REPUBLIC OF PALAU

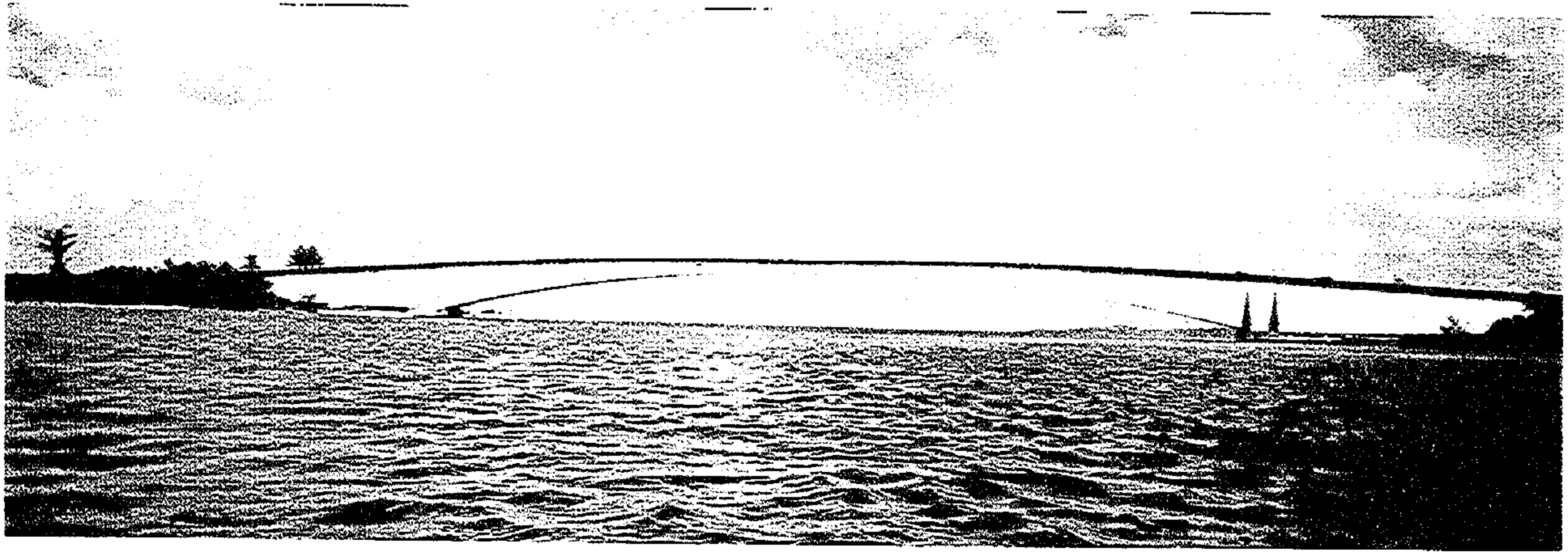
PRESENT CONDITION SURVEY OF THE

KOROR - BABELTHUAP BRIDGE

FEBRUARY, 1990

JAPAN INTERNATIONAL COOPERATION AGENCY

KOROR-BABELTHUAP BRIDGE

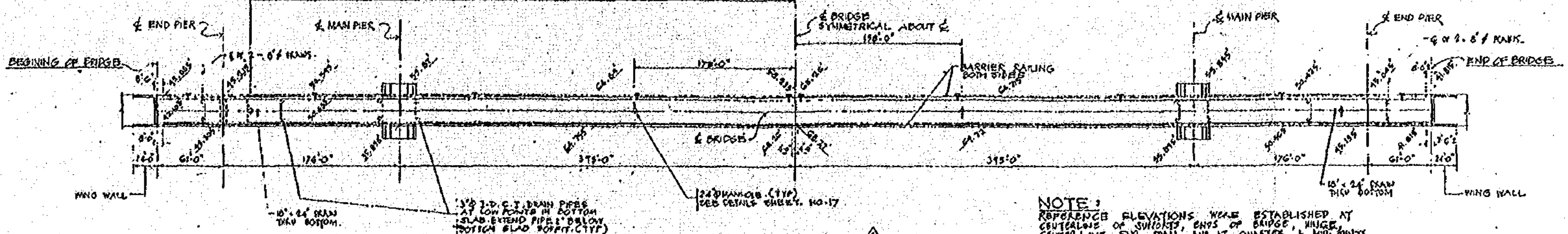


KOROR SIDE

BABELTHUAP SIDE

KOROR ISLAND

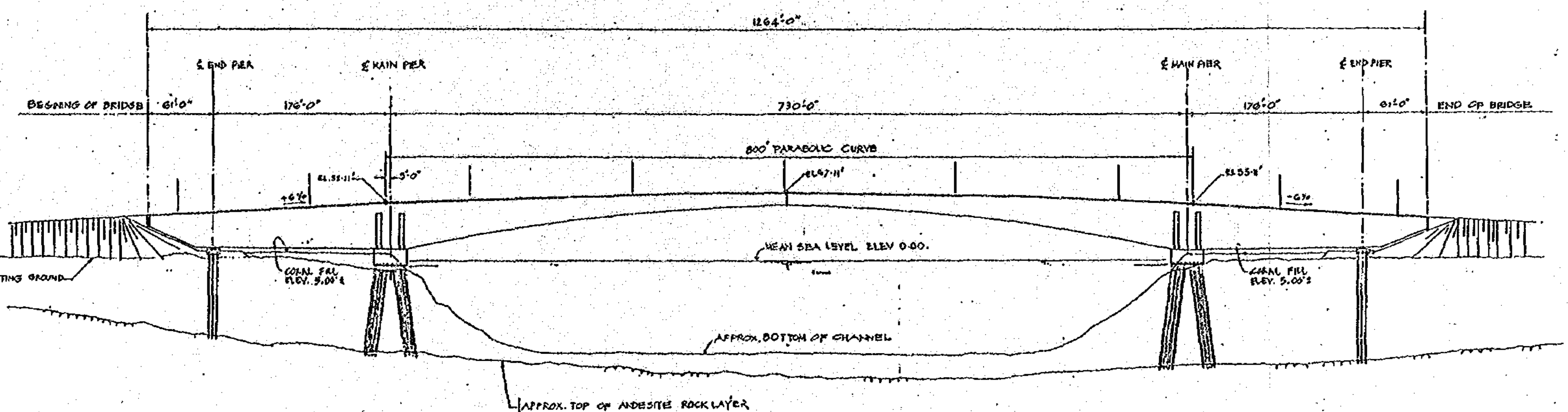
BABELTHUAP ISLAND



BRIDGE PLAN

SCALE: 1"=500'

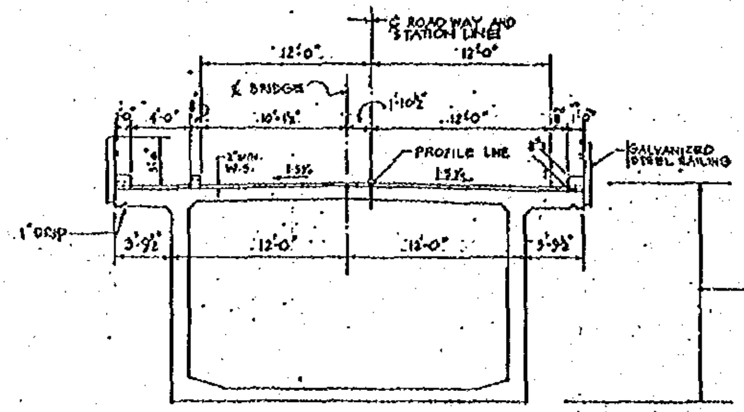
NOTE:
REFERENCE ELEVATIONS WERE ESTABLISHED AT CENTERLINE OF SUPPORTS, ENDS OF BRIDGE, HINGE, CENTERLINE END SPAN, AND AT QUARTER & MID-POINTS OF MAIN SPAN ON THE OUTER CURBS. THE POINTS ARE IDENTIFIED BY CHISELED + MARKS ON THE TOP SURFACE OF CURB AND PAINTED RED. CENTERLINE OF THE MAIN PIER IS ASSUMED TO BE THE BENCHMARK.



BRIDGE ELEVATION

SCALE: 1"=500'

AS-BUILT DWG.
Date: June 30, 1977



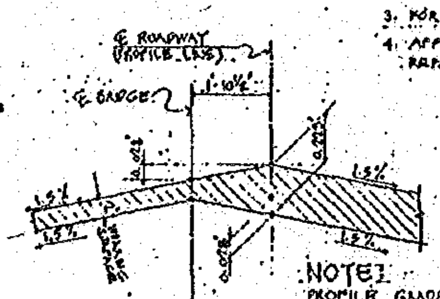
LOOKING EAST

TYPICAL CROSS SECTION

NOT TO SCALE

NOTES:

1. ELEVATIONS SHOWN ON TOP OF BRIDGE ARE AT ℄ OF ROADWAY AND ARE FINISH GRADE ELEVATIONS. (TOP OF WEARING SURFACE)
2. FOR LOCATION OF LIGHT STANDARDS SEE SHEET NO. 18.
3. FOR FOUNDATION AND PILE DETAILS SEE SHEET NO. 6.
4. APPROX. GROUND LEVEL AND ROCK PROFILE ARE BASED ON REPORT FROM HARDING-LAWSON ASSOCIATES DATED MAY 30, 1975.



NOTE:
PROFILE GRADE AT ℄ BRIDGE FOR CANTILEVER CONSTRUCTION = P.G. - 0.1667' - 0.0281'
= P.G. - 0.19'

AS-BUILT WEARING SURFACE DIMENSIONS
N.T.S.

GRAPHIC SCALE:
1" = 50' 100' 50' 0 100' 200'

JULY 16, 1975

REVISION	DESCRIPTION	DATE	APPROVED
4	REVISED DWG. TO SHOW "AS-BUILT" CONDITIONS	30 JUNE 77	

ALFRED A. YEE & ASSOCIATES, INC.
STRUCTURAL ENGINEERS · ARCHITECTS · PLANNERS

TRUST TERRITORY OF THE PACIFIC ISLANDS
DEPARTMENT OF PUBLIC WORKS
DESIGN AND ENGINEERING DEPARTMENT — SAIPAN, MARIANA ISLANDS

PALAU DISTRICT — PROJECT NO. TT-173-76

KOROR-BABELTHUAP BRIDGE
BRIDGE PLAN AND ELEVATION

Design / Drawn / Checked / Supervision / SUPERVISORY ARCHITECT / Approved / CHIEF OF DESIGN

SATISFACTORY TO — DATE
Approved Date 7/10/75
DIRECTOR - PUBLIC WORKS

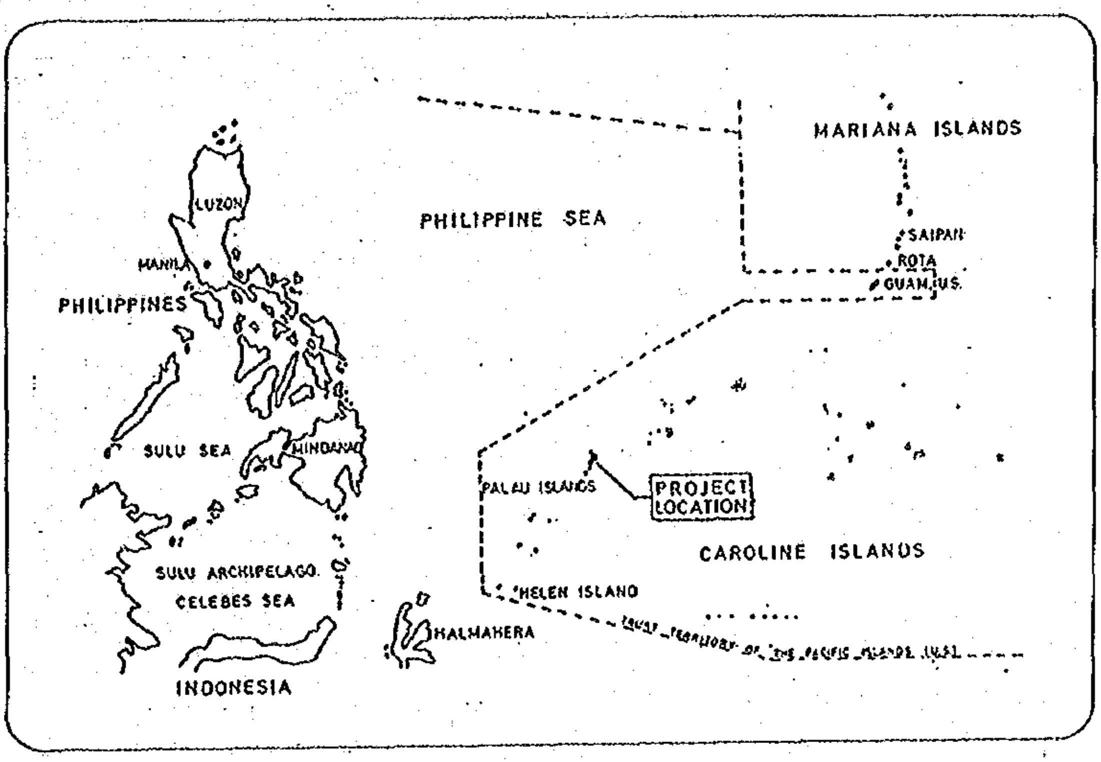
DRAWING NO. V-73(4)
Sheet 4 of 23 Sheets

Dyckerhoff & Widmann Inc.

Survey Location

VICINITY MAP

NOT TO SCALE



PROJECT

NOT TO SCALE

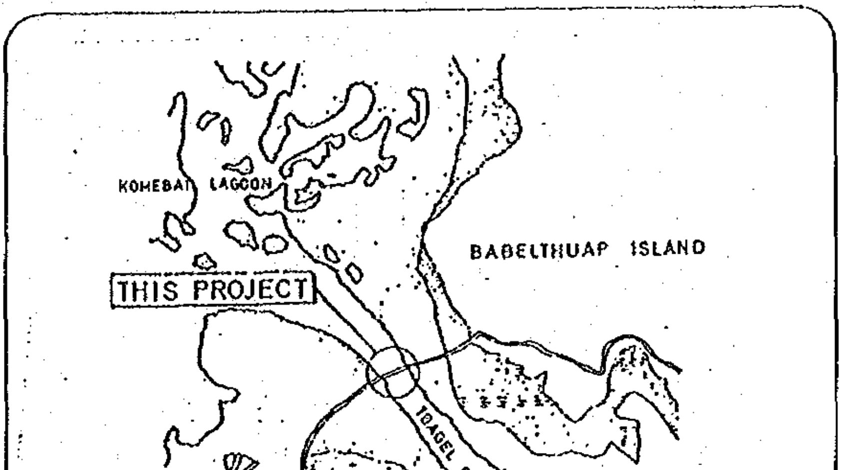


TABLE OF CONTENTS

1. OUTLINE OF SURVEY

1・1 Background of the Study

A technical study of the Koror-Babelthuap Bridge in the Republic of Palau was requested. The Republic of Palau is comprised of about 200 islands and about 15,000 people. The two main islands are Koror Island and Babelthuap Island, the second largest island in Micronesia. Koror is the center of economy and politics, while Babelthuap has the only commercial airport operations in the area. The Koror-Babelthuap Bridge is the only link between the islands of Koror and Babelthuap.

The bridge was desgined by Alfred A. Yee & Assoc., Inc. of Honolulu, Hawaii. Korean companies as well as the Socio Construction Co.,Guam, constructed the bridge. Construction started in 1975 and was completed in June, 1977. The main span is 790 ft. (241 m). The 1264 ft. bridge is the second longest concrete box girder bridge in the world. The Palau Islands Bridge is of the balanced cantilever, prestressed concrete type structure with a midspan hinge.

Since completion the bridge has somehow deflected. It has an irregular deformation causing a severe depression in the riding surface of the bridge at the midspan hinge. This also detracts from its appearance.

For this reason, in May, 1989, the Republic of Palau, represented by President Ngiratkel Etpison, requested to the government of Japan for assistance in surveying the K-B Bridge to discover the specific causes of the midspan sagging and the consequences of the sagging.

1・2 Purpose of Survey

Thirteen years have passed since the bridge was constructed. The bridge at midspan has sagged 3.5 feet more than was originally anticipated in the design drawings. In accordance with the government of Palau's request, the survey development project was conducted as follows :

(1) To examine the cause of deflection at the midspan

(2) To estimate the future damages in case of being left (without any rehabilitaion)

1・3 Operation Schedule

The study consists of two parts, site survey and home analysis in Japan.

- In Palau, the survey was conducted for 14 days from January 15 to January 28 in the following areas : (See page 6, attached, for detailed list)

  (1) Structural elevations were studied.

  (2) Concrete compressibility strength was studied.

  (3) Damage was assessed.

  (4) Degradation was studied.

  (5) A simplified movable load test was conducted.

  (6) Others (Materials, labor and project costs were estimated.)

- In Japan, survey measurements, collected data and documents were examined.

SURVEY SCHEDULE

	DATE	PLACE	ACTIVITIES
1	January 15 (Mon)	Tokyo Guam Koror	Depart Tokyo at 11:30 Arrive Guam at 15:00 Depart Guam at 18:25 Arrive Koror at 19:20
2	〃 16 (Tue)	Koror	Visit the Government of Palau Visit the Bureau of Public Works and discuss the survey schedule
3	〃 17 (Wed)	Koror	Study of bridge (Measurement of elevation on the bridge)
4	〃 18 (Thu)	Koror	Study of bridge (Concrete soundness)
5	〃 19 (Fri)	Koror	Consult with the Palau Government Study of bridge (Movable load test)
6	〃 20 (Sat)	Guam Koror	Depart Koror at 14:15 Arrive Guam at 17:10 (Kanazawa, Mikami, Matsushima) Report to the Consulate General Study of traffic amount
7	〃 21 (Sun)	Guam Koror	(Public Officers go home) Collection and study of data
8	〃 22 (Mon)	Koror	Study of bridge (Degradation) Collection and study of additional information Study of traffic amount
9	〃 23 (Tue)	Koror	Study of bridge (Damage at midspan and above the water level)
10	〃 24 (Wed)	Koror	Study of bridge (Damage inside the box)
11	〃 25 (Thu)	Koror	Study of bridge (Damage)
12	〃 26 (Fri)	Koror	Collection and checking supplementary data and information (Study of machines and unit costs)
13	〃 27 (Sat)	Koror Guam	Depart Koror at 14:15 Arrive Guam at 17:10
14	〃 28 (Sun)	Guam Tokyo	Depart Guam at 06:00 Arrive Tokyo at 08:30

1 · 4 Members of Survey Team

The Survey Team consisted of the following five members.

	Field	Name	Status
1.	Leader of the Team	Atsushi Nishioka	Deputy Director, Development Cooperation Devision, Economic Cooperation Bureau, Ministry of Foreign Affairs
2.	Bridge Planning	Tomoki Kanazaki	Staff, First Design Division, Design Department Honshu-Shikoku Bridge Authority
3.	Grant Aid Planning	Tetsufumi Mikami	Official, Grant Aid Devision, Economic Cooperation Bureau, Ministry of Foreign Affairs
4.	Project coordinator	Masaaki Matsushima	Staff, First Regional Division, Planning Department, Japan International Cooperation Agency
5.	Bridge Structure	Fujiya Fujii	Technical Manager, Registered Consulting Engineer, Bridge Department, Hokkaido Engineering Consultants Co., Ltd.

2. SURVEY

2・1 Areas of Survey

The Survey consists of two parts : Part one of the survey is to collect data concerning the Koror-Babelthuap Bridge. The second part is to gather necessary technical data on the present condition of the bridge.

2・1-1 Collection of Data

Only initial design drawings were available. The essential data such as design documents, execution of scheme drawings, records of execution or maintenance records were not available as they weren't retained by the Palau Government.

2・1-2 Study of the Bridge

a. Measurement of bridge elevation

Bridge elevation was measured at 15 m intervals along the center line to determine any bridge elevation changes between completion and the present.

b. Study of concrete soundness

Concrete compressibility strength of the bridge was measured using a Schmidt Hammer. Core samples from the bridge were extracted using a core sampling machine. Four cores each (ϕ100 x 200) were extracted from the piers, abuttments and girders. The samples were used to determine concrete compressibility strength, modulus of static elasticity, as well as the amount of percolating salt.

c. Damage study

Girder damage and cracks were assessed with the naked eye or with a crack guage. Width, length and location of cracks were recorded. Abuttment damage was assessed using binoculars.

d. Study of degradation

Samples from areas of greatest damage were tested with phenolphtalein solution to determine changes in concrete pH over time. Concrete core samples were taken to Japan to examine levels of salt in the concrete.

Findings were used to determine concrete durability.

e. Simplified movable load test

(1) Four 12.5 ton dump trucks were stopped at the center of the bridge to test elevation changes.

(2) Actual bridge deflection were compared with original theoretical estimates in the plan.

f. Traffic survey

A traffic survey was conducted. Types and numbers of vehicles using the bridge was counted.

Areas and Purpose of Survey

STUDY	PURPOSE	TOOLS AND EQUIPMENT
a. Bridge elevation mesurement	Comparision of present elevations with post construction elevations	Level (1) Adjustable surveyor's staff (2)
b. Concrete compressibility strength	① Testing of concrete compressibility	Schmidt Hammer (1) Recording paper
	② Testing of concrete strength	Core sampler (1) Battery power supply
c. Damage study	To determine which cracks effect structural integrity of bridge	Crack guage (1) Binoculars (1)
d. Degradation	① To determine concrete pH	Phenolephthalein
	② To determine amounts of salt percolation	Salt levels in concrete core samples determined in Japan
e. Simplified load test	To test concrete strength of girder	Vehicle loading 12.5t. dump truck (4) Level (1) Surveyor's staff (2)
f. Traffic survey	Types and numbers of vehicles	

2・2　Findings of Survey

Findings from survey and data collection in Palau as well as sample testing in Japan :

a. Bridge elevation measurement

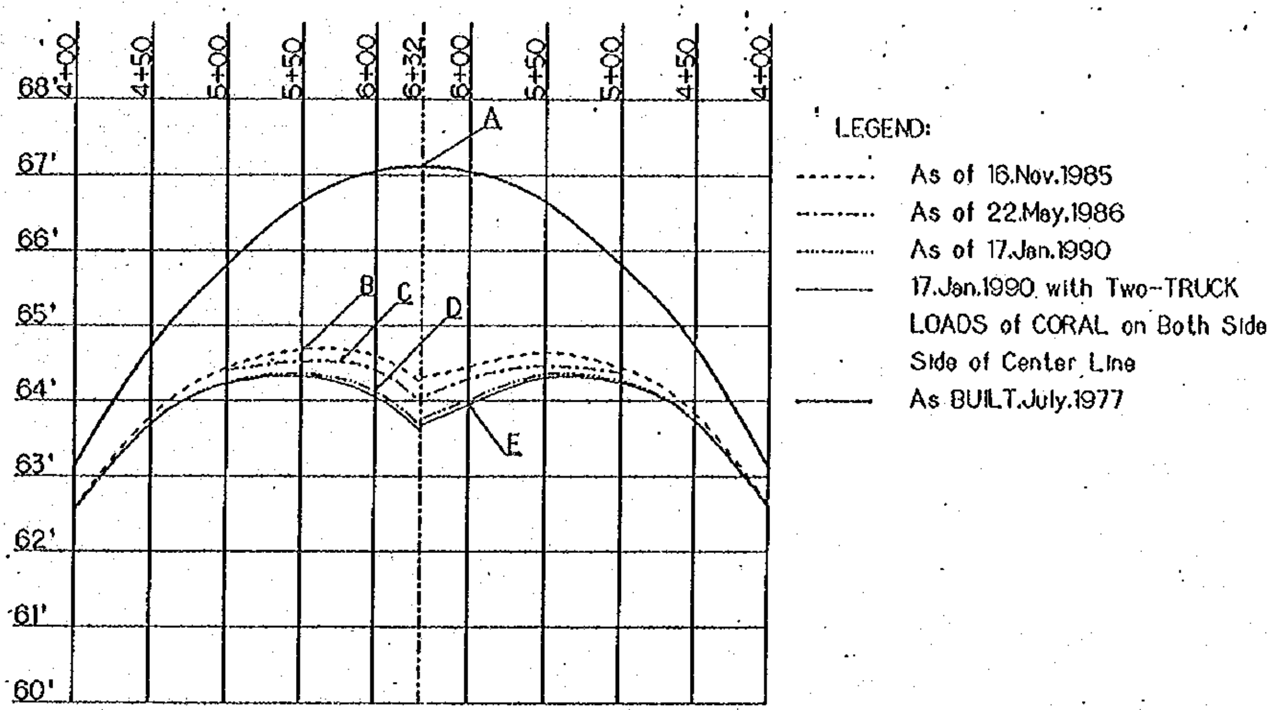
Bridge midspan elevations were measured as follows :

Date		Elevation	Difference
July, 1977 (year of completion)		67.11 ft	
			> 2.84 ft (86 cm)
November, 1985		64.27 ft	
			> 0.25 ft (8 cm)
May, 1986		64.02 ft	
			> 0.30 ft (9 cm)
January, 1990		63.72 ft	
		Total	3.39 ft (103 cm)
January, 1990 (weight of loading : 12.5 ton x 4 trucks)	Ⅲ	63.64 ft	
			> 0.10 ft
January, 1990 (after the removal of load)	Ⅳ	63.74 ft	(3.0 cm)

The bridge has deflected 0.06 ~ 0.09 ft at the central hing.

Bridge elevation changes over time are shown in the following diagram :

BRIDGE ELEVATION



←KOROR SIDE BABELTHUAP SIDE →

Date \ Point		4+00	4+50	5+00	5+50	6+00	6+32 Br.CL	6+00	5+50	5+00	4+50	4+00	
As BUILT. July.1977		63.12	64.72	65.81	66.65	67.05	67.11 67.11	67.05	66.65	65.81	64.72	63.12	A
16.Nov.1985		62.64	63.84	64.44	64.64	64.45	64.3 64.24	64.6	64.68	64.44	63.79	62.56	B
22.May.1986				64.38	64.46	64.29	64.05 63.99	64.41	64.52	64.41			C
17.Jan.1990		62.6	63.75	64.26	64.35	64.02	63.76 63.67	64.13	64.36	64.24	63.7	62.53	D
19.Jan.1990	1	62.59	63.73	64.23	64.3	63.95	63,67 63.59	64.06	64.32	64.22	63.69	62.52	Two-TRUCKs on Both Side E
	2	62.59	63.72	64.24	64.31	63.94	63.67 63.6	64.06	64.31	64.21	63.69	62.51	4-TRUCKs on AIRAI Side
	3	62.59	63.72	64.24	64.3	63.95	63.68 63.6	64.07	64.33	64.22	63.69	62.52	4-TRUCKs on KOROR Side
	4	62.6	63.74	64.26	64.35	64.02	63.78 63.69	64.14	64.36	64.25	63.7	62.52	NORMAL PROFILE

b. Study of concrete soundness

Concrete soundness was studied using a Schmidt Test Hammer to measure concrete compressibility strength by taking core samples. The Modulus of elasticity as well as the unit volume weight and salt amounts were determined.

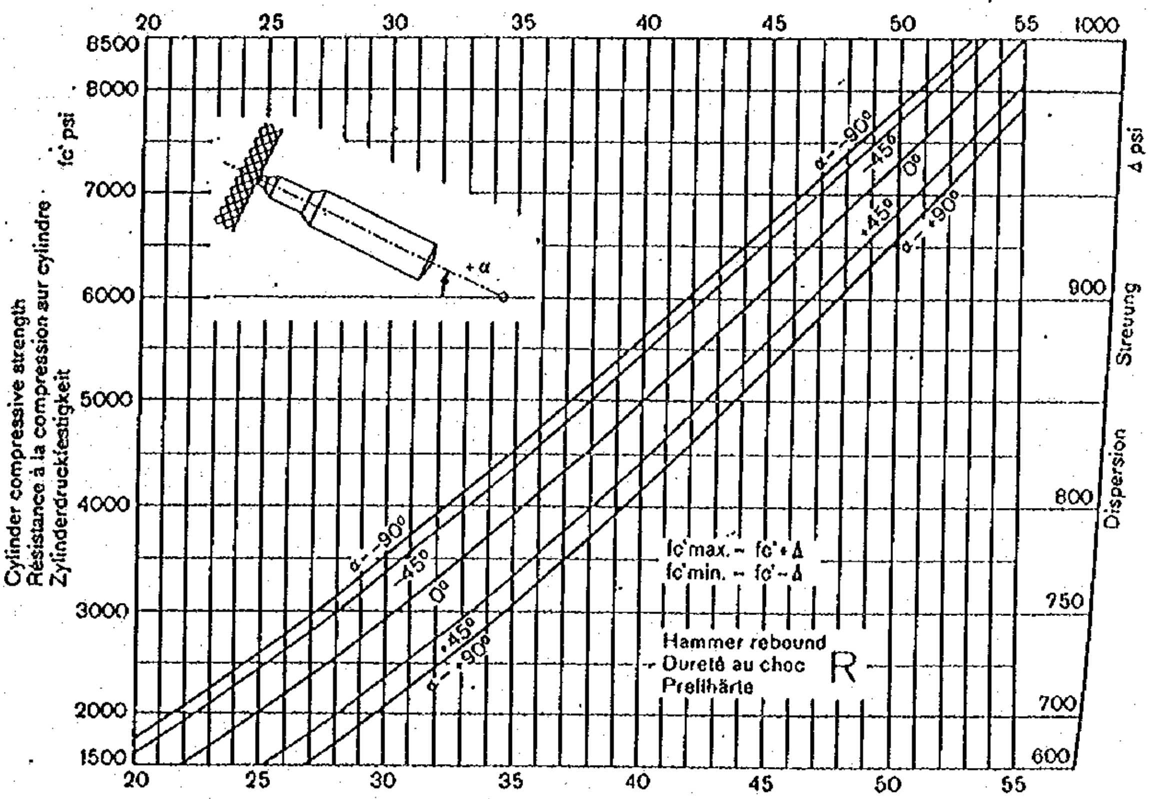
i) Measurement of strength using a Schmidt Hammer

Rebound Number of concrete was measured using a Schmidt Hammer Type N made by PROCEQ of Switzerland.

Concrete compressibility strength was measured using a table of conversion.

Cylinder Compressive Strength in psi plotted against the Rebound Number

Type N Test Hammer



No.	Rebound Number (R)	Compressibility Strength		Survey Location
		lb / in	kg / cm	
1	34	3,750	263	Abuttment on the Koror side in the south
2	36	4,200	295	Pier on the Koror side in the south
3	38	4,600	323	Girder at midspan
4	38	4,600	323	Girder at midspan
5	41	5,250	369	Girder segment 5 on the Babelthuap side
6	35	3,900	274	Pier wing on the Babelthuap side

Girders 4,600 ～ 5,250 psi

Abuttments, piers 3,750 ～ 4,200 psi

Note : Cylinder concrete compressibility strength

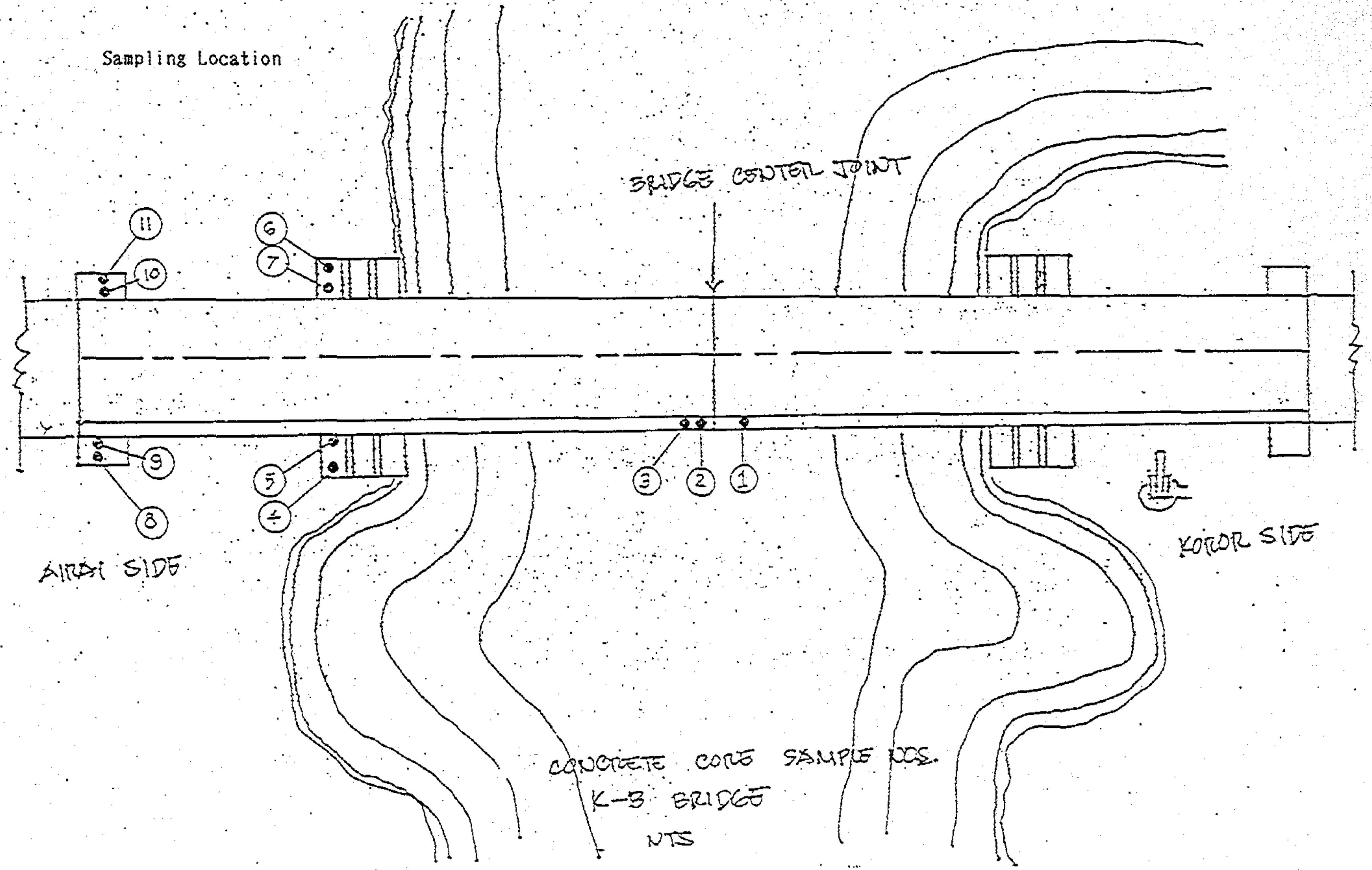
Measuring angle $\alpha = 0°$ (horizontal)

Average value 20 points per place

ii) Compressibility strength using a core-sampler, Modulus of elasticity, test of the amount of salt, unit volume weight, were determined.

Eleven core samples (ϕ 10 cm x 30 cm) were taken. Fndings of the test are as follows :

Sampling Location



Findings of Experiment at Test Location

Test Location	Test Items	Compressibility Strength (psi)	Modulus of Elasticity (psi)	Unit Volume Weight (lb / inch²)	Comments
Girders	1				Short of height
	2	(403) 5,730	(2.26×10^5) 3.21×10^6	(2.31) 83.5	
	3	(360) 5,120	(2.24×10^5) 3.19×10^6	(2.29) 82.7	
	Average	(381) 5,425	(2.25×10^5) 3.20×10^6	(2.30) 83.1	
Piers	4	——	——	——	
	5	——	——	(2.31) 83.5	
	6	——	——	(2.26) 81.6	
	7	——	——	(2.29) 82.7	
	Average	——	——	(2.29) 82.7	
Abutments	8	(442) 6,280	(2.39×10^5) 3.40×10^6	(2.30) 83.1	
	9	(454) 6,460	(2.44×10^5) 3.47×10^6	(2.28) 82.4	
	10	(212) 3,020	(1.69×10^5) 2.40×10^6	(2.31) 83.5	
	11	(196) 2,790	(1.37×10^5) 1.95×10^6	(2.31) 83.5	
	Average	4,640	(1.97×10^5) 2.80×10^6	(2.30) 83.1	

kg / cm² or t / m³ are shown in brackets

Results of Salt Penetration Tests

Test location	Test Items	Test depths (cm)	Limit of Cl^- in concrete (%)	Others
Girders	1	1	0.032	Paved parts are excluded
		5	0.023	
Piers	4	1	0.214	
		3	0.095	
		5	0.011	
Abuttment	11	1	0.048	
		5	0.008	

C. Survey of damage

Survey of bridge appearance showed the following damage :

i) Occurance of cracks

Cracks on the main beam at midspan were observed only from inside the girder box as shown in the following drawing.

The features of the cracks are as follows :

- Cracks were observed between the midspan and segments 7 ~ 8 on both sides.
- The cracks were observed on both sides of the main beam, the Koror Island side and the Babelthuap Island side, and on the webs on both the north side and the south side.
- The cracks start from where the upper slab and web meet and finish in the center of the web. The cracks run at an angle of 45° in opposite directions from the central segments.
- The width of cracks is about 0.04 ~ 0.1 inches.

Occurance of cracks on the main beam at sidespan is shown in the drawing.

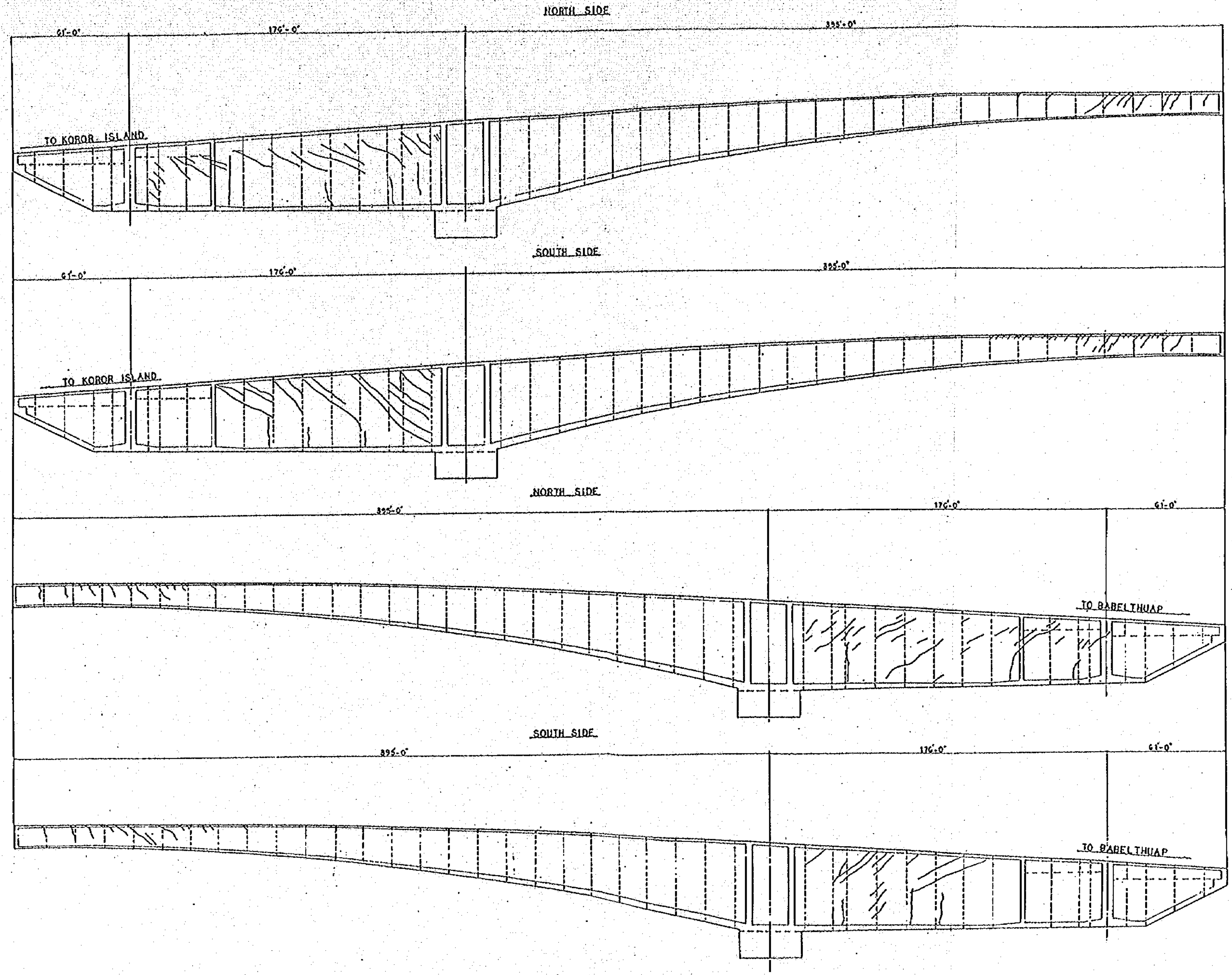
There are both vertical and oblique cracks with the following features :

<u>Vertical cracks</u>

- Vertical cracks were observed on the main beam on both the Koror Island side and the Babelthuap Island side, also on the webs of the north and the south sides.
- They were observed where the lower slab and the web meet.
- The width of cracks is about 0.08 inches.

Oblique cracks

- Oblique cracks were observed on the main beam of both the Koror Island side and the Babelthuap Island side, and on the webs of the north and the south sides.
- The cracks start from where the upper slab and the web meet and finish at the centre of the web. They run an angle of 45° in opposite directions from the central segments.
- Measurement of the width of cracks was not conducted.


NORTH SIDE
61'-0"
176'-0"
395'-0"
TO KOROR ISLAND
SOUTH SIDE
61'-0"
176'-0"
395'-0"
TO KOROR ISLAND
NORTH SIDE
395'-0"
176'-0"
61'-0"
TO BABELTHUAP
SOUTH SIDE
395'-0"
176'-0"
61'-0"
TO BABELTHUAP

ii) Survey of widening of cracks in the pier caused by the midspan deflections

The measurement of the bridge elevations indicates that the central 7 ~ 8 midspan segments have sagged. The midspan expansion gap is partly closed at the top and open at the bottom. At the midspan expansion gap or cover plate, the curved angle of the gap is about 0.04 to 0.05 radians.

iii) Deterioration of the concrete wearing surface at the joint connecting abuttments and girders

- Deflections in the pier on the Koror side are not obvious because of mortar repairs. Also, 0.2 cm cracks are in evidence.
- 3 to 3.5 in. of surface has worn away exposing the reinforcing meshing on the south side of the Babelthuap side.

iv) Other defects

- About 0.6 in. diagonal shear stress was found at central midspan in all end pier rubber shoes.
- There is no gap in the rubber shoes.
- Deflections were found in the vinyl chloride pipe which covers tie-down steel rods in the end pier. Corrosion of the steel rods was observed.
- The concrete wearing surface of the bridge deck is in poor condition with numerous pot holes exposing the reinforcing mesh. Some have been poorly patched.
- The handrails are irregular, and in some cases the handrail standards have broken away from the bridge.

d. Study of degradation

Sampling tests with phenolphthalein solution to determine changes in concrete pH were performed with a core sampler.

- Neutralization of the concrete coated section was complete in core-sample Nos. 1, 2, 3. Due to the protection of concrete the slab was neutralized to 0.2 inches deep.
- Pier Nos. 4, 5, 6, 7 were observed to be neutralized to a depth of 2.5~3.0 inches.
- Neutralized depths of abuttment Nos. 8, 9, 10, 11 were 2.0~2.5 inches deep.
- To measure the amount of salt, cores were sliced. Each slice was then measured after powdering. The amount of Cl^- varied according to the depth of the concrete core sample. Findings are shown in the core-test table.

Recent research indicates that concrete durability is high when chloride levels are below 0.025%.

Test samples were taken from the 3~ 4 cm depth.

Cl^- percolation was found at a depth where it is apt to cause rusting of steel.

e. Traffic survey

A traffic survey was conducted considering the following factors :

1) One half of the population lives in the Koror island. The other half lives in Babelthuap.

2) The capitol of Palau is on Koror. The airport is located on Babelthuap.

The traffic survey was conducted on both Saturday and Monday. The airport is busiest on Saturday. On Monday, it was assumed that a greater number of people would be going to school or work than on any other day.

It was found that the most frequent users of the bridge were small sized cars which numbered about 200 per hour. This was about 80% of all traffic. The remainder of the traffic consisted of large or medium sized cars as well as trucks and buses.

Results are shown in the table.

January 20 (Sat), 1990

Direction	From Koror to Babelthuap			From Babelthuap to Koror		
Time Type	Sedan	Van	Truck or Bus	Sedan	Van	Truck or Bus
6:00 ~ 7:00	130	1	2	34	1	2
7:00 ~ 8:00	34	3	0	120	17	0
12:00 ~ 13:00	82	0	0	58	2	0
13:00 ~ 14:00	77	9	2	58	3	3
14:00 ~ 15:00	51	11	1	120	15	3
15:00 ~ 16:00	40	5	1	35	0	2
18:00 ~ 19:00	85	0	1	68	0	1
19:00 ~ 20:00	70	1	0	68	3	1

January 22 (Mon), 1990

Direction	From Koror to Babelthuap			From Babelthuap to Koror		
Time Type	Sedan	Van	Truck or Bus	Sedan	Van	Truck or Bus
7:30 ~ 8:30	51	2	1	86	9	2
8:30 ~ 9:30	61	2	1	50	3	5
9:30 ~ 10:30	54	0	5	44	3	9
16:00 ~ 17:00	75	10	2	45	3	5
17:00 ~ 18:00	96	5	9	38	3	0

2 • 3 Evaluation

The estimation made from the investigation are as follows (The original blue-prints were not available) :

a. Causes of main beam sagging in the center of the bridge

i) Influence of deflections on the bridge

The elevation survey of major girders shows that bridge deflection hasn't changed since completion of the bridge except the major girders at midspan. The bridge therefore has not sagged or subsided. This is supported by following three points :

- There is no vertical movement between abuttments and main beams.
- There is no gap in the end pier rubber shoes.
- There is no evidence of sagging or deflection in the basements of the endpiers.

The deflection of the major girder at midspan is caused by an irregular deformation of the bridge.

ii) Modulus of elasticity of concrete

Sample cores taken from the main beam at midspan have a compressibility strength of about 380 kg / cm^2. The original theoretical strength was 350 kg / cm^2. The unit volume weight is about 2.3 t / m^3 , which is considered to be a normal figure.

Theoretically, the modulus of elasticity is about 3.0 x 10^5 kg / cm^2 when concrete compressibility strength is 380 kg / cm^2. Actual strength is 2.25 x 10^5 kg / cm^2. This figure is very low.

It is an appropriate figure because the measurement of deflections made by the car loading on the central main beam has a theoretical modulus of elasticity value of 2.40 x 10^5 kg / cm^2.

iii) Influence of diagonal shear stress

In terms of the deflection curve with vehicle loading at the central main beam, theoretical figures and actual measurements correspond well. Theoretical values do not take diagonal shear stress into consideration, but do consider the bending irregular deformation. Because of the correspondence between theoretical figures and actual measurements, main beam shear stress near the midspan should not affect the sagging.

iv) Inference of the coeficient of creep

Assuming that the sagging and deformation of the main beam are due to plastic creep, coefficient creep is measured as follows :

The modulus of elasticity is measured based on the following assumptions ;

Unit weight of the main beam	2.5 t / m^3
Weight of the superstructure	2.1 t / m
Modulus of elasticity of the main beam	2.25 x 10^5 kg / cm^2
Pre-stress tendon of Prestressed Concrete steel rod	55 t / rod

In this case, the modulus of elasticity of the main beam at the midspan hinge is as follows :

Elasticity deformation produced by

Weight of main beam	81 cm
Weight of superstructure	9 cm
Weight of prestressed tendons	- 64 cm
Total elasticity	26 cm

If some loss of prestress elasticity occurred due to plastic creep or a shrinkage relaxation of 15% occurred, elastic deformation would be as follows :

$$64 \times 0.15 \approx 10 \text{ cm}$$

The amount of plastic deformation that has occurred since completion of the bridge is 102 cm. Coefficient of creep calculated as follows :

$$(102 - 10) \div 26 \approx 3.5$$

This is an appropriate figure. The reasons for this conclusion are as follows :

1) Coefficient of Creep in normal air is 2.0. In very dry air, it is 3.0. The softer the concrete is mixed, the higher the modulus will be.

2) The bridge is in a hot country where drying out of concrete easily occurs.

3) There are many examples of cold joints at the main beam at sidespans. Therefore, it is likely that soft mixed concrete with a higher water cement ratio was used.

v) Evaluation of deflection at midspan hinge

If the central hinge were horizontal, deflection at midspan hinge due to elastic deformation after completion would be 0.05 rad, which can be inferred from the gap at midspan hinge or the concrete at cover plate.

Deflection at midspan is 0.03 rad. This is a measure of the change in elevation between completion of the main beam and this survey.

Assuming that the elevation measurements under present survey conditions were obtained in the same manner as after completion, the elasticity angle of the widened gap at the end of the main beam which is half of the angle of deflection at midspan is as follows :

Main beam elasticity angle	0.013 rad
Bridge superstructure elasticity angle	0.001 rad
Prestress elasticity angle	−0.010 rad
Total	0.004 rad

The angle formed by the loss of prestress due to creep or shrinkage

$$-0.010 \times 0.15 = -0.0015$$

Therefore, if coefficient of Creep is 3.5, the angle of deflection at midspan hinge by elastic deformation between completion and now, should be as follows :

$$(0.004 \times 3.5 + 0.0015) \times 2 \approx 0.03 \text{ rad}$$

Therefore, it can be concluded that a coefficient of creep of 3.5 is not an inappropriate figure.

vi) Conclusion

The cause of the sagging of the main beam at the central part of the bridge can be considered to be the creep deformation of the main beam at midspan itself.

Creep deformation is measured theoretically by multiplying elasticity deflections and coefficient of Creep. The modulus of elasticity of this bridge is much lower than average. The coefficient of Creep is high, indicating creep deformation.

Creep deformation is said to finish in 10 years but with this bridge it is increasing.

b. The cause of cracks

i) Cracks around the central hinge of the bridge

• The greatest load on the main beam

Judging from present traffic volumes the greatest load was put on the main beam at midspan while the cantilever section of the main beam was being constructed, just after newly-installed blocks on the wagon were concreted.

• Estimate of the degree of diagonal tensile stress

Under the loading situation mentioned above, the degree of diagonal tensile stress is estimated by taking the 4th block from the central hinge.

With the weight of the wagon and introducing the power of pre-stress as a parameter, the measurement of the degree of diagonal tensile stress is as shown in a diagram.

As the degree of diagonal tensile stress on bridges of this size is about 16 kg / cm^2, stress due to dry shrinkage or thermostatic stress should be considered.

ii) Cracks at the sidespans

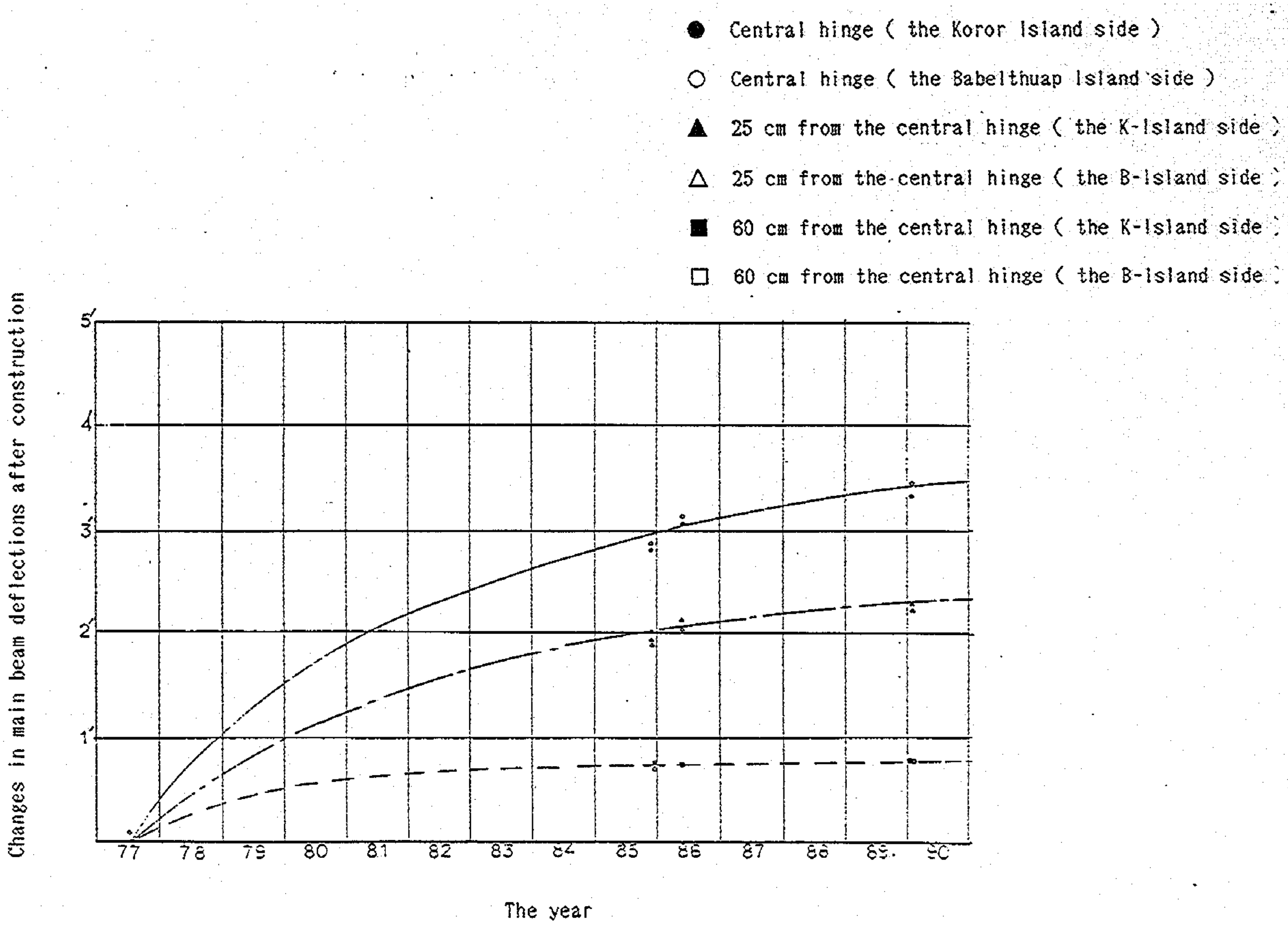
• Inference of cause and occurance of vertical cracks

Judging from the tie beams of the concrete, the web must have been built on the main beam at sidespans after the lower slab.

As there are no vertical cracks on the lower slab, the cracks on spans are caused by the thermal stress.

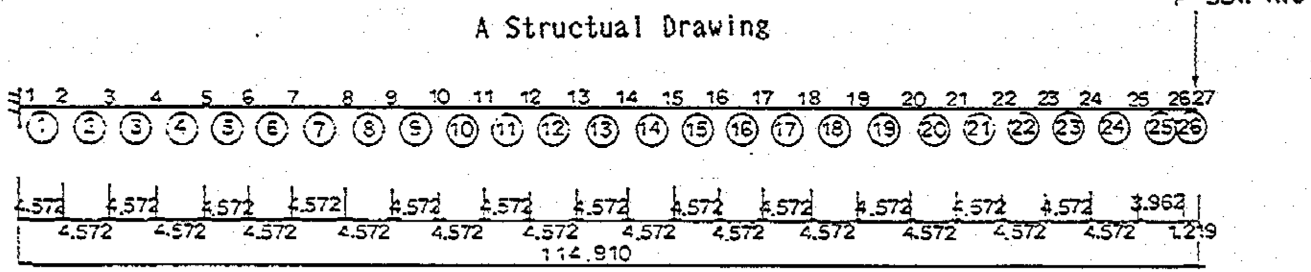
- Possible causes of diagonal tensile cracks

The weight on a main beam at midspan produces negative reactions in the main-pier and positive reactions in the end-pier. The diagonal tensile cracks on this bridge were produced by diagonal tensile stress on the main beam which is produced by upward stress in the main pier and down-ward stress in the end pier.

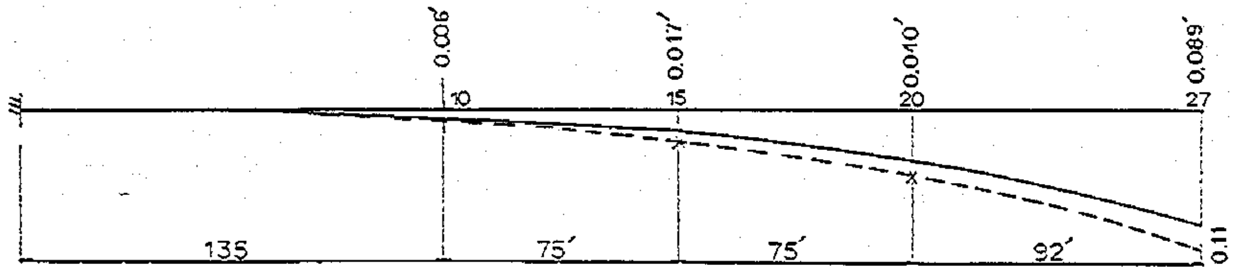

● Central hinge (the Koror Island side)
○ Central hinge (the Babelthuap Island side)
▲ 25 cm from the central hinge (the K-Island side)
△ 25 cm from the central hinge (the B-Island side)
■ 60 cm from the central hinge (the K-Island side)
□ 60 cm from the central hinge (the B-Island side)
Changes in main beam deflections after construction
5′
4′
3′
2′
1′
77
78
79
80
81
82
83
85
86
87
89
The year

The K-B Bridge

A Structual Drawing



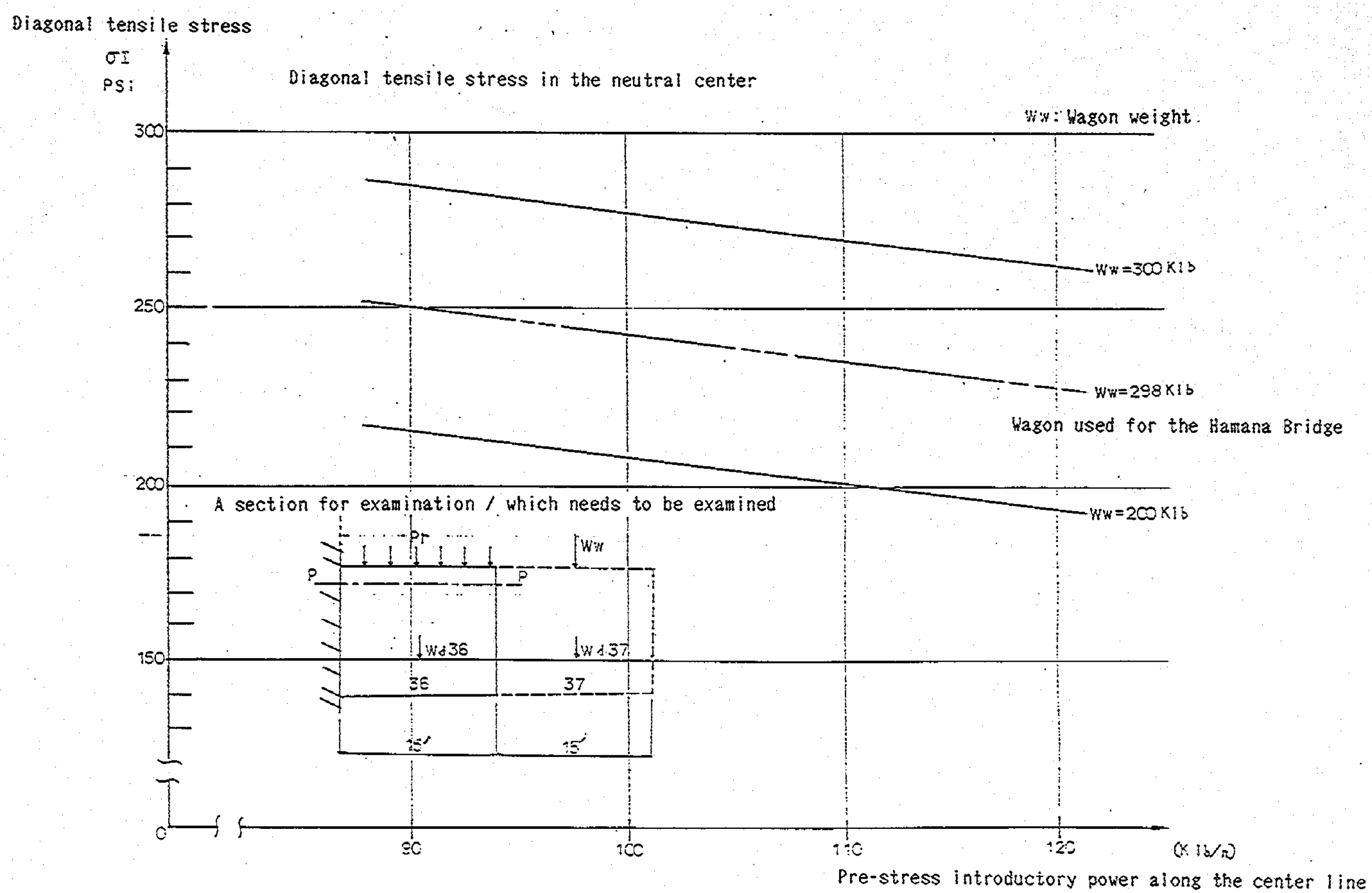
A Displacement Drawing Diagram



$f_{ck} = 5\,000$ Psi

$E = 4.20 \times 10^6$ Psi

X = a figure by actual measurement



Diagonal tensile stress
σI
PSI
Diagonal tensile stress in the neutral center
Ww: Wagon weight.
300
250
200
150
0
Ww=300 Klb
Ww=298 Klb
Wagon used for the Hamana Bridge
Ww=200 Klb
A section for examination / which needs to be examined
Pr
Ww
P
P
Wd36
Wd37
36
37
15′
15′
90
100
110
120
(K lb/n)
Pre-stress introductory power along the center line

c. Conclusion

i) The sagging of the main beam

The current condition of the bridge is structurally no problem because the sagging is not caused by rotation or deflection of the whole bridge, but by creep deformation of the main beam. Although the sagging is increasing slightly, the bridge is durable and structurally safe considering present traffic conditions.

It is certain that driving comfort is one of the basic functions of the bridge. In addition, aesthetics of the bridge must be considered. However, such problems are secondary and have nothing to do with the structural durability of the bridge.

Consequently, it is considered that immediate rehabilitation is not necessary and should not be planned without essential data such as original design documents. It is desired therefore to determine the most suitable repair plan after checking these essential data and the progress of the deflection.

ii) Main beam cracks

Both oblique and vertical cracks on the main beam were probably created during construcion. Since the main beam with cracks already experienced extreme loading conditions when the wagons were at midspan during the cantilever erection, the bridge would be structurally safe without any repairs considering the present traffic volume.

However because this bridge has no protection from oceanic winds, it is possible that reinforcing rods may be corroded and concrete weakened by salt bearing winds through the cracks. Cracks will certainly become a cause of lower bridge durability and should be repaired in the future.

iii) Others

Other defects except the deflection of the main beam and cracks are as follows :

- Concrete cracks on the front side of abuttments

  Corrosion of reinforced concrete

- Defects in the protective tubing (vinyl chloride pipe) of PC steel rods used for tie-down

- Exposure of reinforcing mesh on the concrete pavement

- Irregular alignment of handrails

These should be improved in the near future. Before the survey there had been fear of scoring and sagging of the pier. No underwater examination of the bridge could be made.

The bridge will be safe without repairment because no large cracks or slanting of the piers were observed.

iv) Maintenance

Routine as well as periodical inspections should be conducted in order to preserve the present level of safety, functional structure and durability.

- Routine inspections

The following areas should be checked regularly :

① Bridge surface

② Joint expansion

③ Joining parts of the bridge

④ Curbs and handrails

⑥ Other bridge equipment

- Periodic inspections

Periodic biannual inspections should be conducted to locate any bridge defects or abnormalities in the following areas :

① Bridge elevation

② Progress of cracks

③ Widening of the gap at the central hinge

④ Pier defects or movement

- Preservation of the durability and functional structure of the bridge

It is recommended that the following measures be implemented to reduce traffic damage to the bridge :

① A distance between vehicles of more than 50 meters

② A speed limit of 30 km / hr on the bridge

3. LIST OF OFFICIALS CONSULTED BY SURVEY PARTY

1) Ngiratkel ETPISON : President Republic of Palau

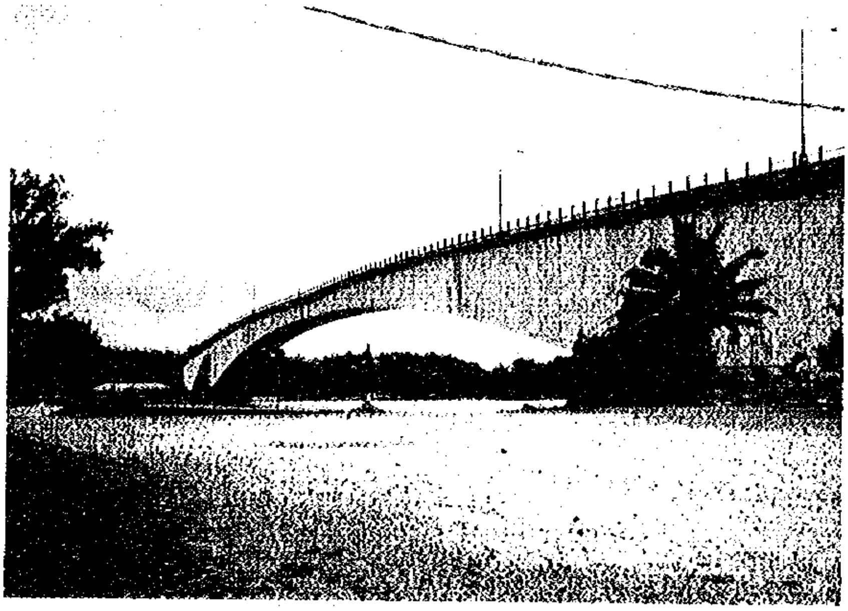
2) Koichi L. WONG : National Planner

3) Regis AKITAYA : Energy Program Manager

4) Marcelino MELAIEI : Director, B.P.W.

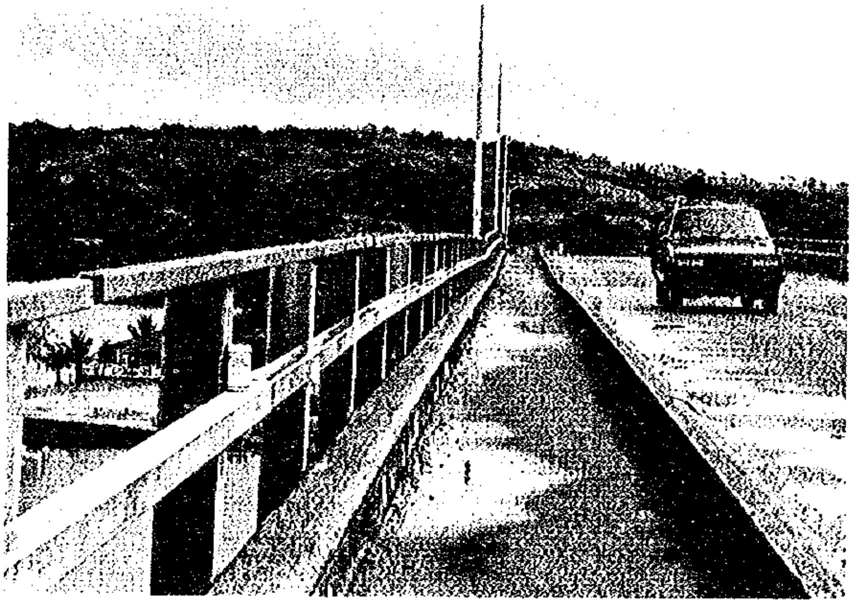
5) Valerio A. CUETO : Public Works, Surveyor

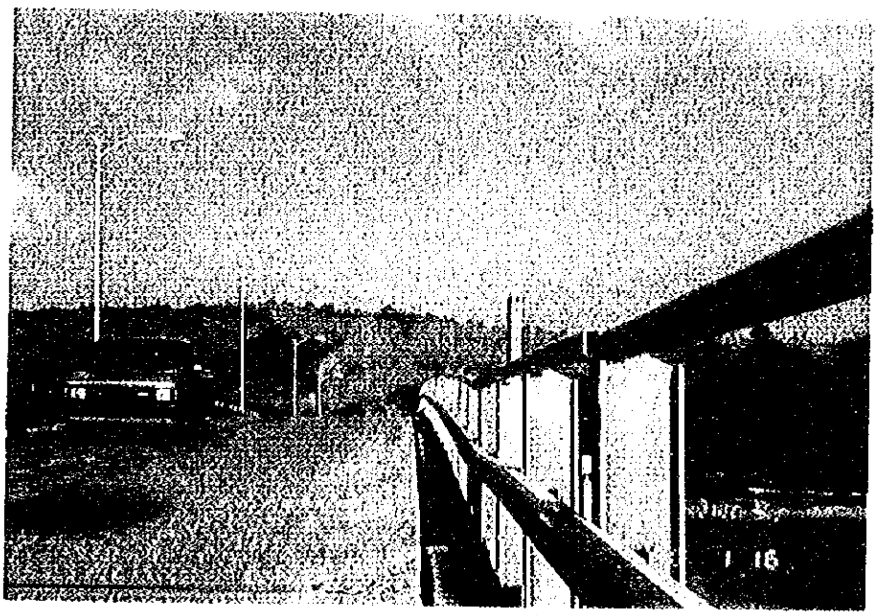
4. PHOTOS



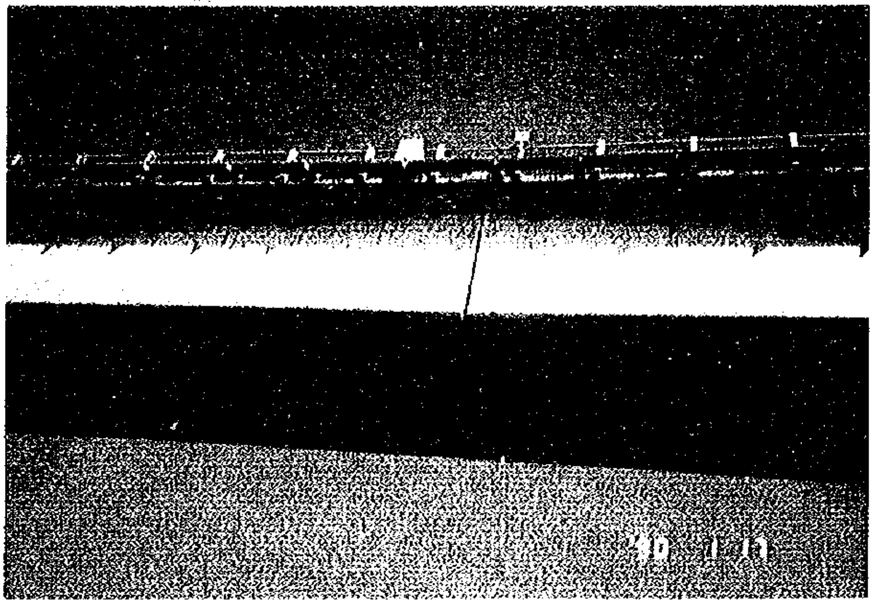
View of the K-B Bridge from the south side of the Koror Island

Bridge central hinge part
(South side)

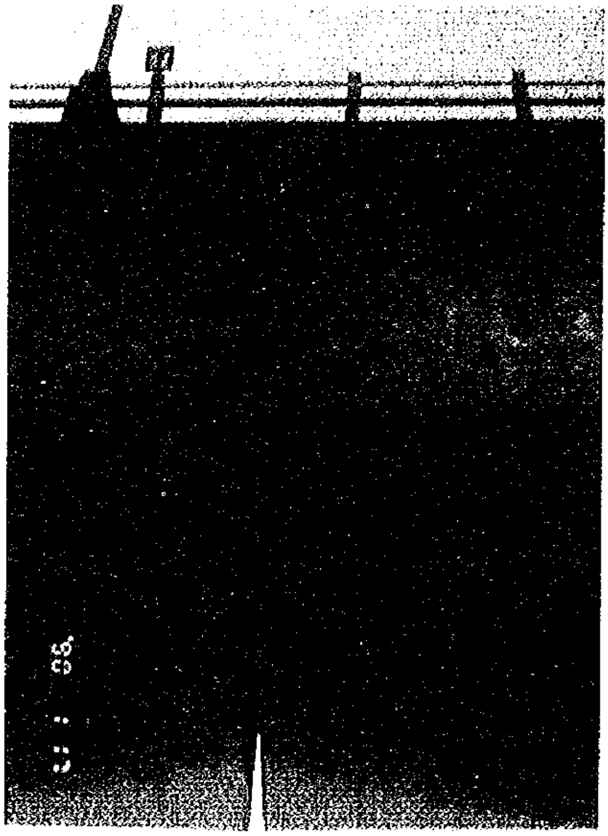




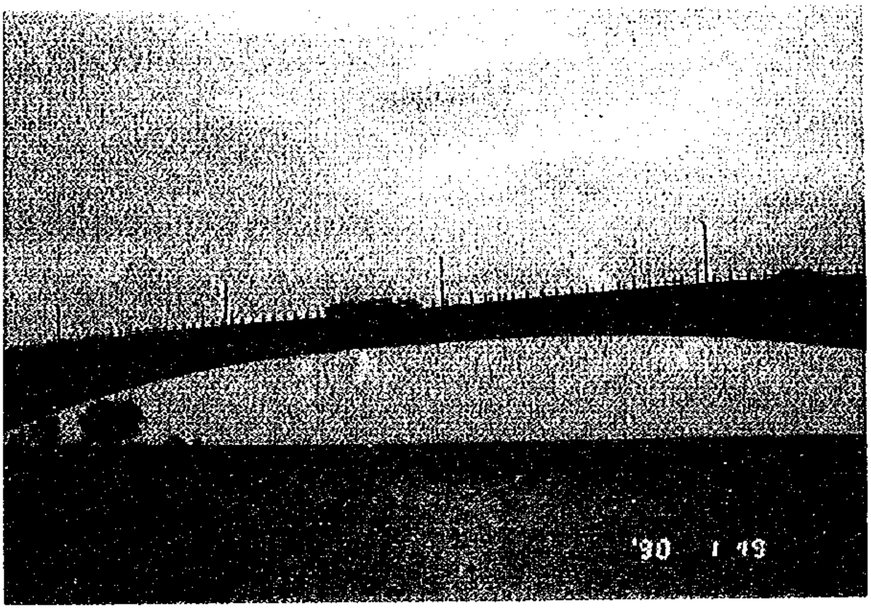
Bridge central hinge part
(North side)



View of the central hinge part
from underneath the bridge



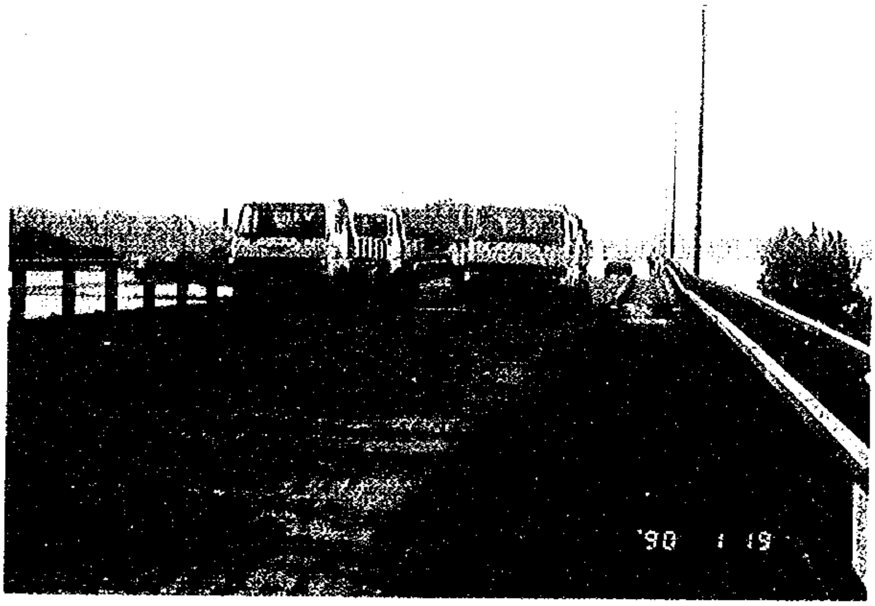
Close-up of the central hinge
from underneath the bridge



Loading test

Loading test

(On the bridge on the Koror Island side)



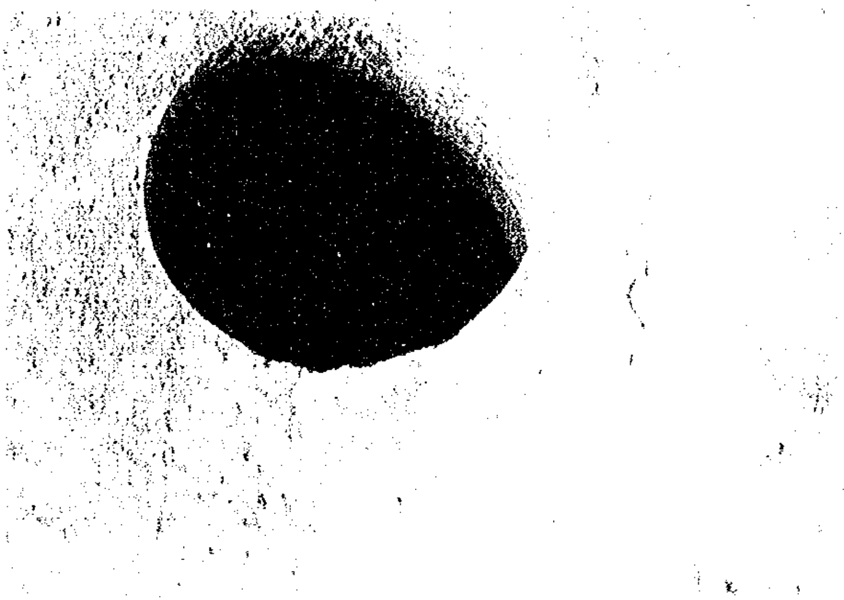
Loading test

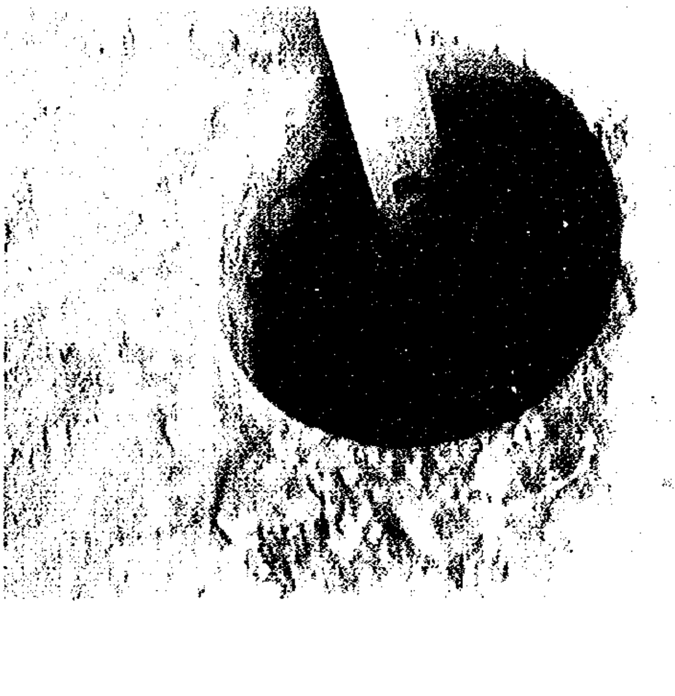
(On the bridge on the Babelthuap Island side)

Core-sampling

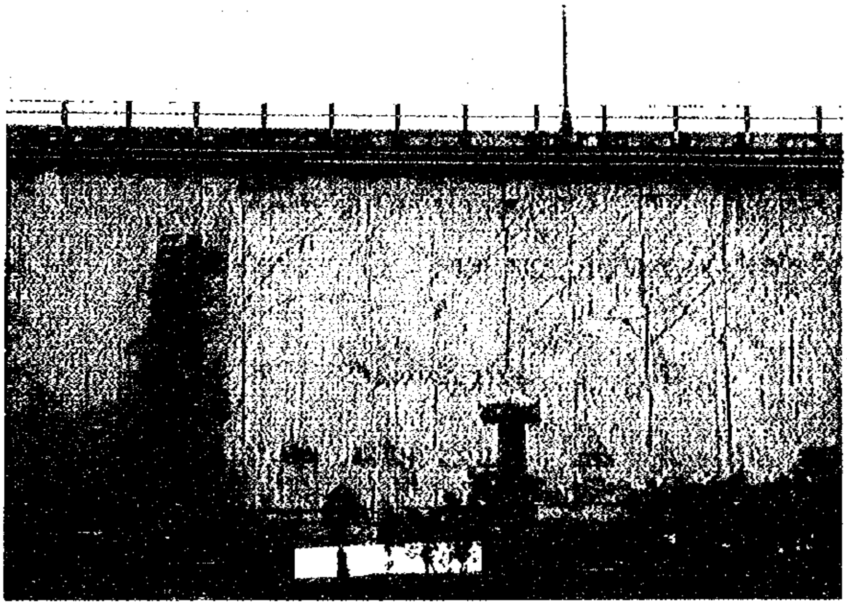
(On the pier)

pH test by boring



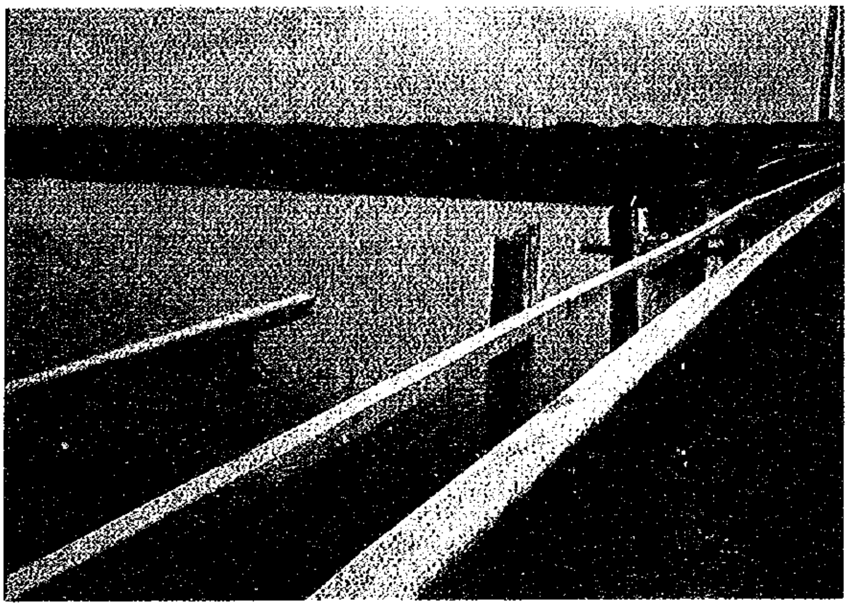


pH depth test

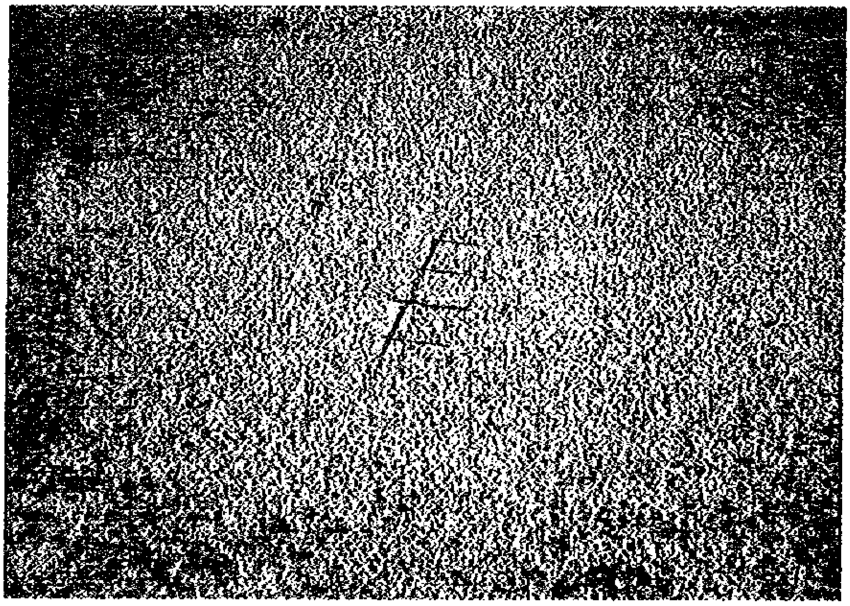


Koror south side

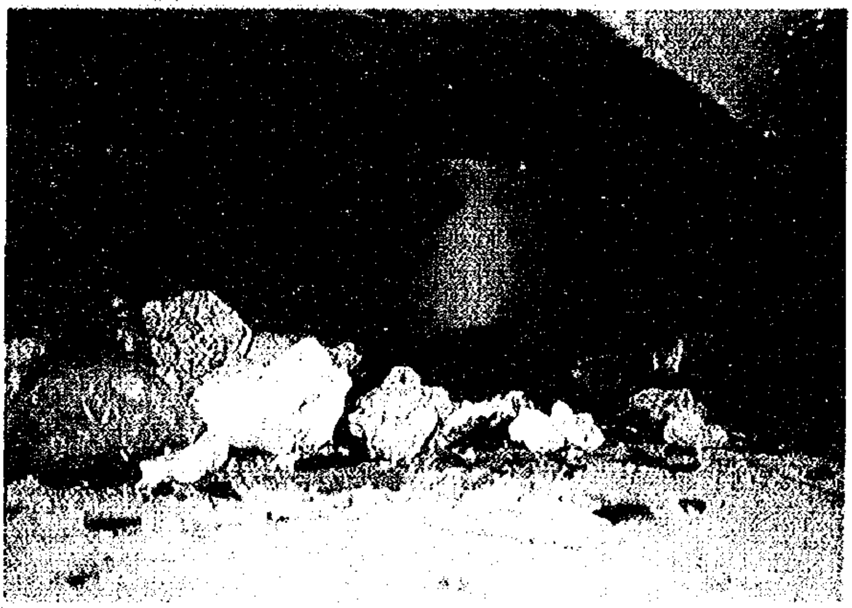
(Sidespan)



Defective hand rails



Exposure of reinforcing mesh on the bridge

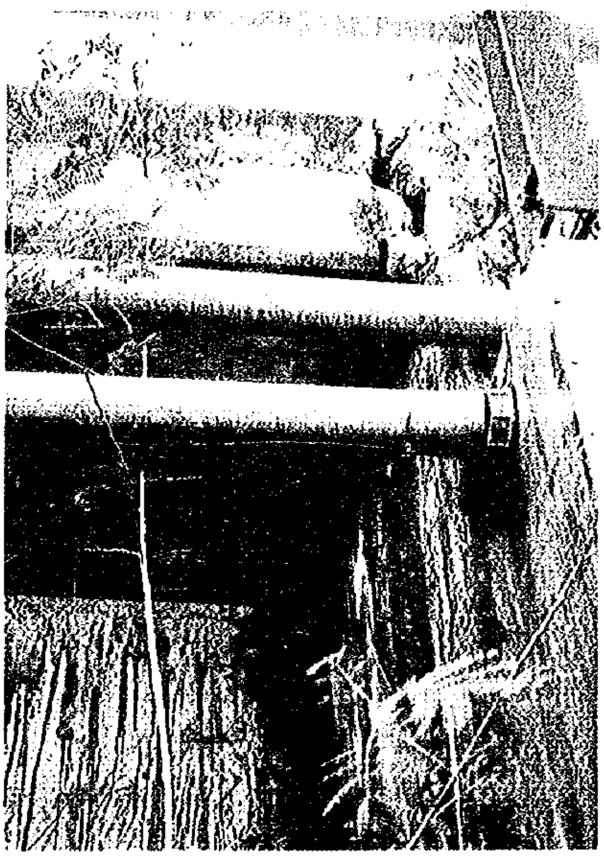


Tie-down steel rod

(defective cover)

Abuttment and

retaining wall joint



Abuttment and

retaining wall joint