	12949	19.0	124	4	5	5
2	123	NINQUIHUE	8	13313	6485	206	2053	10.0	130	4	4	5
3	140	LAJITA •	8	8422	6593	304	1277	4.2	128	4	5	4
4	117	NIQUEN	8	4232	6485	261	653	2.5	122	4	5	3
5	142	BATUQUITO	8	65542	6593	144	9941	69.0	130	4	4	5
6	141	BATUCO	8	11192	6593	331	1698	5.1	125	5	4	4
7	152	BUREO	8	33899	5659	1408	5990	4.3	132	5	4	4
8	143	SALTO DEL LAJA	8	166744	6593	1187	25291	21.3	121	5	5	4
9	160	CHAMICHACO	9	5176	4366	163	1186	7.3	130	5	4	4
10	159	HUEQUEN	9	75540	4366	233	17302	74.3	125	5	5	5
11	165	CHANCO	9	6076	5429	203	1119	5.5	120	5	4	3
12	156	MININCO	9	29034	5659	588	5131	8.7	132	4	5	4
13	161	DUMO	9	85112	4366	294	19494	66.3	118	4	5	3
14	166	QUINO	9	79212	5429	578	14591	25.2	124	4	4	5
15	168	PS PUA	9	8620	5429	314	1588	5.1	123	5	4	4
16	213	RAHUE	10	62582	2898	1539	21595	14.0	123	5	5	5
17	233	TRAPEN BAJO	10	5853	2794	360	2095	5.8	113	4	5	3
				934691								

Chapter 6 Outline of The Guideline

A bridge is one of the structural facilities which compose a road network system. It normally requires the largest amount of cost for its construction and maintenance. It is also inclined to face greater chances to suffer from natural disasters due to its functional characteristics. When the time comes for a bridge not to be able to keep it function, it will put enormous adverse efforts not only on road transportation, but also to stability and security of the society. Furthermore, restoration of the bridge function requires a huge cost as well as long period of time. Therefore, maintenance activity of the bridge plays a very important role to ensure safe, smooth and comfortable flow of road traffic.

This guideline is prepared for the engineers concerned in charge of the bridge maintenance. It presents the basic principles, methods and standards of the bridge inspection and subsequent maintenance. Therefore it does not cover all sorts of bridge inspection methodologies, nor introduce the detailed rehabilitation methods. The guideline is composed of the following contents.

1) Basic principles of bridge inspection and maintenance
2) Definition of terminology related to bridge engineering
3) Standard procedures of periodic bridge inspection
4) Evaluation of the results of inspection and evaluation criteria
5) Standardized rehabilitation methods
6) Standard procedures of detailed bridge inspection
7) Case study of bridge rehabilitation

This guideline is separately prepared from the Main Text of the Study, and is entitled "Guideline for Bridge Maintenance Inspection".

Chapter 7 Bridge Maintenance Management Systems

7-1 System Concept

The bridge management system presented in this paper is a support system to aid planning of bridge maintenance programs in a way that is both scientific and practical. The system involves the use of a microcomputer to store bridge-related data in a data base system.

When supplied with data for a number of bridges the system is able to devise inspection schedules, determine the order of priority for various maintenance operations as well as diagnose the condition of existing bridges. The basic structure of the system is as shown in Figure 7-1.

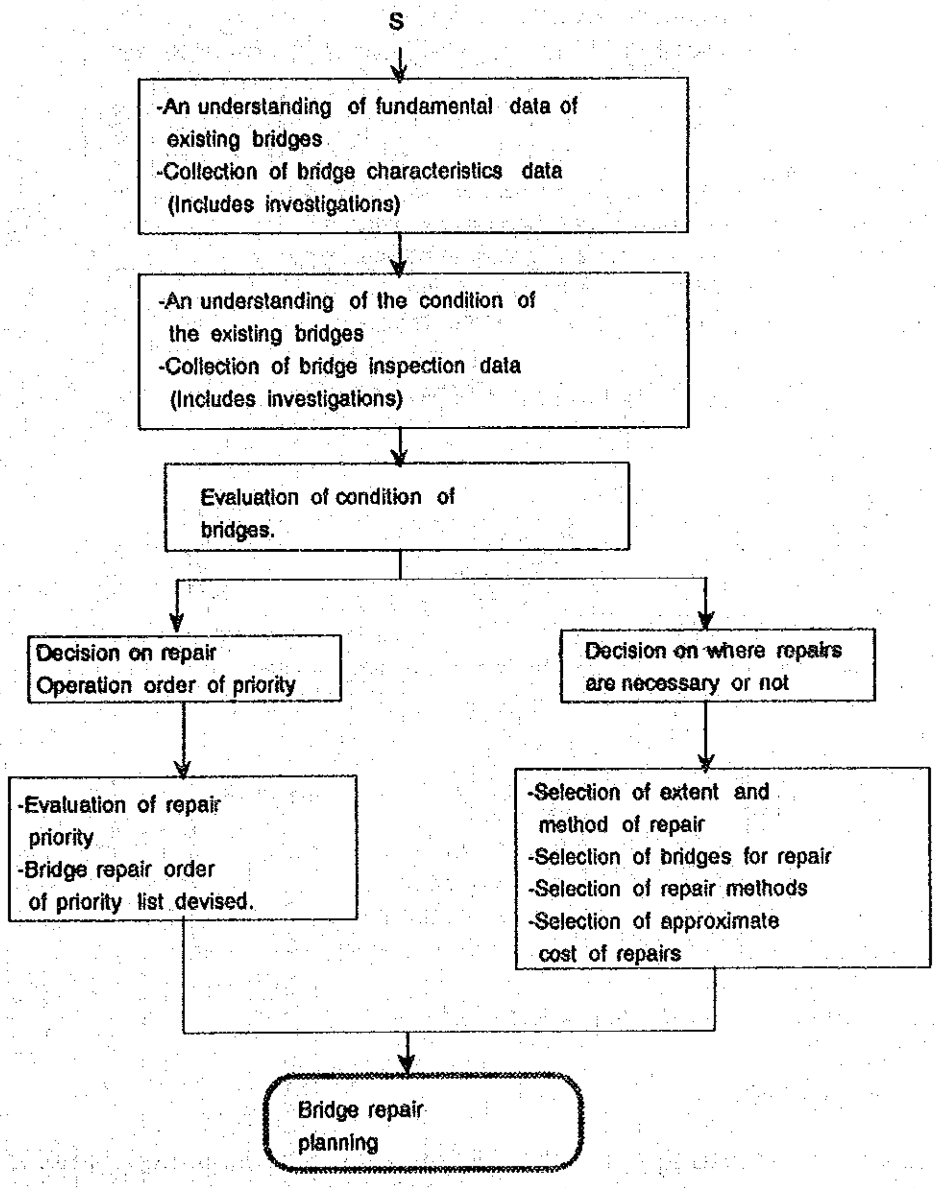

Figure 7-1 System Concept

Figures 7-2 and 7-3 indicate the hardware and software used in the system.

7-2 System structure

1) Software

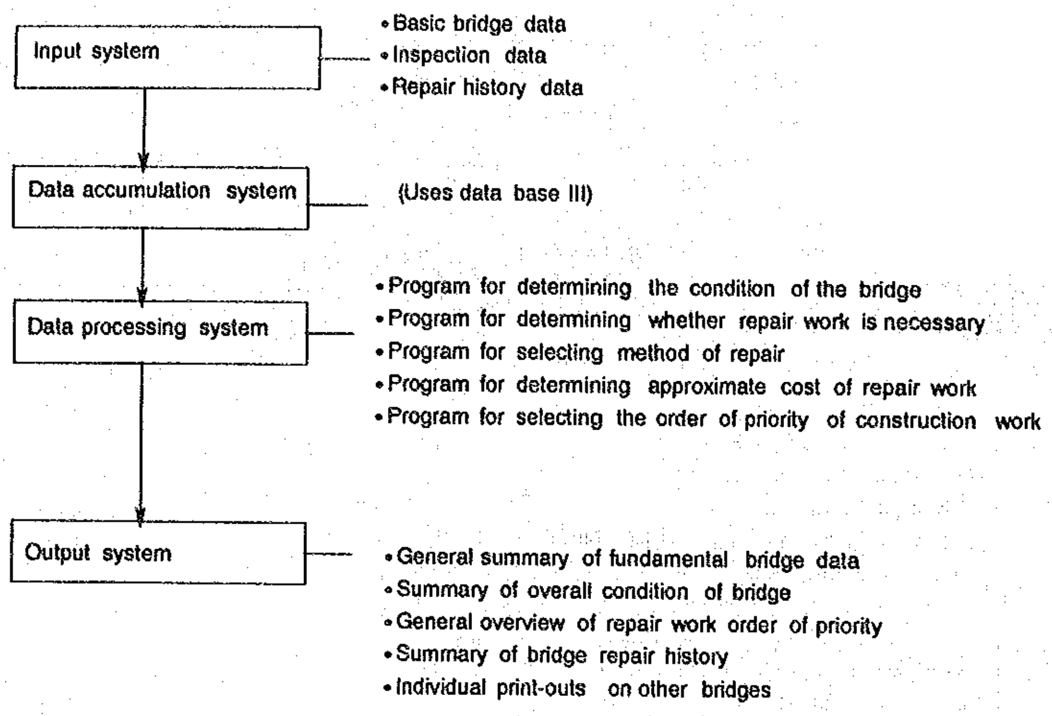

Figure 7-2 Structure of Software

2) Hardware

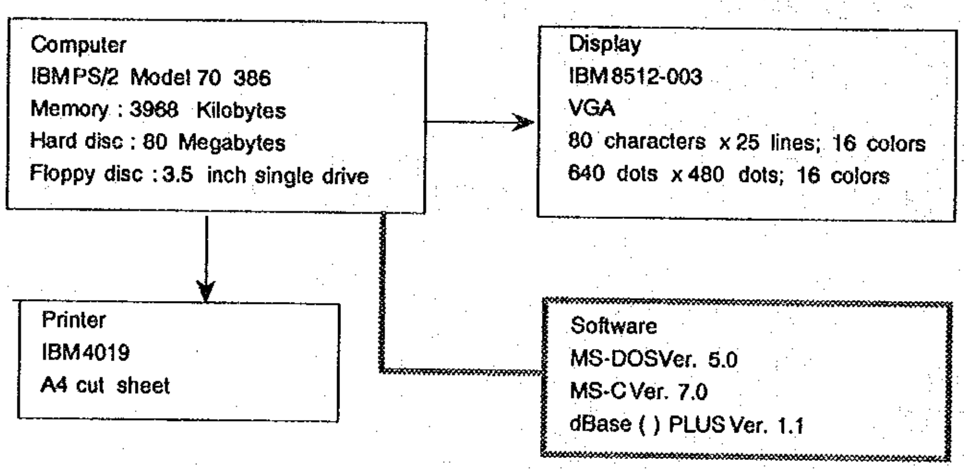

Figure 7-3 Hardware

3) System processing block chart

Figure 7-4 uses a program processing block chart to indicate the processing software system for the bridge repair management system.

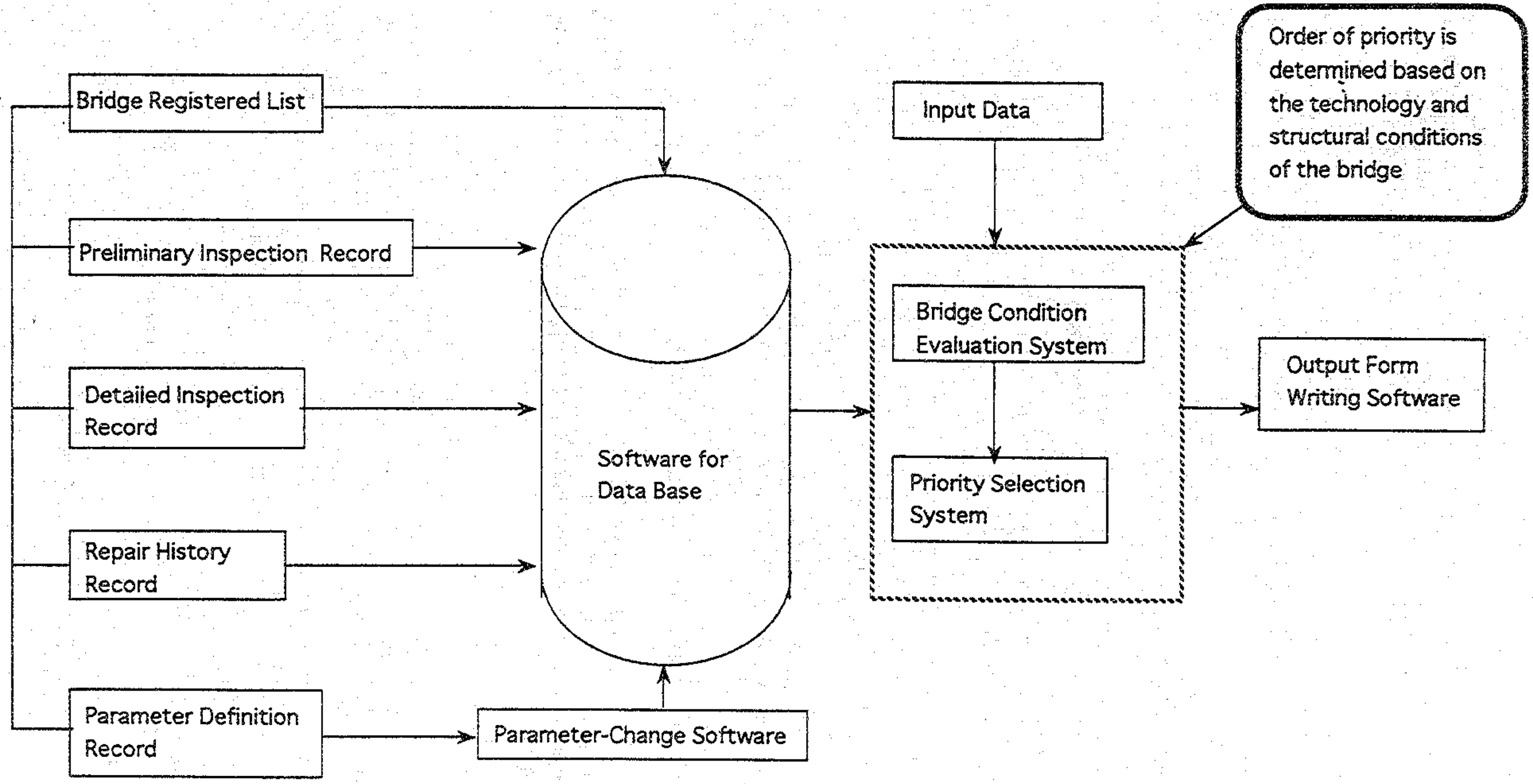

Figure 7-4 Bridge Maintenance Management System Processing Flowchart

7-3 Basic functions of the system

The functions of the system can be divided into those of data base and those of data processing.

(1) Data base functions

Data base functions include data recording, updating, storage, accumulation and retrieval/output functions. The following section describes these functions in detail.

1) Data recording and updating functions

Data recording and updating functions consist of the following:

a. The recording and updating of basic bridge data
b. The recording and updating of preliminary bridge data
c. The recording and updating of detailed bridge data
d. The recording and updating of bridge repair history
e. The recording and updating of system management parameter data

Each of the recording and updating functions in 1~4 have batch and on-screen interaction functions.

2) Data storage and accumulation functions

These comprise of interface software that assesses the dBase with the data record/update and the data retrieval/output screens. The basic software used here is dBase –Plus V – 3.5.

The main storage accumulation functions are as follows:

a. Data storage and accumulation (mainly data peculiar to the bridge being investigated) using a relational data base.
b. Data storage and accumulation (mainly code data and work files) using sequential files.

3) Data retrieval/output functions

Data retrieval/output consists of two functions. One of these functions, the fixed retrieval/output function, sets forms that are used every day and brings them on-screen after a code is entered. The other function retrieves specific data stored in the data base. To do this the operator enters the items to be retrieved, the retrieval/output and data editing parameters. The following list describes the content of these functions in detail:

A. Fixed retrieval/output function

The following documents may be retrieved for each state using the fixed retrieval/output function:

General bridge documents:
1 Bridge outline
2 Bridge inspection history
3 Bridge condition evaluation
4 Bridge maintenance history

Specific bridge documents
5 Fundamental bridge register
6 Bridge preliminary inspection document
7 Bridge condition evaluation
8 Bridge maintenance history
9 Fundamental bridge register (MOP format)

B. Optional retrieval/output functions

The optional retrieval/output functions allow the operator to retrieve optional items stored in the relational data base (d Base). The procedure for setting the conditions for retrieval/output is fixed. A fixed set of rules also applies to the number of pieces of data retrieved, the number of output items, the output format and the selection of the output unit. Such procedures and restrictions will be revealed during the detailed designing stage. The following is an outline of the optional retrieval/output function: Refer to Figure 7-5.

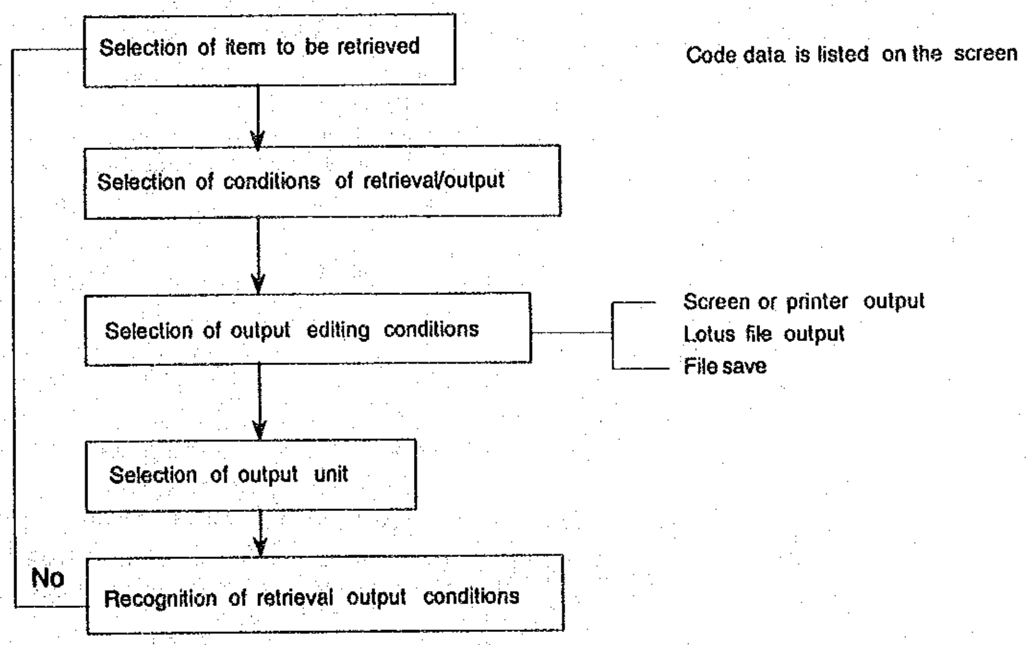

Figure 7-5 Outline Of Optional Retrieval/Output Function

(2) Data computing / processing functions

Data computing/processing functions are a set of application programs that carry out data processing /computing functions using the data and input data in the data base appropriate to the aim. The system we used has the two computing/processing blocks shown below as was shown in Figure 7-4

1) Bridge condition evaluation system

The bridge condition evaluation system uses the damage inspection data to evaluate the condition of the bridge and to determine whether repair is necessary. The system has the following three sub-routine programs:

1 Bridge sectional condition evaluation processing program
2 Bridge overall condition evaluation processing program
3 Repair method selection and rough estimate cost

2) System for determining the order of preference for Bridge repair/rebuilding

This system ranks and selects the bridges along say, the length of state highway 5 according to the degree of urgency of repair. The system bases its decisions on the results of the bridge condition evaluation while taking into account economic, social, technological, and political factors.

Chapter 8 Conclusion And Recommendation

8-1 Conclusion

The Study on Rehabilitation and Conservation Program of Bridges was proceeded with the inspections of 256 existing bridges in total, 246 bridges among those on the National Route 5 and 10 bridges selected on the arteries branched out of it. Based on the results of inspections, a fairly comprehensive bridge inventory register was prepared, which was followed by bridge defect degree evaluation and priority rating for rehabilitation. Then, formulation of bridge rehabilitation plan was attempted. In parallel with these works, preparation of a guideline for bridge maintenance inspection, and development of a micro-computer system on bridge maintenance management were undertaken.

(1) Bridge Inspection and Rehabilitation Planning

Because of the reason that the design documents of the existing bridges subjected for inspections were not kept at the Ministry of Public Works, measurement of the major dimensions and photographing of the bridges and their surroundings were carried out at time of inspections, along with drawing of their general designs. By that way, a bridge inventory register was prepared and compiled. The outcomes of these works were not only very productive to formulation of the bridge rehabilitation plan, but also will be expected to contribute to the bridge maintenance activities of the ministry in the future. It is suggested that similar type of data collection and compilation of the existing bridges on the regional roads to be a proper bridge register will greatly contribute to the bridge maintenance activities and their rehabilitation planning in the future.

Among those bridges inspected on the National Route 5, the bridges which were evaluated to be of defective degree rankings of 4 and 5 were selected and incorporated in formulation of the bridge rehabilitation plan. The total budget of the plan worked out by accumulation of the estimated costs of rehabilitation works amounts to Chilean Pesos 4,000 million. It is to be pointed out that the proposed rehabilitation plan is intended to restore the originally required function of the existing bridges, with the standardized rehabilitation methods. Therefore, it is neither planned to strengthen this function, nor included large scale rehabilitation of the special types of bridges. For planning of large scale rehabilitation and for that of the special types of bridges, it would be necessary to undertake further detailed studies with different approach.

Many of the bridges included in the rehabilitation plan are quite widely ranged from very old ones to lately constructed ones. This means that there are great differences in the design concept and design specifications like design load, etc., according to the ages when the bridges were constructed. Apart from this fact, some bridges were found to have deformations at their girders and piers, regardless of the times of their design. Since there are no design documents at completion being kept at the administrative offices concerned, verification as to whether the deformations were caused at time or after the bridge construction was found to be very difficult.

Judging from these facts, for the future planning of development, improvement and maintenance of the bridges on a certain road network, consistency and integration in the design concept and standards would be necessary, in close coordination with those for roads. For that purpose, some of the bridges seem to be required to elevate the level of functions, which leads to the consideration on necessity of rehabilitation with strengthening of function or replacement.

With regard to the rehabilitation designs of 10 bridges selected for detailed inspection, they are intended to demonstrate the basic ideas and examples of rehabilitation designs, with the main purpose of restoring their original structural functions, and therefore not worked out based on structural calculations. Also, although geological surveys of the bridge foundation was attempted for the bridges where it was considered necessary, they were conducted only to a practically possible point per bridge, instead of proper positions near the bridge piers, they seems to be insufficient to grasp the excavation depth of foundation, for correct designs of the sub-structure rehabilitation. Therefore, at time of implementation of the substantial rehabilitation works of the foundation, it is recommended that the design works shall be done based on additional detailed surveys and investigations.

Also, there are some bridges inspected in details which are identified to require certain sorts of proper structural improvement and/or have been inadequately rehabilitated before by improper methods. Furthermore, some bridges are found to have barely enough structural strength, but with fairly great deformation inducing transverse vibration or rolling which are causing anxiety to the road users, and need constant observation and investigation in the future (Malleco). Also, some are found to have been severely deformed (Amolanas). With these facts in consideration, it is recommended that the design concept and standards would be reviewed and revised to be established as the national standards so that they properly conform to future requirements to strength and measures to deformation as well as to the structural details which can not be defined by just the design calculation.

(2) Guideline for Bridge Maintenance Inspection

The guideline for bridge maintenance inspection prepared in the Study is intended as a reference or a specimen to those engineers who are engaging in the bridge inspection works. It describes not only the key points of bridge inspection upon its execution, but also the fundamentals of bridge maintenance, such as the evaluation method of bridge defect and standardized bridge rehabilitation method. However, it does not cover the inspection of wooden, Fink and suspension bridges and other types which are widely located on the local roads in the country, because the Study is for the bridges on the National Route 5.

The guideline is also recommended to be revised and improved with additions and/or modifications in the course of actual utilization, and to be made as a proper manual for bridge maintenance inspection and rehabilitation. For this purpose, periodic monitoring from the field engineers will be recommendable.

(3) Bridge Maintenance Management System

For practical and economical adoption, a bridge maintenance management system with a micro-computer was developed which has the data-base on various bridge dimensions and records of inspection to determine the defect degrees of bridges. This system was expanded to include the sub-systems to calculate the rehabilitation costs