CHAPTER 3 MAINTENANCE AND REHABILITATION STUDY ON NINE EXISTING BRIDGES

CHAPTER 3

PART B

MAINTENANCE AND REHABILITATION STUDY ON NINE EXISTING BRIDGES

3.1 General Conditions of Existing Highway Bridges

The Directorate General of Roads (DGR), Ministry of Communications of the Sultante of Oman, is currently performing maintenance of all 58 bridges. The road network in the Sultante of Oman consists of the Batinah Highway which is the main trunk running north to south along the coast line, and the other roadway systems that intersect with this roadway and form the road networks.

The main roadways of requiring the study of road bridges by the project area consist of National Roads Routes 1, 7, 13, 15, 21 and 23. Of the 58 bridges, almost all are concrete bridges (reinforced concrete and prestressed concrete bridges), and only two have superstructures of structural steel.

The improvement of road networks in the Sultante of Oman was started in 1970, and most of the road bridges were completed from 1975 to 1982. All road bridges have been in service for more than 20 years, and in recent years with the increase of traffic and size of the vehicles, and due to the superannuation of existing bridges their deterioration has progressed at an alarming rate.

This project has been discussed with the Directorate General of Roads to study the road bridges of which 6 are cast-in-place reinforced concrete bridges and 3 are prestressed concrete bridges for a total of 9 bridges.

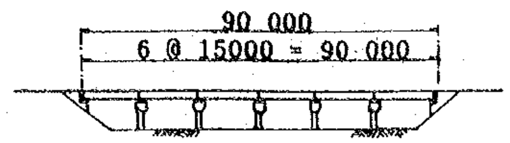
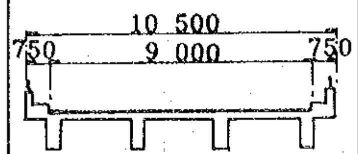
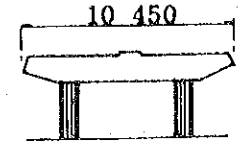
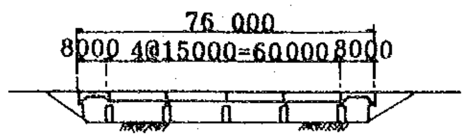
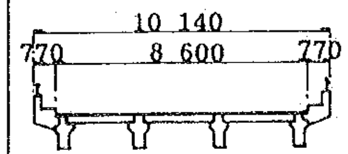
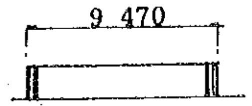
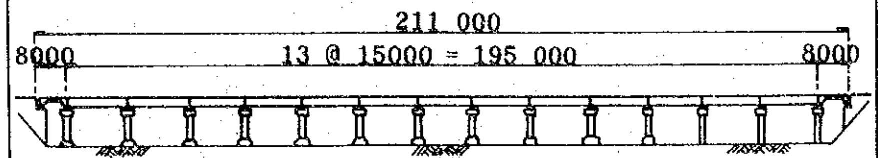
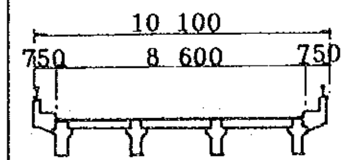
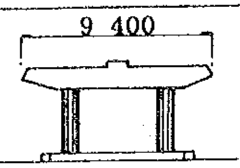
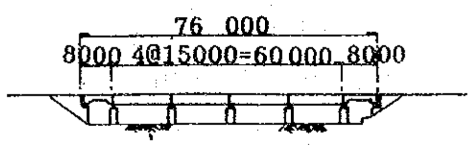
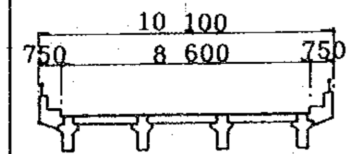
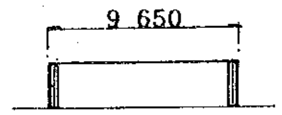
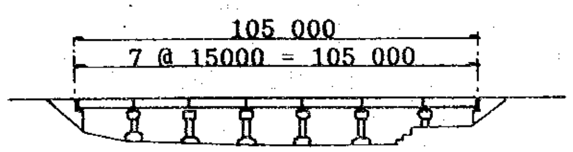
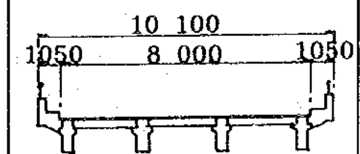
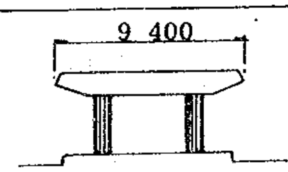
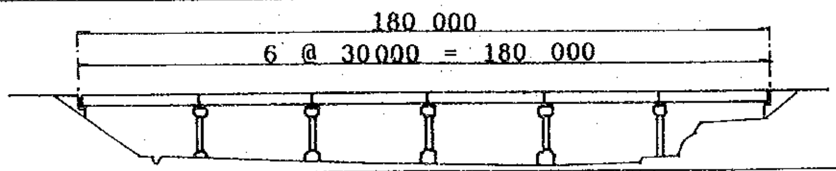
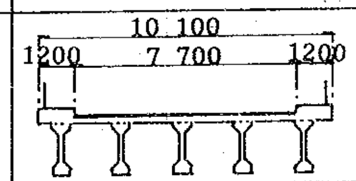
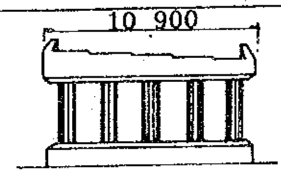
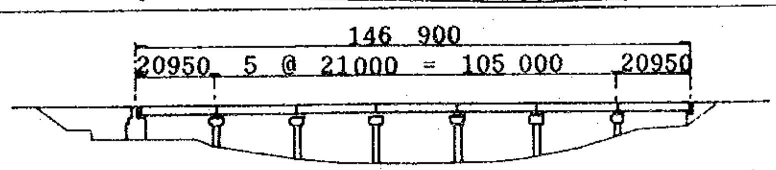
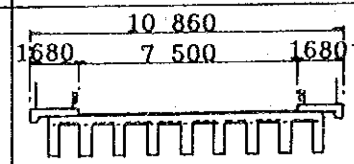
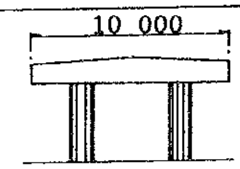
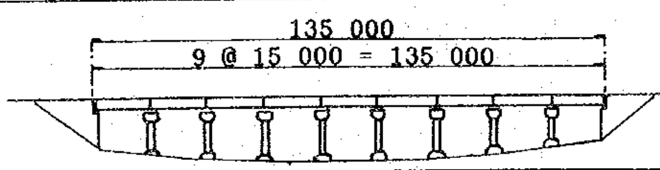
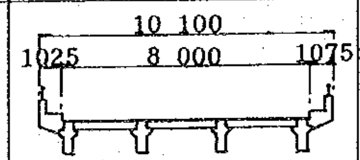
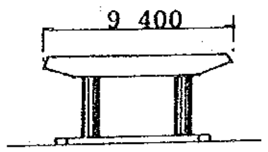
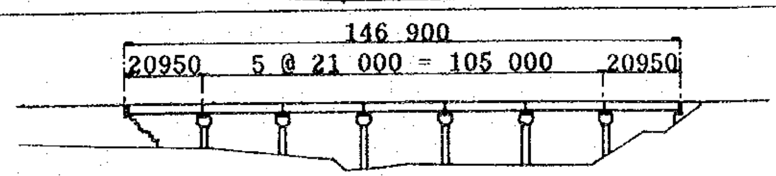
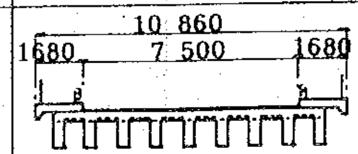
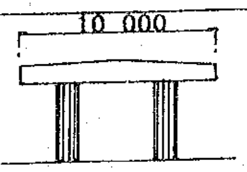
The bridge locations of 9 existing bridges are given in location map and general features are shown in Fig. B.1.

3.2 Methods of Investigation for Soundness Test and Loading Test

Maintenance and rehabilitation study on nine existing bridges consists of two major categories, namely.

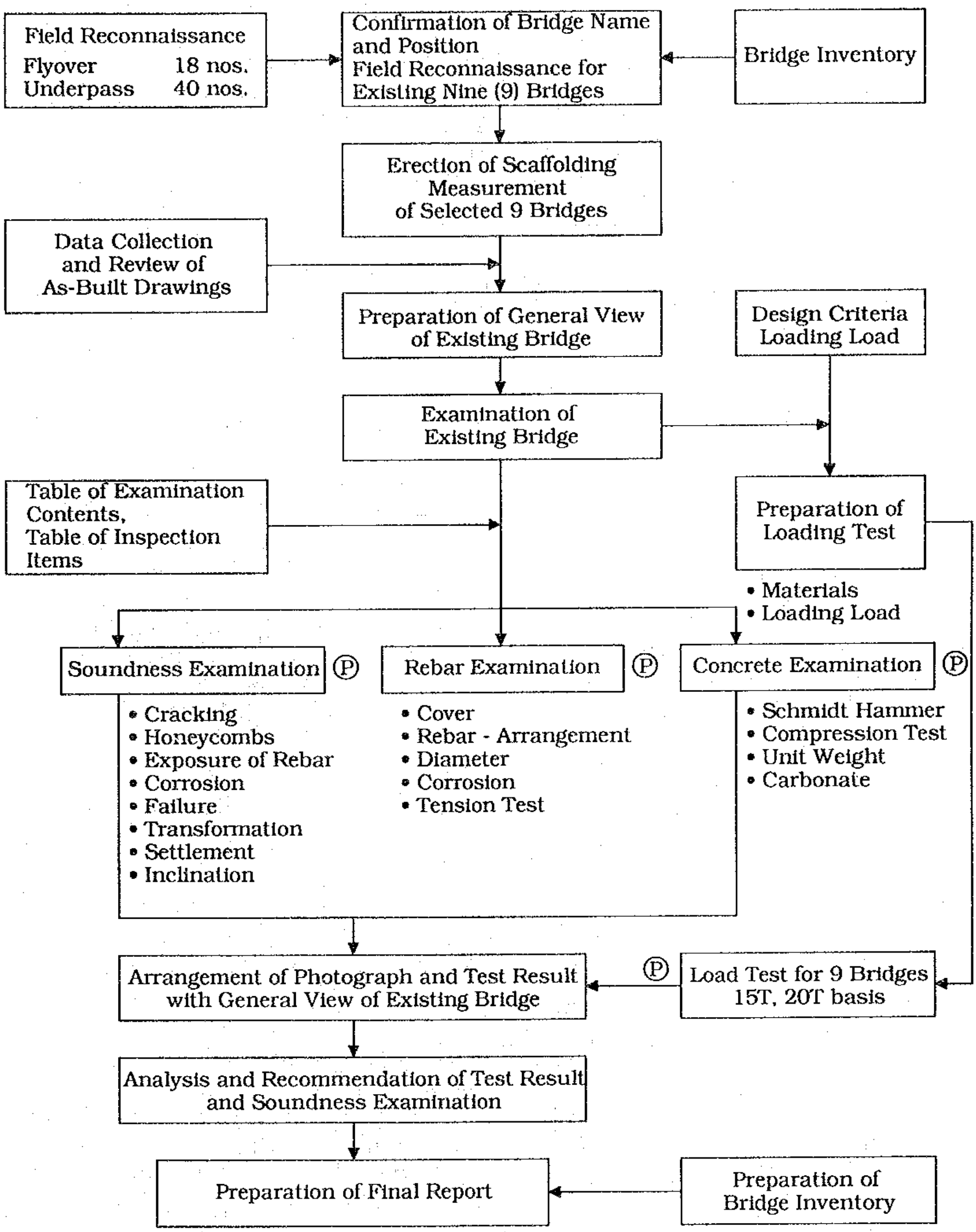
Investigations for Soundness Test, and Loading Test.

The overall flow chart of the study are shown in Fig. B.2 Flow Chart of the Study.

BRIDGE NO.	BRIDGE TYPE	SIDE ELEVATION	PLAN ALIGNMENT	TYPICAL CROSS SECTION	SECTION OF PIER
NO. 1	PRECAST R.C GIRDER WITH CAST IN PLACE RC SLAB		R = ∞		
NO. 2	PRECAST R.C GIRDER WITH PRECAST R.C SLAB		R = ∞		
NO. 3	PRECAST R.C GIRDER WITH PRECAST R.C SLAB		R = ∞		
NO. 4	PRECAST R.C GIRDER WITH PRECAST R.C SLAB		R = 4 000		
NO. 5	PRECAST R.C GIRDER WITH PRECAST R.C SLAB		R = ∞		
NO. 6	P.C I GIRDER WITH CASTIN PLACE R.C SLAB		R = 470		
NO. 7	P.C RECTANGULAR GIRDER WITH CASTIN PLACE R.C SLAB SUPPORTED ON PRECAST R.C BLOCKS		R = ∞		
NO. 8	PRECAST R.C GIRDER WITH PRECAST R.C SLAB		R = 575		
NO. 9	P.C RECTANGULAR GIRDER WITH CASTIN PLACE R.C SLAB SUPPORTED ON PRECAST R.C BLOCKS		R = ∞		

THE STUDY ON ROAD DEVELOPMENT PROJECT	JAPAN INTERNATIONAL COOPERATION AGENCY	**Fig. B.1** List of 9 Bridges

Flow Chart for the Survey



Note: Ⓟ means with photograph

Fig. B.2 Flow Chart of the Study

3.2.1 Investigation for Soundness Test

In order to determine the soundness of the 9 birdges for this project, the following items of investigation were performed in the field. The investigations were made of the bridge superstructure, substructure and the foundations, and the entire structure of the bridges were investigated to determine their soundness. (see Table B.1, and B.2).

Table B.1 Inspection and Examination Contents

Examination Items	Examination Contents	Inspection Method and Test Methods
(1) Present Condition	Cracking, Honeycombs, Reinforcing Corrosion Inspection from Table B.2	Photograph of Damaged Parts
(2) Construction Condition	Measurement of Section	Convexes, Measurement Tape
	Reinforcement Covering	Measurement and Inspection of Covering by Pacometer
(3) Cracking	Crack Width	Naked Eye (Crack scale)
	Crack Length	Convexes
(4) Quality of Concrete	Compressive Strength Modulus of Elasticity Unit Weight Absorption Ratio	Schmidt Hammer Compressive Test of Concrete Core
	Carbonation Test	Phenol Phthalein Method
(5) Reinforcement Bar	Corrosion Damage	Chipping & Naked Eye
	Tensile Test	Tensile Test
	Reinforcement Arrangement Diameter of Reinforcement	Inspection by Pacometer and Chipping

Table B.2 Inspection and Examination Items

Members			Inspection Items
Super-structure	Concrete	Main Beam	Cracking, Scaling, Free Lime, Honeycombs, Corrosion Damage, Leakage, Vibration, Deflection, Loss of Member, Discoloration
		Cross Beam Stringer	Cracking, Scaling, Free Lime, Honeycombs, Corrosion Damage, Leakage, Loss of Member, Discoloration
		Slab	Cracking, Scaling, Honeycombs, Come-off, Damage of Joint, Corrosion Damage, Leakage
Sub-structure	Concrete	Abutment Pier	Cracking, Scaling, Corrosion Damage, Free Lime, Honeycombs, Wear, Discoloration, Leakage, Loss of Member
	Foundation		Settlement, Movement, Inclination, Scour
Shoe	Steel Shoe		Corrosion, Cracking, Loosening, Falling, Failure, Discoloration, Leakage, Deformation, Stuffed, Settlement, Movement, Inclination
	Rubber Shoe		Discoloration, Leakage, Deformation, Stuffed, Loss of Member
	Mortar		Cracking, Loss of Member
	Anchor Bolt		Corrosion Damage, Cracking, Loosening, Falling, Failure, Deformation
Hand Rail	Steel		Corrosion, Cracking, Loosening, Falling, Failure, Discoloration, Deformation
	Concrete		Cracking, Scaling, Corrosion Damage, Free Lime, Honeycombs, Discoloration, Loss of Member
Curb	Steel		Corrosion, Cracking, Loosening, Falling, Failure, Discoloration, Deformation
	Concrete		Cracking, Scaling, Corrosion Damage, Free Lime, Honeycombs, Discoloration, Loss of Member
Favement	Asphalt		Pot Holes, Cracking, Rutting, Leakage
Expansion Joint	Steel		Corrosion, Cracking, Loosening, Falling, Failure, Abnormal Opening, Abnormal Sound, Deformation
	Rubber		Failure, Abnormal Opening, Abnormal Sound, Deformation, Loss of Member
Drainage			Corrosion, Cracking, Loosening, Falling, Failure, Discoloration, Leakage, Deformation, Loss of Member
Lighting			Corrosion, Cracking, Loosening, Falling, Failure, Discoloration, Leakage, Deformation, Loss of Member
Accessory			Corrosion, Cracking, Loosening, Falling, Failure, Deformation, Loss of Member

3.2.2 Loading Test

The load test was performed on all bridges by selecting the span in the worst condition and conducting the static load test with the load test vehicle. The bridge deflection together with the strain in the reinforcing steel, strain in the concrete, and thermal stress caused by the deflection are measured, and the results compared with the theoretical values (grid framework analysis). Changes in the bridge are thus obtained to determine the safe load capacity of the bridge and filed with the load characteristics of the bridges.

(1) The Load Testing Vehicle

The load testing vehicle is a dump truck with a water tank strapped on the truck bed. The front wheel load and rear wheel load are measured at a weigh station in Muscat so that the truck with the water tank will meet the T-20 ton rating. The following values were obtained.

	Front Wheel	Rear Wheel
T-20 ton (water load)	3.0 x 2 ton	7.0 x 2 ton
T-14.6 ton (no water load)	2.7 x 2 ton	4.6 x 2 ton

The bridge inspections were performed using a test load vehicle with the above characteristics.

(2) The Position of the Load Testing Vehicle

The positioning of the load test vehicle on the bridges is simple so that the rear wheel load is located at the center of the section of the bridge span. The spacing of the front and rear wheel axles is 4.90m, and the spacing of the rear wheel axles is 1.85m. The method of truck loads applied to the bridge is as described in Fig.B.3.

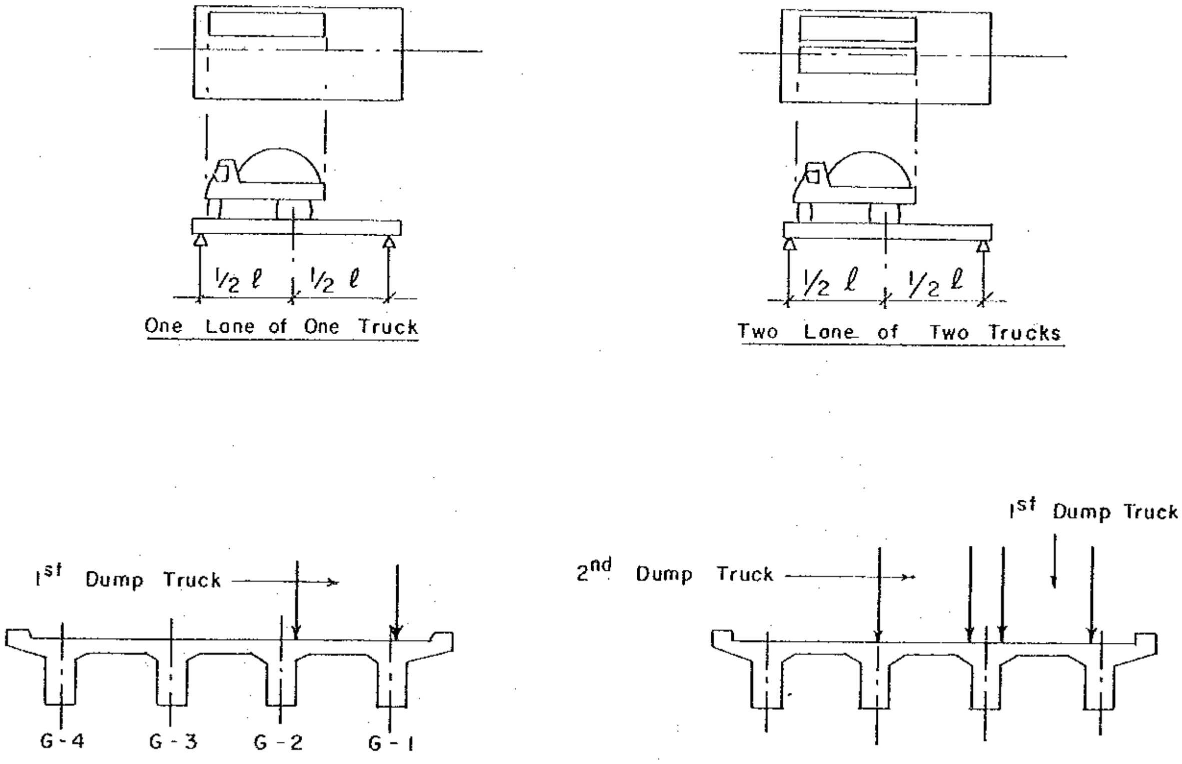


Fig. B.3 Loading Position of Bridges

The load testing of the bridges consists of the T-20 ton (water load) and T-14.6 ton (no water load), applied on a single lane, and to the double lane (1 truck, 2 trucks), for a total of 4 cases. Due to the amount of traffic and the detour routes, there were some bridges where the T-20 ton truck was applied to the single lane, double lane, and finally 2 trucks in 2 lanes. (See Table B.3 and Fig. B.4.)

Table B.3 Loading Case on Bridges

(Unit: ton)

Case No.	A-Load					B-Load					Total Load
	A.F.W.	A.F.W.	A.R.W.	A.R.W.	A-Total	B.F.W.	B.F.W.	B.R.W.	B.R.W.	B-Total	
1	3.0	3.0	7.0	7.0	20.0						20.0
2	3.0	3.0	7.0	7.0	20.0	3.0	3.0	7.0	7.0	20.0	40.0
3	2.7	2.7	4.6	4.6	14.6						14.6
4	2.7	2.7	4.6	4.6	14.6	2.7	2.7	4.6	4.6	14.6	29.2

Legend

A.F.W. : A-Truck Load Front Wheel
A.R.W. : A-Truck Load Rear Wheel
B.F.W. : B-Truck Load Front Wheel
B.R.W. : B-Truck Load Rear Wheel

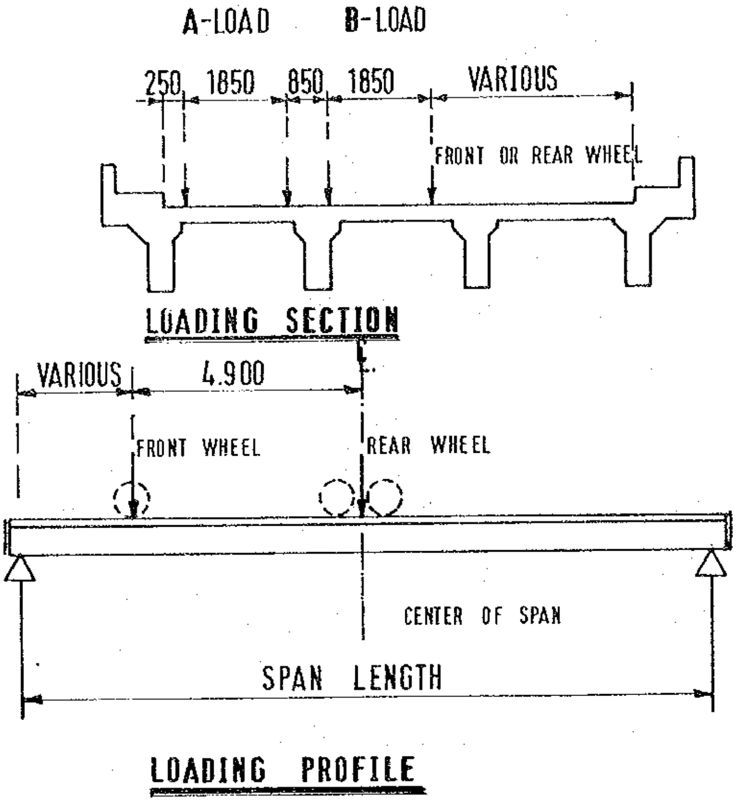


Fig. B.4 Load Condition of Each Case

(3) Measuring Method and Measuring Positions

Monitoring the behaviour of the structures is made using the various instruments, and the measuring made in accordance with the following flow chart in Fig. B.5.

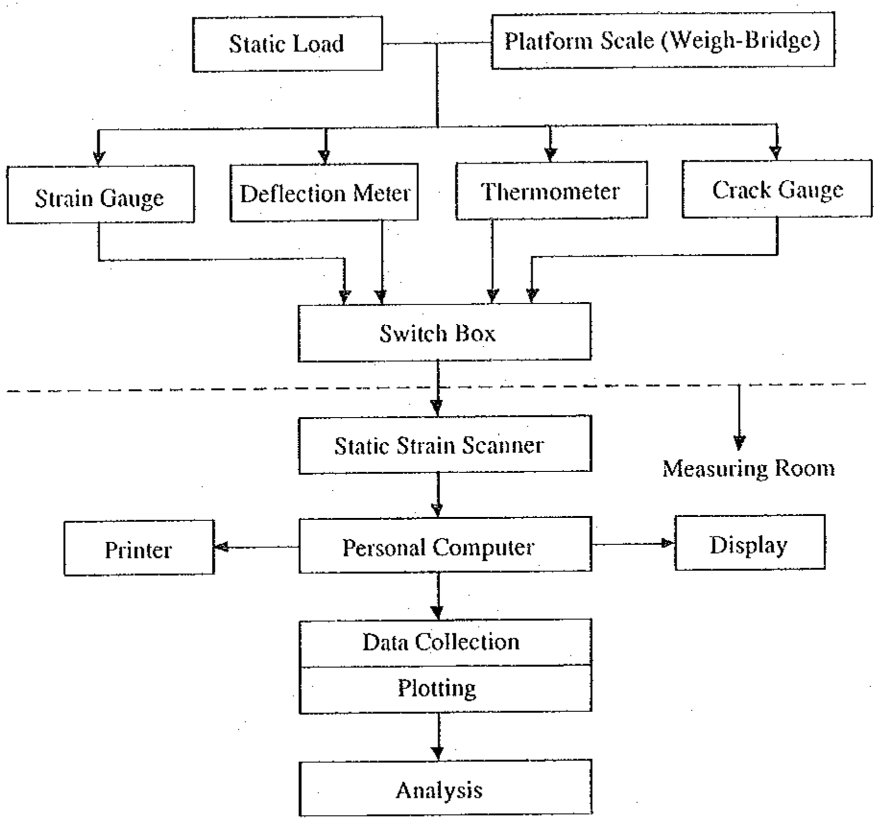


Fig.B.5 Flow of Static Strain Load Test

The various tests by strain gauge, deflection, and crack gauges were taken at each bridge and are as indicated in TableB.4.

TableB.4 Number of Measurement Equipment (1 bridge, 1 span)

		For RC,PC Beam
1	Strain Gauge for Rebar (FLK-2)	36 Nos.
2	Strain Gauge for Concrete (BT-102B)	32 Nos.
3	Deflection Meter (CDP-50-100)	28 Points
4	Crack Gauge (KV-5C, KV-25B)	11 Points
5	Crack Meter (BCD-5B)	12 Points
6	Thermometer (BT-102B)	8 Points
7	Thermo Gauge (KTR-KTC)	8 Points
8	Plate Mirror	5 Points

The actual location of the measurement points on the RC bridges and PC bridges were at the center of the span or at the halfway points, and were performed in accordance with the following diagrams.

Location of Strain Gauges on RC bridges (Fig B.6)
Location of Strain Gauges on PC bridges (Fig B.7)
Location of Strain Gauges on RC, PC bridges (Fig B.8)

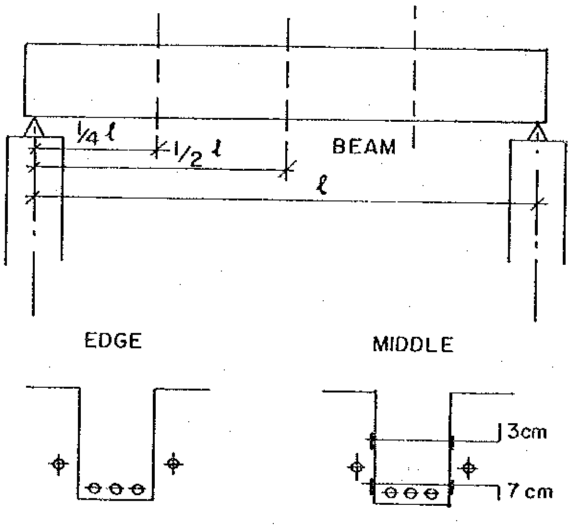


Fig. B.6 Setting Point of Strain Gauge (RC Bridge)

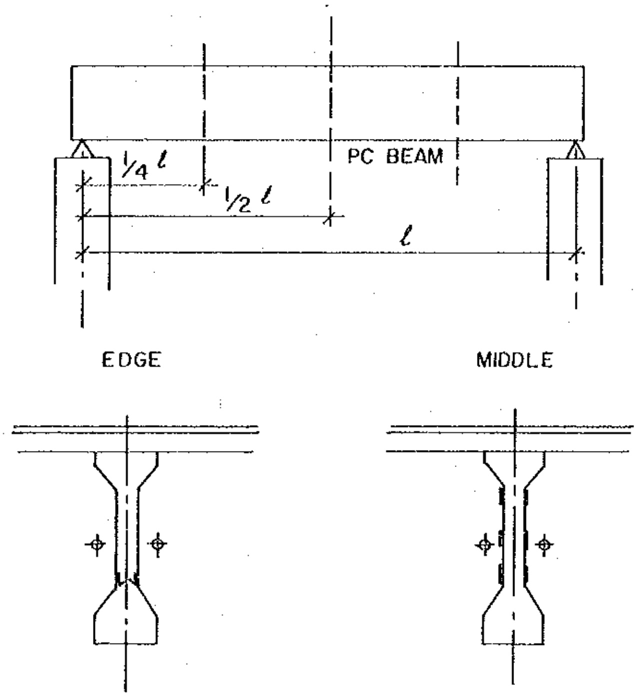
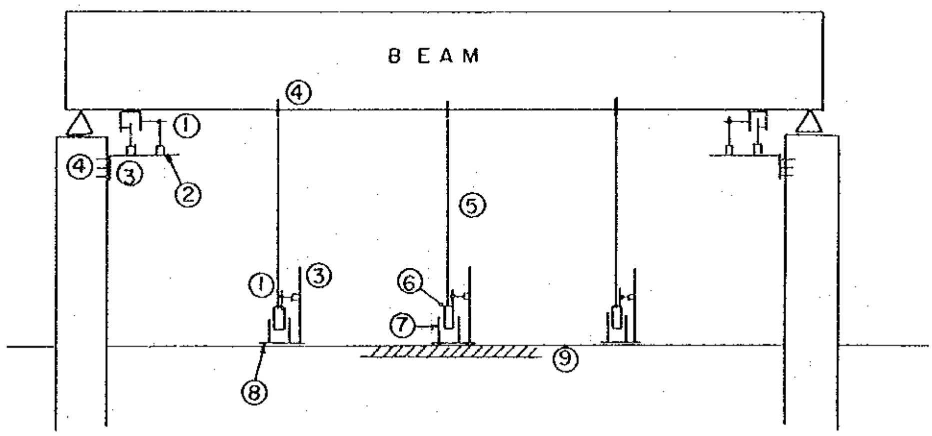


Fig. B.7 Setting Point of Strain Gauge (PC Bridge)



① Deflection Meter CDP - 50 ~ 100mm

② Magnet Stand

③ Fixing Arm

④ Anchor Bolt

⑤ PC Wire

⑥ Weight 80 x 170

⑦ Sway Stopper

⑧ Fixing Plate

⑨ Scafolding Pipe or River Bed

Fig. B.8 Setting Point of Other Measurement Equipment (RC, PC)

3.3 Test Results of Investigation for Soundness Test and Loading Test

3.3.1 Investigation for Soundness Test

The results of investigation for soundness tests of the 9 bridges were shown in VOLUME III 4.2. Results of the Investigation for Soundness to determine their soundness and conditions were as follows:

Present Conditions and Cracks (VOLUME III, Fig. 4.5 through Fig. 4.48)

The Survey Data for Longitudinal Sections and Bridge Cambers (VOLUME III, Fig. 4.49 through Fig. 4.57)

The Results of Concrete Strength (VOLUME III, Table 4.5 through Table 4.16)

The Results of Reinforcing Bar Strength (VOLUME III, Table 4.17)

Structural Drawing of Existing Bridges (VOLUME III, Fig. 4.59 through Fig. 4.63)

Chloride Contents (VOLUME III, Table 4.18)

Damage Ranking Lists (VOLUME III, Table 4.19 through Table 4.45)

3.3.2 Loading Test

The results of the monitoring of the 9 bridges (6 RC bridges, 3 PC bridges) were recorded using the testing instruments, and the stresses in the reinforcing steel and the concrete were calculated.

Based on the load testing, the stresses in the bridge components were calculated for the various cases in accordance with the following formula.

$$\sigma_C\ (\sigma_S) = \varepsilon \bullet E_C\ (E_S)$$

where, σ_C : concrete stress (σ_S : reinforcing bar stress) kg/cm²

ε : value of strain 10^6

E_C : elasticity modulus of concrete
(E_S : elasticity modulus of rebar) kg/cm²

The stress and strain of reinforcing bar and concrete, deflection of girder, widening of crack and temperature of concrete were measured and summarized in Table 5.3 through Table 5.43 of Main Text Volume III.

Also it has been noticed that there are numerous cracks in the RC bridges, and the crack gauges have been set at these cracks, and the increase in the cracks with the application of live loads were measured. These results have been shown in VOLUME III, Table 5.44 through Table 5.46.

Based on the above load tests, the relation of the results of the live loads for each case and the maximum stress at the middle of the span in the rebars and bridge deflection have been plotted in the graphs in VOLUME III, Fig. 5.31 through Fig. 5.39.

3.4 Evaluation of Existing Bridges

3.4.1 The Evaluation Method for Testing Bridges

The overall evaluation of the soundness of the existing bridges is conducted from the following items.

(1) Evaluation of Soundness of Existing Bridges Based on Their Degree of Deterioration:

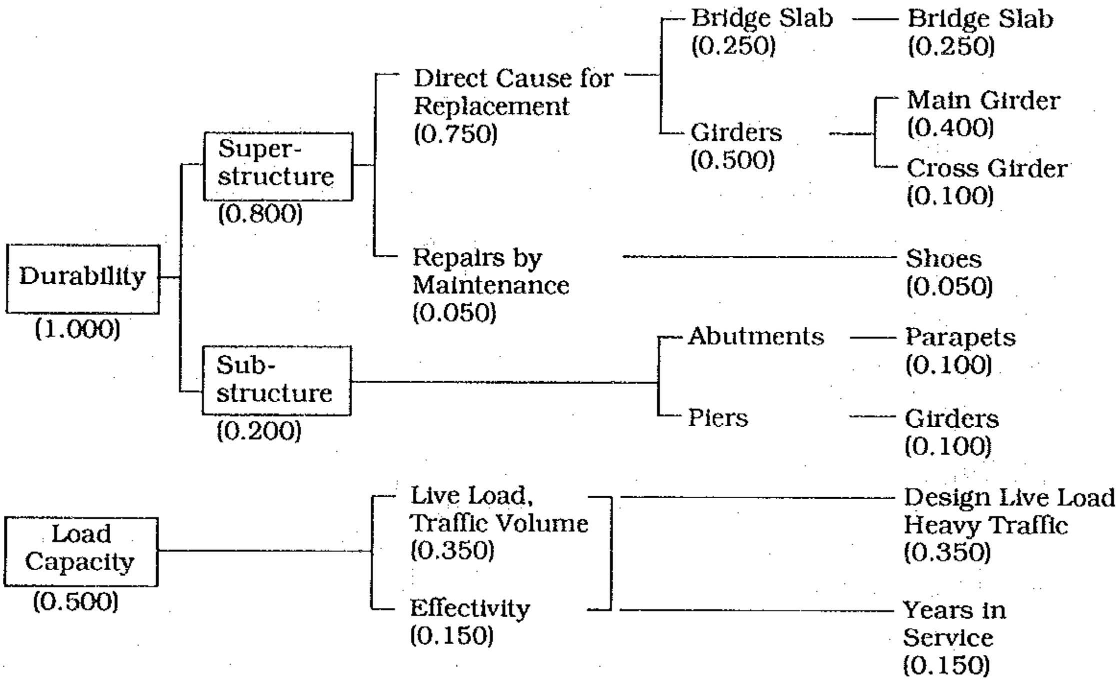
It has been decided to appraise the current physical state of the bridges from their "**durability**" and "**load capacity**".

Durability: Physical changes in the main bridge structural members

Load Capacity: Changes in traffic volumes, heavy vehicle traffic from the original bridge specifications with the passing of time

This project proposes to make studies of the bridges based on the Damage Ranking List and prepare a list of the principal bridge elements to appraise the durability and load capacity of the bridges, and grade them by points. The evaluated weight of the items will have the factors (bt) given in Table B.5.

Table B.5 Establishment of Weight Factors (bt) for Evaluation Items



Notes: Figures in ( ) indicate Durability and Load Capacity as 1.000, 0.500, and Weight Factor (bt)
(Research Data: Ministry of Construction in Japan)

The Evaluated Points (at) for the durability will be defined as follows:

A: 1 point
B: 2 points
C: 3 points
D: 4 points
E: 5 points

The points (at) to appraise the bridges for the Load Capacity are defined as follows:

Live Load and Heavy Vehicle Traffic	Load per axle less than 7.0 tonnes, and little heavy vehicle traffic	:	1 point
	Load per axle more than 7 tonnes, and heavy vehicle traffic	:	3 points
Year Bridge Completed (Time in Service)	Completed after 1975 (less than 20 years in service)	:	1 point
	Completed before 1975 (more than 20 years in service)	:	3 points

The overall evaluated points are calculated by multiplying the evaluated points (at) by the weight factor (bt in the previous table), and the bridges will be ranked by the points.

Table B.6 gives the evaluated points (at) and the weight factors (bt).

Table B.6 Evaluated Points (at) and Weight Factor (bt)

		Evaluated Item	Evaluated Points (at)	Weight Factor (bt)	Points at x bt
Durability	Super-structure	Girder, Main	A-1, B-2, C-3, D-4, E-5	0.400	
		Girder, Cross	A-1, B-2, C-3, D-4, E-5	0.100	
		Slab	A-1, B-2, C-3, D-4, E-5	0.250	
		Shoe	A-1, B-2, C-3, D-4, E-5	0.050	
	Sub-structure	Abutment	A-1, B-2, C-3, D-4, E-5	0.100	
		Pier	A-1, B-2, C-3, D-4, E-5	0.100	
Load Capacity	Live Load & Heavy Vehicle	Weight per axle less than 7.0 ton, little heavy traffic	1	0.350	
		Weight per axle more than 7.0 ton, with heavy traffic	3	0.350	
	Year Bridge Completed	Completed after 1975 (less than 20 years service)	1	0.150	
		Completed before 1975 (more than 20 years service)	3	0.150	
Overall evaluated points					

From Table B.6 the overall points are calculated by multiplying the Evaluated Points (at) by the Weight Factor (bt), and all 9 bridges are ranked for their degree of soundness.

The overall degree of soundness will be listed for their degree of soundness in Fig. B.9.

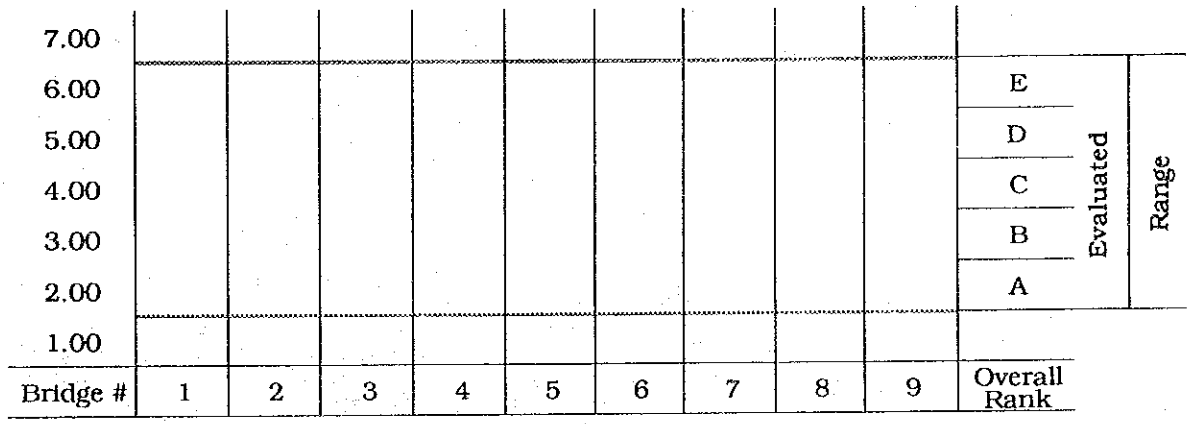


Fig. B.9 Composite Evaluation Diagram for Soundness

(2) Evaluation of Bridges Based on the Test Results of Concrete and Reinforcing Bar

The results of the tests of the materials for the RC bridges and PC bridges are evaluated by establishing standards for the appraisal and determine whether they comply with the standards.

As a general rule the design standards prevailing at the time of completion of the bridges will be used and except for the strength requirements, the design standards of Japan and the AASHTO will be used.

The tests were made principally of the main girder materials and the average values of the bridges were used. The evaluation based on the results of tests of the materials are given in Table B.7.

Table B.7 Evaluation Based on the Testing of Concrete and Reinforcing Steel

Rank	Description of Evaluation
I	Satisfies standard value
II	Meets requirements of standard value or is somewhat less than the standard value
III	Is much less than the standard value

(3) Evaluation of the Bridges Using Loading Tests

Loading tests performed at the center of the bridges and at 1/4 span points in order to measure the deflection and to determine the strength of the reinforcing bar and the concrete using the following formula:

Stress of Reinforcing Bar (Stress of Concrete) (kg/cm^2)
= Strain ($x10^{-6}$) x Modulus of Elasticity for Reinforcing Bar (Concrete) (kg/cm^2)

The deflection of the beams was obtained by the deflection meter.

On the other hand, theoretical calculations were made using a load similar to the loaded truck used in the test, and the stresses in the concrete, reinforcing bar and the deflection. The differences in the test and the calculations were compared.

When there are large cracks in the main girders and slabs as in this case, there are large variances in the deflection of the concrete and it is not easy to compare the field test results with those obtained from the calculations. Hence it was decided to evaluate the bridges based on the rigidity of the concrete which is affected by the sag, and strength of the reinforcing bars which affect tensile strength.

At bridges with large cracks, crack gauges were installed to measure the increase of the crack width when they were loaded with live loads.

Since the loading tests were of the non-destructive type and the rear wheel loads of the test load truck are from 7 to 10 tons, the loads for the RC bridges were of the T-20 tons, and the loads for the PC bridges also were of T-20 tons as the rigidity of the girders were larger, as the measurements of the deflection to be taken and the deflection of the concrete were larger considering the span 20 m to 30 m long.

(4) Evaluation of the Existing Bridges Based on Their Load Bearing Capacity

The load bearing capacity of the main girders of the existing RC and PC bridges allow the calculation of the live load that can be permitted on the existing bridges. The calculations of the load bearing capacity differ for the RC bridges and the PC bridges.

A grid framework analysis was made based on the live load case based on the design standards established by the Sultanate of Oman. The results of the calculations were compared with the allowable stresses and check should be made whether the actual stresses meet with the allowable stresses.

1) Calculation Method of the Allowable Loads for RC Bridges

The bending bearing stress for the main girders is expressed by the current design live load (AASHTO load) Bending Safety Factor (γ). The load bearing capacity of the outer girder and inner girder was calculated and the minimum value be used to determine the load bearing capacity of the bridges.

$$\gamma = f \bullet \frac{M_u - 1.1\ M_d}{M\ell}$$

$$M_u = A_s \bullet \sigma_{sy} \bullet (d - 1/2 \bullet \frac{A_s \bullet \sigma_{sy}}{0.85 \bullet \sigma_{28} \bullet b})$$

where,

- γ : safety ultimate bending ratio of the main girder to AASHTO load
- f : measured and calculated stress ratio = calculated/measured
- M_u : ultimate bending moment of girder (t•m)
- M_d : bending moment of girder duc to existing dead load (t•m)
- $M\ell$: bending moment of girder due to AASHTO load (t•m)
- σ_{sy} : yield stress of reinforcing bar (test value at time of construction, σ_{sao} = 1800 was 4,200 kg/cm²)
- b : effective width of compressed flange (cm)
- d : effective height to main reinforcing bar (cm)
- σ_{28} : standard design strength of concrete (kg/cm²)
- A_s : Area of main steel bar for tension (cm²)

The method of calculation of the load bearing capacity is made in accordance with the four methods given in Table B.8. The method for calculating δ_o, σ_o, $M\ell$ is made by the same methods (simplified method or the load distribution method).

Table B.8 Calculation Method of Load Bearing Capacity

Load Capacity Calculation	Calculation Standard	Value of f (Ratio of Measured and Calculated Stress)
Method #1	Calculate $M\ell$ by the simplified method, and obtain γ using f = 1.4	1.4
Method #2	Obtain the value of $M\ell$ considering distribution of loads on the girder and calculate γ using f = 1.0	1.0
Method #3	Measure deflection by load test, for f divide the calculated deflection by the measured value and calculate γ	$\frac{\delta_o}{\delta} = \frac{\text{calculated defl.}}{\text{measured defl.}}$
Method #4	Measure the stress in the rebar with loading test, for f divide the calculated stress by the measured stress and calculate γ	$\frac{\sigma_o}{\sigma} = \frac{\text{calculated stress}}{\text{measured stress}}$

The load bearing capacity shall be calculated starting with Method #1 thru #4, and when the value for α exceeds 1.0, the bridge shall be considered safe to carry the loads, and the largest value of the four methods shall be determined as the load bearing capacity α of the bridge. When all the values for α is less than 1.0, the value for γ calculated from Method #4 is the failure factor under live loads γ for the bridge.

$$\alpha = \frac{\gamma}{\beta}$$

where, α : load bearing ratio

β : failure safety factor for the bridge required under AASHTO live load and is a value determined for the actual traffic on the bridge and fixed from the number of years that the bridge will be in service and $\beta_{met} = 2.5$

The Load Bearing Capacity (P) for the bridge will be as follows:

P = AASHTO Live Load x α (ton)

2) Evaluation of Load Bearing Capacity of PC Bridges

The evaluation of load bearing capacity of existing PC bridges is the same as for bridges where the RC components are still active in the axial direction, and the stresses imposed on the bridge are not proportional with the stresses on the cross section. Also the stress in the wires and the type of wire used for tensioning the member becomes important. The load bearing capacity of the component is determined by the ultimate bending moment of the cross section which is compared with the safety factor (load factor design method) at ultimate breaking strength of the member.

The ultimate bending moment is obtained from the original design documents and AASHTO HS 20-44 live load system by the grid framework analysis.

- Design Condition: The amount of PC wire (AP cm²)
  The breaking factor of the PC wire (tension) (σ_{pu} kg/cm²)
  The effective prestress load (σ_{pe} kg/cm²)
  Effective width of compression flange (B cm)
  Standard design strength of concrete (σ_{28} kg/cm²)
  Effective height (d cm)
  Dead load bending moment of each main girder (M_d t•m)
  Live load bending moment of each main girder (M_ℓ t•m)
  Properties of the PC cable (E_p kg/cm²)
  Ultimate deflection of concrete (ε_{cu})
  Combined tension (T kg)
  Combined compression (C kg)
  Distance to combined compression from compression edge (k • x cm)

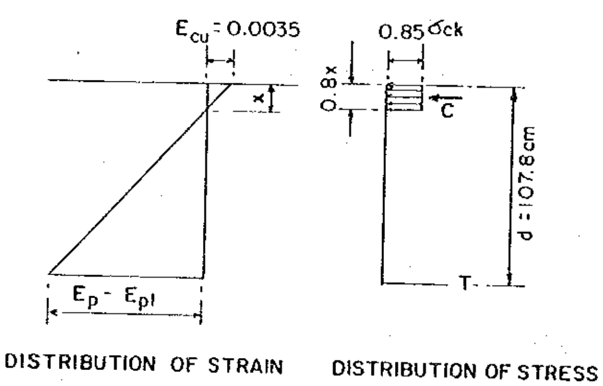


Fig. B10 Distribution of Stress and Strain

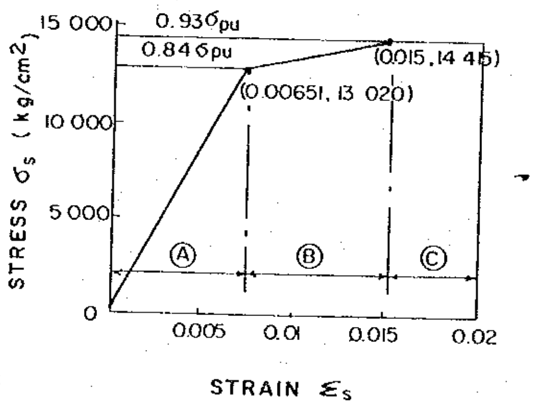


Fig. B11 Stress and Strain Diagram of 7mm PC Cable

Ultimate bending moment (M_u t•m)

$$M_u = T(d - k \cdot x)$$

The ultimate load (M_{du}) will be as follows:

a) 1.3 [dead load] + 2.5 [live load]

b) 1.7 [dead load + live load]

Therefore the safe load of PC bridges will be considered safe when

$$\frac{M_u}{M_{du}} > 1.0$$

3) Study of Stress According to the Omani Design Standard

The bending moment for the representative bridges No. 1, 2, 6 and 9 shall be calculated for the dead load and live load using the live load design standards of the various countries and prepare VOLUME III, Fig. 6.5) and from the results the maximum bending moment, it correspond to the Omani Design Standard case for loading a 2-lane highway with a 60 ton truck.

So for the bridges in this project, the case of the representative live loads are the two cases in VOLUME III, Fig. 6.6 and Fig. 6.7, theoretical calculation is performed and the actual stresses are calculated and compared with the allowable stresses, and the load capability will be studied.

① Bridge No. 1, RC Bridge with T-Girders (L = 15 m)
② Bridge No. 2, RC Bridge with T-Girders (L = 15 m)
③ Bridge No. 5, RC Bridge with T-Girders (L = 15 m)
④ Bridge No. 6, PC Bridge with T-Girders (L = 30 m)
⑤ Bridge No. 9, PC Bridge with T-Girders (L = 21 m)

For all 9 bridges, theoretical calculations (grid framework analysis) cases are given in VOLUME III, Table 6.6 and summarized as the theoretical calculation list. The list in the Table also gives the load capacity obtained under the AASHTO calculation case.

3.4.2 Results of Evaluation for Testing Bridges

(1) Evaluation of Soundness of Existing Bridges Based on Their Degree of Deterioration

The condition of the bridges according to the evaluation methods described in 3.4.1 (1) have been listed in Fig. B.12 giving their soundness in the order of their ranking. The durability of the bridges have been described by their appraised points (at) and weighted factor (bt). (See VOLUME III, Table 7.2 through Table 7.10).

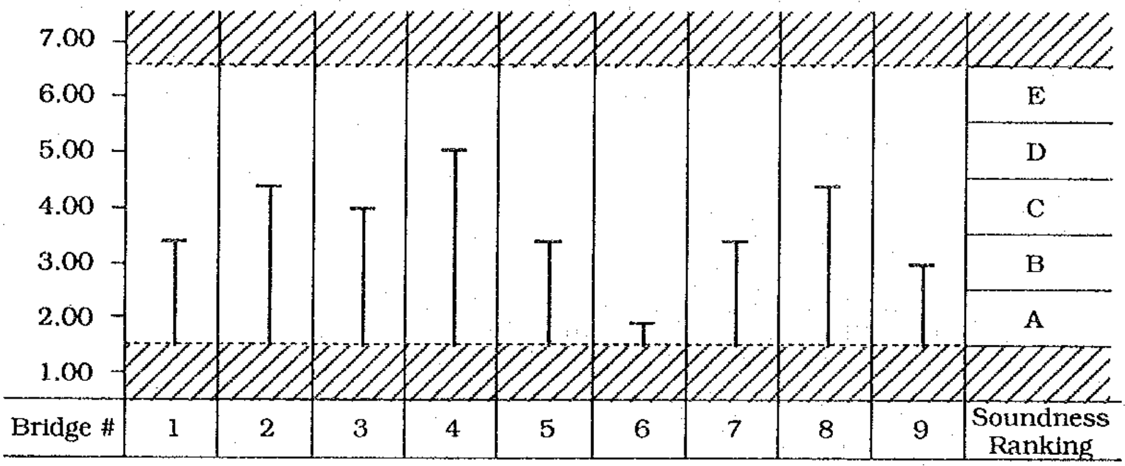


Fig. B.12 Composite Evaluation Diagram for Soundness

(2) Evaluation of Bridges Based on the Test Results of Concrete and Reinforcing Steel

According to the ranking explained in 3.4.1 (2) Evaluation of Bridge Based on the Test Results of Concrete and Reinforcing Steel, the quality of the concrete was evaluated and the results given in Table B.9.

In the same manner, the evaluation of the reinforcing steel was made and posted in Table B.10.

(3) Evaluation of Bridges Using Load Tests

From the investigations, the strength of reinforcing steel and concrete and the deflections were calculated. From the results, the theoretical value was calculated from a load system similar to the load test, and the load test diagram in VOLUME III, Fig. 7.3-1 and Fig. 7.3-2 was obtained, and the bending moment, stress and deflections in the girders of the bridges were calculated.

In the RC bridges, the stress and deflections of the reinforcing steel were observed, and in the PC bridges deflections were observed and a composite graph of the loaded measurement and calculations of the bridges are given in VOLUME III, Fig. 7.4 to Fig. 7.12. The relations of these results are given for

Table B.9 Judgement due to Results of Concrete Test

Test Item		Bridge No. No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9	Standard Evaluation Value (from Const. Dwg. or Design Standard)
Compressive Strength	(kg/cm^2)	383	373 (372)	288 (245)	359 (236)	335 (264)	336 (328)	320 (333)	271	295 (211)	RC Precast $\sigma_{28} = 290$ RC Cast in place $\sigma_{28} = 215$ PC Br. No. 6 $\sigma_{28} = 340$ PC Br. No. 7, No. 9 $\sigma_{28} = 315$
	Eval.	I	I	II	I	I	II	I	II	II	
Young's Factor	(kg/cm^2)	3.3×10^5	2.2×10^5	2.7×10^5	2.3×10^5	2.1×10^5	3.0×10^5	2.0×10^5	2.4×10^5	3.7×10^5	RC $\sigma_{28} = 270$ 2.65×10^5 RC $\sigma_{28} = 340$ 2.92×10^5 PC $\sigma_{28} = 315$ 2.85×10^5
	Eval.	I	II	I	II	II	I	(III)	II	I	
Tensile Strength	(kg/cm^2)	26	22	27	28	23	28	27	19	30	Tensile Strength > Compressive Strength x $\frac{1}{10}$
	Eval.	I	I	I	I	I	I	I	I	I	
Unit Volume Weight	(t/m^3)	2.5 (2.3)	2.4 (2.5)	2.5 (2.5)	2.4 (2.4)	2.3 (2.4)	2.4 (2.3)	2.4 (2.5)	2.2	2.4 (2.4)	$2.35\ t/m^3$
	Eval.	I	I	I	I	II	I	I	II	I	
Water Absorption	(%)	1.7	3.9 (2.2)	3.7 (2.1)	4.0	4.1	3.9 (4.2)	3.3 (2.1)	4.6	1.6 (2.1)	—
	Eval.	I	II	II	II	II	II	I	(III)	I	
Water Ratio	(%)	2.1	1.4 (2.3)	0.3 (1.9)	1.2	1.7	1.2 (2.5)	0.6 (1.7)	2.6	0.2 (2.4)	—
	Eval.	II	I	I	I	II	I	I	(III)	I	
Neutralization Depth	(mm)	5.6	15.5 (2.2)	18.1	16.8 (22.0)	16.6 (2.7)	19.8 (3.7)	4.7 (1.8)	12.8	13.9 (0)	10 ~ 15mm (More than 20 years after Construction)
	Eval.	I	(III)	(III)	(III)	(III)	(III)	I	II	II	
Schmidt Hammer	(kg/cm^2)	378 (378)	311 (291)	278 (335)	285 (343)	331 (322)	378 (308)	278 (271)	269 (252)	369 (338)	
	Eval.	I	I	II	II	I	I	II	II	I	

Note: ( ) value means slab.

Table B.10 Judgement due to Results of Reinforcing Bar Test

Test Item			Bridge No.						Standard Evaluation Value (from Const. Dwg. or Design Standard)
			No. 1	No. 2	No. 3	No. 4	No. 5	No. 8	
Nominal Diameter	(mm)		Dø32	Dø36	Dø36	Dø36	Dø32	Dø36	ø32 6.403 ø36 7.906
Unit Weight	(kg/m)		6.24	7.79	7.78	7.98	6.00	7.87	
Yield Point Stress	(kg/mm²)		46	42	42	42	47	42	30 ~ 40
	Eval.		I	I	I	I	I	I	
Tensile Strength	(kg/mm²)		64	67	63	64	69	66	More than 50
	Eval.		I	I	I	I	I	I	
Elongation	(%)		19	20	22	21	24	24	More than 14
	Eval.		I	I	I	I	I	I	
Chemical Analysis	(%)	C	0.19	0.38	0.25	0.37	0.37	0.37	Maximum 0.40
		Si	0.34	0.27	0.22	0.22	0.24	0.27	Maximum 0.55
		Mn	0.77	1.38	1.28	1.40	1.15	1.39	Maximum 0.80
		P	0.02	0.02	0.02	0.03	0.03	0.02	Maximum 0.05
		S	0.03	0.02	0.02	0.03	0.02	0.02	Maximum 0.05
	Eval.		II	II	II	II	II	II	
Young's Factor	(kg/cm²)		—	1.84×10^6	—	1.83×10^6	1.99×10^6	1.82×10^6	$2.0 \sim 2.1 \times 10^6$ kg/cm²
	Eval.			II		II	I	II	

the RC bridges and they are used to obtain the load capacity of the value of f and larger the value, the bridge have the capability to carry the load.

The theoretical calculation of each bridge for the bending moment in the main girder for the dead load and live load have been presented in VOLUME III, Table 7.14.

The detailed theoretical calculations for each bridge are given in VOLUME III, Tables 7.15 to 7.19.

(4) Evaluation of the Existing Bridges Based on the Load Bearing Capacity

1) Load Bearing Capacity of the Main Girder

The load bearing capacity and the degree of safety under the test load will be calculated on the three representative RC bridges No. 1, No. 2 and No. 5 and two PC bridges No. 6 and No. 9, for a total of 5 bridges using the present AASHTO HS20-44 live load as described in VOLUME III, Chapter 6.4 Evaluation of the Existing Bridges Based on Their Load Bearing Capacity. For the RC bridges the load on the main girder considers the load distribution calculation by the grid calculation method and the base factor $f = 1.0$ and the bending rupture factor (γ) are determined.

The new Omani Uniform Load and Concentrated Load which uses a live load of AASHTO HS20-44 x 2, the load bearing capacity and safety factor are calculated to determine the load bearing capacity of the main girders.

On the other hand, the live load system of Omani Design Standard of 60 ton truck x 2 is the largest live load, the actual load bearing capacity is calculated, and the result compared with the allowable load bearing capacity to determine whether it is within the allowable stress or to what degree it exceeds the stress allowed.

The results of the safety ratio and load bearing capacity of the main girders in RC Bridges are given in Table B.11.

Table B.11 Results of Safety Ratio of Ultimate Bending Moment and Load Bearing Capacity

Bridge No.	Case No.	Girder No.	Md (t.m)	$M\ell$ (t.m)	M_{au1} = 1.3Md+2.5$M\ell$	M_{au2} = 1.7(Md+$M\ell$)	Mu (t.m)	f	$\gamma = f \cdot \frac{Mu-1.1Md}{M\ell}$	$\alpha = \frac{\gamma}{\beta}$	P = AASHTOxα (32γ)(ton)	$F = \frac{Mu}{Mdu\ max}$
1	AASHTO HS20	G1	81.6	29.3	179.3	188.5	280.7	1.0	6.52	2.61	83.5	1.49
		G2	82.8	40.9	209.9	210.3			5.76	2.30	73.6	1.33
	AASHTO 2x(HS20)	G1	81.6	58.6	252.6	238.3			3.26	1.30	41.6	1.11
		G2	82.8	81.8	312.1	279.8			2.32	0.93	29.8	0.90
2 (3.4)	AASHTO HS20	G1	104.8	35.9	226.0	239.2			4.61	1.84	58.9	1.17
		G2	75.8	34.6	185.0	187.7			5.70	2.28	73.0	1.50
	AASHTO 2x(HS20)	G1	104.8	71.8	315.7	300.2			2.30	0.92	29.4	0.89
		G2	75.8	69.2	271.5	246.5			2.85	1.14	36.5	1.03
5 (8)	AASHTO HS20	G1	104.2	35.7	224.7	237.8			4.65	1.86	59.5	1.18
		G2	75.4	34.5	184.3	186.8			5.73	2.29	73.3	1.50
	AASHTO 2x(HS20)	G1	104.2	71.4	314.0	298.5			2.33	0.93	29.8	0.89
		G2	75.4	69.0	270.5	245.5			2.87	1.15	36.8	1.04

Notes: $Mu = As \cdot \sigma_{sy} (d - \frac{1}{2} \cdot \frac{As \cdot \sigma_{sy}}{0.85 \cdot \sigma_{28} \cdot b}) = 64.3 \times 4200 \times (117.0 - \frac{1}{2} \times \frac{64.3 \times 4200}{0.85 \times 270 \times 45}) \times 10^{-5} = 280.7$ t.m, As_{min} = 8 - ø32 = 64.3 cm

$\beta_{max} = 2.5$

f value = 1.0 (Grid frame work Analysis)

The load bearing capacity of main girders of PC Bridges have been calculated for the ultimate bending safety ratio and given in Table B.12 and Table B.13.

2) Load Capacity of Decks

The bridge deck is that component of a bridge that the live load is directly in contact with, and is subject to repeated fatigue loads. The safety of the bridge is calculated from its condition, and the design of the deck is based on the rear wheel load of truck loads.

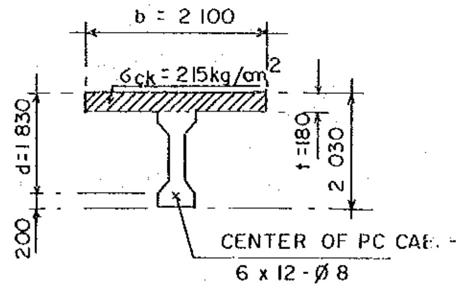
For the RC and PC bridges, load testing is performed with a 7.0 ton rear wheel load, and the heaviest AASHTO 7.26 (1+i) ton design standard from which the allowable load capacity is compared for the deck in order to investigate bridge safety.

The bridge deck is subject to repeated loads and fatigue loads as stated previously, and the design standards used in Japan will be used for the allowable values for this study, and the allowable stress for the concrete (σ_{ca}) will be one-third of the σ_{28} for σ_{ca} = 71 kg/cm^2 or 90 kg/cm^2, the allowable stress for reinforcing steel (σ_{sa}) for the deck will be assumed for σ_{sa} = 1,400 kg/cm^2 at a low value where the normal stress is 1,800 kg/cm^2. (refer to VOLUME III, Main Text)

3) Substructure Supports

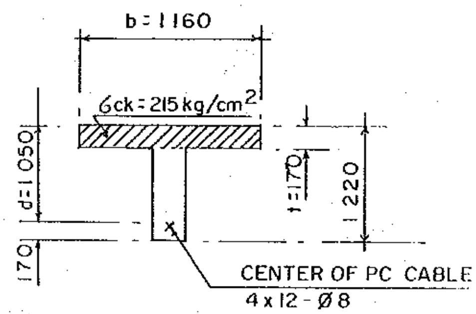
There are cracks in the rigid frame pier of the substructure and so the live loads will be calculated in accordance with the AASHTO live load systems and compared with the actual loads. (refer to VOLUME III, Main Text)

TableB.12 Safety Ratio of Load Bearing Capacity for Bridge No. 6 (PC Bridge)



		(tm) Md	(tm) Mℓ	(tm) Mn1 = 1.3Md+2.5Mℓ	(tm) Mn2 = 1.7(Md+Mℓ)	(tm) Mu	$F = \frac{Mu}{Mn}$
AASHTO HS20	G1	313.7	99.0	655.3	701.6	890.7	1.270
	G2	330.8	91.0	657.5	717.1		1.242
	G3	329.4	87.0	645.7	707.9		1.258
AASHTO 2x(HS20)	G1	313.7	198.0	902.8	869.9		0.987
	G2	330.8	182.0	885.0	871.8		1.006
	G3	329.4	174.0	863.2	855.8		1.032

Table B.13 Safety Ratio of Load Bearing Capacity for Bridge No. 7. 9 (PC Bridge)



		(tm) Md	(tm) Mℓ	(tm) Mn1 = 1.3Md+2.5Mℓ	(tm) Mn2 = 1.7(Md+Mℓ)	(tm) Mu	$F = \frac{Mu}{Mn}$
AASHTO HS20	G1	83.4	23.6	167.4	181.9	326.2	1.793
	G2	87.7	27.5	182.8	195.8		1.666
	G3	84.0	31.2	187.2	195.8		1.666
	G4	81.8	32.9	188.6	195.0		1.673
AASHTO 2x(HS20)	G1	83.4	47.2	226.4	222.0		1.441
	G2	87.7	55.0	251.5	242.6		1.297
	G3	84.0	62.4	265.2	248.9		1.230
	G4	81.8	65.8	270.8	250.9		1.205

3.5 The Overall Evaluation of Existing Bridges

Overall Evaluation

The safety features of all existing 9 bridges were discussed as mentioned before.

(1) Evaluation of Soundness of Existing Bridges Based on Their Degree of Deterioration

(2) Evaluation of Bridges Based on Testing Concrete and Reinforcing Steel

(3) Evaluation of the Bridges Using Load Tests

(4) Evaluation of the Bridges Based on the Load Bearing Capacity

Each bridge has been appraised for their superstructure, substructure, and other component parts for their overall condition and their soundness and load bearing capacity has been described in VOLUME III, Chapter 6 The Evaluation Method for Existing Bridges giving their present soundness and future safety features. The overall soundness are given in the following Table B.14.

Table B.14 Summary of Overall Evaluation and Judgement for Bridges

Bridge No.	Deterioration from Soundness	Quality of Concrete and Steel Bar	f-Value from Load Test	Load Bearing Capacity		Overall Evaluation and Judgement (Ao ~ Eo)		Requirement of Repair
				Safety Ratio of Ultimate B.M.	Allowable Stress			
1	B	I	I	I	I	Girder Slab	Bo Ao	Record
2	D	II	III	II	II	Girder Slab	Do Co	Detailed Re-Inspection
3	C	II	II	II	II	Girder Slab	Co Co	Under observation
4	E/D	II	II	II	II	Girder Slab	Eo Do	Emergency Repairs
5	C	II	III	II	II	Girder Slab	Co Co	Under observation
6	A	II	I	I	I	Girder Slab	Ao Ao	—
7	B	I	III	I	III	Girder Slab	Ao Eo	Slab: Emergency Repairs
8	C	II	III	II	II	Girder Slab	Do Co	Detailed Re-Inspection
9	B	I	I	I	I	Girder Slab	Ao Do	Slab: Emergency Repairs

[Notation]

Overall Evaluation

Rating	Condition	Action Taken
Ao	Sound	–
Bo	Fairly Sound	Recorded
Co	Fairly Unsound	Condition under observation
Do	Not Safe	Make detailed bridge inspection
Eo	Dangerous	Make emergency repairs

Soundness Determination Table

*Rating	Condition	Action Taken
A	No damage noticed.	–
B	Small damage noticed.	Damage recorded.
C	Damages found.	Conditions under observation
D	Large damage found.	Make detailed bridge inspection
E	Large damage found. Could be dangerous to the public.	Make emergency repairs

Note: * Rating A through E is shown in the Damage Ranking List of VOLUME III.

Quality of Concrete and Reinforcing Steel

Rating	Condition
I	Satisfies standard values.
II	Equals standard values or is slightly inferior.
III	Does not meet standard values.

f-Value from Load Test (Calculation/Measurement)

Rating	Condition
I	Value of f is more than 1.2 for Deflection and Stress.
II	Value of f is from 1.0 to 1.2 for Deflection and Stress.
III	Value of f is less than 1.0 for Deflection and Stress.

Safety Ratio of Ultimate Bending Moment and Load Bearing Capacity

Rating	Condition (Girder)
I	Safety Ratio is larger than 1.2 for the AASHTO Live Load.
II	Safety Ratio is between 1.0 to 1.2 of the AASHTO Live Load.
III	Safety Ratio is less than 1.0 of the AASHTO Live Load.

Load Bearing Capacity (Allowable Stress, RC)

Rating	Condition (Girder and Slab)
I	σ_c and σ_s are both within the allowable stress of the AASHTO Live Load.
II	σ_c and σ_s both exceed the allowable stress of the AASHTO Live Load but are within the σ_{28} x 0.75 and σ_{pr} (yield point stress) x 0.75.
III	σ_c and σ_s both exceed σ_{28} x 0.75 and σ_{pr} (yield point) x 0.75 of the AASHTO Live Load.

3.6 Proposed Plans of Maintenance and Rehabilitation for Existing Bridges

3.6.1 Proposed Repair Plans for Testing Bridges

As a result of inspection and load test, the soundness of bridge was evaluated and recommended the repair plan for evaluated 9 existing bridges.

Repair plan for superstructure and substructure for inspected bridge recommended and at the execution stage, repair plan will be decided with deeply consideration.

The six bridges there is necessity of repair/strengthening out of inspected nine bridges, repair/strengthening plan shall be recommended.

Detailed information refer to VOLUME III, Chapter 9.

Bridge No. 4 (Wadi Al Jizi DAH-7/202-27) and Bride No. 7 (BID-Sur DAK-23/100-02) is in a dangerous condition, therefore, there is necessity of urgent repair plan. The degree of damage and Repair/Strength Plan is shown in Table B.20.

The following countermeasures for bridge No. 4 were carried out by Directorate General of Roads (DGR) as maintenance work in 1994.

(1) Restriction of Heavy Vehicle

Heavy vehicle should be detoured and ultimate strength reduced.

(2) Mortar Injection to Cracks of Main Beam, Slab and Cross Beam

① Progress of crack under condition of heavy vehicle loading should be inspected by routine inspection.

② Re-corrosion and progress of neutralization of reinforcement bar should be prevented.

(3) Repair of Bridge Pavement

For the other bridge, following the proposed repair plan, maintenance work will be carried out in order and soundness of bridge should be judged by inspection item.

3.6.2 Maintenance Management Plan

The guideline of maintenance management system for 58 bridges under the control of the Directorate General of Roads on the basis of inspection result of soundness was summarized as shown below:

- Bridge Inventory (Detailed Information refer to Volume III Chapter 10, Proposal of Bridge Inventory)
- Check up Guidelines (Detailed Information refer to Volume III Chapter 10, Proposal for Check up Guidelines).

Tabel B.20

Br. No.	Bridge Name	The Degree of Damage	Repair/Strengthen	Sketch
No. 2	Wadi Al Jizi BAT-7/102-02	• There are cracks in the main girder and cross beam.	• Pressure injection method. • Coating with cement concrete or mortar. • Coating with anti-neutralizing agent. • Strengthening steel plates can be added with expansion bolts of epoxy adhesive. • Restricting weight of vehicles, or controlling bridge traffic.	
No. 3	Wadi Al Jizi BAT-7/105-15	• There are cracks in the main girder, cross beam and concrete deck. • Some of the bridge footings are exposed.	• Pressure injection method. • Application of anti-neutralizing agent. • Add to the reinforced concrete a new concrete covering. • Adding Reinforcing Steel Plates.	
No. 4	Wadi Al Jizi DAH-7/202-27	• There are cracks on the bottom side of the main girder, in the web and flange of the main girder, and the cracks extend through the beam and is in a dangerous condition. This indicates that the bridge is deteriorated in general and the capacity has lowered and is in a dangerous condition. • There are cracks in the bottom side of the cross beam and deck slabs. • There are also many cracks in the substructure.	• Laminating method which is add new materials or construct a box culvert under the main girder. • Adding support method which is construct a support at the mid point of the girder span and shorter the span. • Restrict load and limit traffic on bridge. • Replace main girder and deck slabs of the superstructure.	
No. 6	Rusail-Nizwa DAK-15/100-01	• The rubber bearings are disfigured.	• Replace the rubber bearing.	
No. 7	Bid Bid Sur DAK-23/100-02	• There are no cross beams to distribute the loads with the result that the main girder is required to carry the load thereby lowering its rigidity. • The deck slab is precast concrete slab (5 cm) over which a concrete slab (13 cm) has been poured for a total (18 cm) thick deck, but the two layers have not formed an integrated panel to act as single concrete deck.	• Add cross beams at both supports and a beam at mid point to distribute the load. • Remove and replace concrete deck slab over the precast slab to form an integral concrete deck. • Restrict heavy vehicle traffic.	
No. 8	Buaimi/Ibri/Nizwa DAK-21/600/01	• There are many cracks in the main girder. • The substructure is damaged from the flow of stones and mud.	• Pressure injection. • Coating method. • Increase strength of bridge supports by adding concrete. • Drive H-beams around bridge footings. • Restrict loads on bridges and regulate traffic.	

3.7 Conclusions and Recommendations

3.7.1 Conclusions

The bridges in the sultanate of Oman are almost all made of concrete due to the material obtainment situation, and concrete bridges will continue to predominate in the future.

While the existing bridges have been designed based on various country codes, however, almost all of those that applied AASHTO HS20-44 standard. It was found that the material properties of the concrete and reinforcing bars vary by bridge, and also there exist almost no documents from the design stage or construction records from the construction stage.

Therefore, the current conditions of the bridges were mainly examined from field investigations. They are summarized as follows.

(1) Reinforced-concrete bridges

- Almost all the superstructures had cracking in parts. An examination of cracks in main girders revealed that no new crack initiation or propagation had occurred after first repair. Judging from this, the cracks formed upon a temporary heavy loading.

- Concrete neutralization is not advanced and the compressive strength of the concrete is still sufficient. Deterioration is not great.

- Despite the cracks in the concrete, little rusting of the reinforcing bars has occurred.

- The pavement near the bridge expansion joints is not smooth, thereby impairing road maneuverability.

- Some bridges have cracks in part of their substructure, but no substructure settlement or inclination has occurred.

- There are scoured areas around some substructures.

(2) Pre-stressed concrete bridges

- There are bridges with structural defects, such as a lack of cross beams.

- The concrete slabs were made by pouring concrete while using precast plates as forms. However, the precast slabs and the poured concrete have not merged into a single entity. In addition, because the slab concrete is thin, the slabs have little strength. Cracking occurred as a consequence.

- There are no problems with the substructures.

(3) Loading test results

Upon a comparison between theoretical values and measured values of main girder reinforcing bar stress and main girder deflection as measured in loading tests, it was found that the measured values were less than the theoretical values and the actual rigidity of the bridge is higher than that assumed in the design. Consequently, the load bearing capacity is also higher than the design value.

Converting the load bearing capacity of the test results into an equivalent axle load, bridge functionality could be assured with a maximum axle load of 14.5t for Bridge Nos. 1 and 6 and 10.8t for all other bridges.

3.7.2 Recommendations

From the investigation results, the following recommendations are proposed to assure the functionality of existing bridges and for the construction of bridges in the future.

<u>For Existing Bridges</u>

- Restrictions of axle load of vehicles

- To smooth out the bridge surface by paving to lessen vehicular impact load

- To repair cracks on RC bridge by mortar injection method and to check up progress of cracks

- To repair or reinforce the structural defects of PC bridges (for example, replacement of slabs, installation of cross beam, etc.)

- To establish a maintenance and rehabilitation system that includes a bridge inspection system, and to file the records of degree of soundness for all bridges which include as-built drawings, construction records and inspection records, and to carry out routine monitoring.

For New Bridges

- Store and file such documents as the design standards, design report, at design stage.

- Store and file as-built drawings, records of material types, quality control results, etc.