A Continuous Reinforced Concrete Pavement (CRCP) Overlay for the Torrejón By-pass

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1. INTRODUCTION

This Paper describes the process which have led to the definition of actions shortly to be undertaken on the Torrejón by-pass: in particular, surveys and studies carried out since 1985 to determine the best solution.

Some 20 km from Madrid, beyond its airport, Route 2 (Madrid to Barcelona) was in 1965 the busiest motorway in Spain: average daily traffic was then above 30,000. In 1966, a 7 km long by-pass was built around the town of Torrejón de Ardoz. Each carriageway had a 1.5 m inner shoulder, two 3.5 m lanes, a 2.5 m outer shoulder, and a 1.0 m berm; median width was 12 m. Yearly rainfall is 466 mm, temperature varies between –5 and 39°C; there are 29 days per year with temperatures below 0°C.

2. THE EXISTING PAVEMENT

2.1 Design

The pavement of the Torrejón by-pass was a 25 cm jointed plain concrete pavemnt (**JPCP**) slab on a 15 cm cement-treated base (**CTB**), separated by a polyethylene film. For construction reasons, the 10 cm granular subbase was also cement-treated. (See Fig. 1)

According to the then current practice, no expansion joints were planned; dowelled contraction joints were placed at 6 m intervals. Dowels were 25 mm in diameter and 50 cm long, at 50 cm intervals; below them a breaker strip of corrugated asbestos was placed on the **CTB**, to start the transverse crack at the joint and to give it a load-transferring shape. Longitudinal joints had tie-bars of high-adherence steel, 12 mm in diameter at 50 cm intervals.

2.2 Construction

A vertical-axis mixer concrete plant with an output of 120 m^3 per hour was used, although the 3 m^3 capacity mixer was used filled only ar 2 m^3, not to strain the automatic controls. Fresh concrete was transported to a maximum of 4 km, on side-tipping lorries with no canvas cover. Height of pour did not exceed 1.0 m.

Concrete was placed between steel forms on a mortar leveling bed, after placing the polyethylene film on the **CTB**. Paving train included:

- A bucket spreader
- A transverse finisher
- A dowel inserter
- A vibrating knife to form the transverse joints
- A diagonal float
- A curing-compound spreader

Final finish was done by hand, from the last machine before the curing-compound spreader, which towed a 200 m long train of rolling roofs to further protect freshly placed concrete. Forms were removed between 24 and 36 hours after concreting.

2.3 Joints

One every three transverse joints was sawn with a diamond blade 8 to 12 hours, after concreting except when excessive temperature changes were foreseen: in this case joints were vibrated into the fresh concrete, every 36 or 48 m, and sealed with a polyurethane strip (later replaced by an asbestos strip). Later, all the remaining transverse joints were sawn as well. Timing of longitudinal joint sawing was not critical.

In both cases, sawing was done in two passes: the first and earliest one, deeper and 3 mm wide; a shallower second one, some days later, to achieve a wider and chamfered groove into which to place a neoprene sealing strip, after sandblasting.

2.4 Control

Control showed an above average quality and uniformity, even by today's standards:

- Cement-treated subbase material (**CTS**) had a sand equivalent (**SE**) over 35, and compressive 7-day strength (after 4-hour inmersion) was an average of 1.2 MPa.
- **CTB** materials had a **SE** over 75, and compressive 7-day strength was 4.5 MPa.
- Concrete was made up of three aggregates, with 320 kg/m^3 of **P-350** cement, with a W/C ratio of .43. Compressive strength achieved is shown in Fig. 2, and flexural strength in Fig. 3. Respective overall average was 32 and 4.5 MPa.
- Upon arrival of the fresh concrete, slump and entrained-air were checked, and daily 6 test prisms were cast (3 for 7-day and 3 for 28-day strength tests).
- Evenness of the complete pavement was checked with a 3-m straightedge: most of the pavement showed a difference below 3 mm (which is very good), and only 101 slabs (3 % of total number), with an area of 990 m^2 (1 % of total area) showed differences between 5 and 10 mm.
- Sand-patch texture tests showed a depth of .5 mm (the standard then prevailing, later raised to .75 mm).

3. SOMETHING LEARNED FROM THIS EXPERIENCE

At the time, the following conclusions were drawn from the construction of the Torrejón by-pass:

- Pavement quality depends mainly on the concrete plant, an idea never stressed enough: batch uniformity and a steady supply are the foundations of a good job.
- Progress speed is set by the first machine in the paving train.
- Total daily progress can reach to around 6 times the total available form length, if setting and transport are well organized.
- Vibratory dowel inserting machine was very efficient, simpler and cheaper than dowel baskets. Traces left by it were removed by the longitudinal float.

- The longitudinal float should never stop. This stresses the importance of avoiding supply cuts.
- Sawed joints are superior to moulded ones. Previous tests are necessary to determine output, but in any case enough sawing machines should be available.

These conclusions have varied very little in thirty years, although equipment has undergone a great development.

4. FIRST ASSESSMENTS

In 1986, a report was drafted by the Highway Agency, the Madrid Polytechnic School for Civil Engineering, and the Spanish Cement Institute, the main conclusions of which were:

- After 22 years, pavement behavior had been better than expected. Surface micro-cracking due to insufficient curing, and some cracks over the dowels had not progressed. Shallow placement of many dowels (6 to 8 cm below the pavement surface), displaced during concreting, had not led to any distress after 22 years. A repair in the adjoining section had needed demolition of some slabs, during which their sound condition had been ascertained..
- There was no clear need for an overlay: it could be delayed some 10 years, if the pavement was rehabilitated in 1987, by fully reconstructing slabs with more than one structural crack, partly reconstructing some others with a bonded fiber-reinforced concrete patch, sealing cracks and spalls with a flexible epoxy, and re-sealing the joints with neoprene.
- **Delaying the overlay could be considered a good chance to study pavement behavior to fatigue** failure and to adquire experience for other concrete pavements. Unless the results of the surveys needed for a rehabilitation were very negative, delaying of the overlay was recommended.
- For an overlay, three solutions were coned:
  1. **CRCP** 22 cm thick, with .7 % longitudinal steel.
  2. **JPCP** 28 cm thick, with dowelled joints at 5 m intervals.
  3. Asphalt concrete (**AC**) 18 cm thick, with a grid such as Hatelit to delay reflection of cracks and joints.
- A cost comparison and a detailed distress survey were recommended.
- For traffic reasons, widening to 3 lanes was already needed, with a pavement section shown in Fig. 4

5. THE 1986 SURVEY

5.1 High-performance Surveys

Microtexture was measured with a Sideways Coefficient Routine Investigation Machine (**SCRIM**), according to Standard **NLT-336/92.** Table 1 shows the results, which can be deemed as very acceptable.

5.2 Test Cores

In four zones of the right lane of both carriageways, 25 149-mm diameter test cores were taken, from slabs having a distress level above 75 % of a defined range (of which only 5 had a deflection above 20/100 mm); also 2 cores were taken from slabs in good condition. Cores were tested by both non-destructive and destructive methods.

The results were:

- Average concrete thickness: 26.0 cm
- Average **CTB** thickness: 15.3 cm
- Average concrete density: 2.39 kg/dm^3
- Average **CTB** density: 2.31 kg/dm^3
- In 16 out of the 25 cores, the **CTS** could not be recovered. The rest show a good condition, with an average split-test strength of 260 KPa.
- **CTB** cores also show a non-eroded (more than 5 % cement contents), good condition, with an average split-test strength of 2.0 MPa.
- Concrete cores have a high and uniform split-tensile strength, averaging 2.8 MPa. Flexural strength required was 4.4 MPa. Average compression strength of cores was 27 Mpa, while the design strength was 29.4 MPa.

5.3 Visual Inspection

On a slab-by-slab basis, all 1,021 slabs of each right-hand lane were inspected; main distresses were photographed, and both slabs and transverse joints were rated according to the following system, depicted in Figs. 5 and 6.

5.3.1 Joint Ratings

A three-digit number was assigned to each joint:

5.3.1.1 **First Digit: Joint Soundness**

1) Seal in good condition; moderate, shallow edge spalling; longitudinal cracks less than .5 mm wide.
2) Moderate loss of adherence of sealing material. Moderate or strong surface crazing. Possible first stages of deep spalling in wheelpaths. Longitudinal cracks up to 1.0 mm wide.
3) Loss of adherence of sealing material; intensive edge spalling: longitudinal cracks up to 1.0 mm wide, clearly above the dowels.
4) Joints of types 2) or 3) above, showing a deep spalling in one or both wheelpaths, or transverse cracks joining the longitudinal ones over the dowels.
5) Last stage of distress of type 3) joints, with longitudinal cracking over the dowels, transverse cracking and deep spalling in wheeltracks.
6) Type 4) joint in which the deep spalling is extended all along the joint, with a generalized transverse cracking, or totally repaired or patched, in a bad condition.

5.3.1.2 **Second digit: Cracks:** **0)** Uncracked.

1) Longitudinal cracks within dowel length, i.e. 25 cm from joint.

2) Longitudinal cracks grow from wheeltracks towards the slab center. These cracks can be wider (up to 1.5 mm) and shows spalls.

5.3.1.3 **Third digit: Repairs:** **0)** Unrepaired joint

1) Repaired joint

5.3.2 Slab ratings

Seven ratings were given to slab condition, according to the following:

1. No cracks, or spall-less fine cracks (< .5 mm) with a grid at a less than 120° angle.
2. Surface cracks up to 1.0 mm wide with spalls, mostly at the wheelpaths. Maximum number 4, maximum length 3 m.
3. Surface cracks up to 1.5 mm wide with spalls, mostly at the wheelpaths. Maximum number 8.
4. Surface cracks up to 2.0 mm wide with overall spalling. Maximum number 12. Also serpentine cracks affecting total slab length, mostly at the wheelpaths. Also slabs showing transverse cracks (up to 1.0 mm wide) going from the edge or longitudinal joint to the nearest wheelpath.
5. Overall map cracking, less than 2.0 mm wide.
6. One transverse, longitudinal or diagonal structural crack, block breakaway, or repair in bad condition.
7. More than one of the distresses of type 6).

5.4 Recommendations

After the survey, it was recommended to:

- Repair slabs of the types 6) and 7), and joints of the types 4), 5) and 6),
- Widen the carriageway to 3 lanes, and overlay both the widening and the existing **JPCP** pavement with another 26 cm of **JPCP**, with transverse joints at 5 m intervals.

However, this project did not go ahead, and after 6 more years it was deemed necessary to update it, beginning with a new condition survey carried out in February, 1994 using the same ratings as the 1986 one.

6. THE 1994 SURVEY

6.1 Evolution of Distress in Joints

In Fig. 7 a comparison is shown of 1988 and 1994 joint condition ratings, including also the results of the 1996 survey mentioned later in this Paper.

The main conclusions of the 1994 survey were:

- Most of the type 1) joints had evolved towards types 2) and 3).
- Most joints fall into types 2) or 3). Many of these latter are on the brink of becoming type 5).
- Type 4) joints have evolved from type 2) joints in which material loss has been noticeable; **AC** patches have given poor results.
- Type 5) distress, although important, does not amount to a significant percentage of slabs. Also, type 6) seems rather stabilized..
- Cracking has progressed from 0) to 2), under the combined effect of traffic loads and the structural distress of the pavement.

6.2 Evolution of Distress in Slabs

In Fig. 8 a comparison is shown of 1988 and 1994 slab condition ratings, including also the results of the 1997 survey mentioned later in this Paper.

The main conclusions of the 1994 survey were:

- Most type 3) slabs have evolved to type 4).
- Many type 4) slabs are on the brink of becoming type 5).
- At the pavement ends, and also over some drainage ducts (80 cm diameter), some serious distresses have appeared, generally linked to poor drainage

7. STUDY OF SOLUTIONS

7.1 Pavement widening

Construction problems can be alleviated by shifting all traffic to one carriageway while working in the other. Therefore, the widening of the existing pavement must be of a quick construction, able to carry heavy traffic, and compatible with the overlay.

7.2 Overlay

Six solutions, ranging from no overlay to a **CRCP** one, have been considered for the overlay; their description and expected life are shown in Table 2.

7.3 Repairs to the Existing Pavement

For each of the six overlay solutions, repairs to the existing **JPCP** are progressively less needed as the the overlay is thicker. In Table 3 these repairs are described and their cost estimated.

7.4 Economic Analysis

Since it is not fair to compare solutions the life of which ranging from 10 to 35 years, an economic analysis (see Table 4) has been carried out over a 30-year life cycle, bearing in mind that:

- **#1** can only be an initial solution.
- **#3** can only be an initial solution, or follow inmediately **#1**.
- There are two bridges which must be jacked up before any substantial overlay thickness can be placed
- Delays to traffic (daily average 115,000, 10 % trucks) caused by shifting it to only one carriageway must be taken into account, estimating job duration and average delay.

8. FINAL CHOICE

After the above described economic analysis, solution **#6** (24 cm **CRCP** overlay), depicted in Fig. 9, has been chosen, after the following considerations:

- Solutions **#1** and **#2**, no entailing any structural strengthening of the existing pavement, could pose a problem.
- About solution **#3** (bonded concrete overlay) there is no experience in Spain.
- Economic differences amongst the other three solutions are non-relevant.

Traffic management measures to maintain lane number are shown in Fig. 10.

9. PRESENT SITUATION

Bid for the widening, repair and overlay job has been awarded in late 1996, and works should start in the spring of 1997.

A further survey of the state of the slabs and joints has been carried out in early 1997, the results of which are included in Figs 7 and 8. A shift in the ratings towards further distress is clearly visible, showing the need for inmediate action.

10. ACKNOWLEDGEMENTS

The author wishes to thank Prof. Carlos Kraemer, of the Madrid Polytechnic for Civil Engineering (at the present moment, on a commission to the Valencia one); Dr. Carlos Jofré, of the Spanish Cement Institute (**IECA**), for their assistance in the earliest surveys and strategies; Dr. José Luis Elvira, Deputy Road Technology Director at the Highway Authority of the Spanish *Ministerio de Fomento*, for valuable advice and assistance; and Prof. Sandro Rocci, of Vigiconsult S.A., for establishing the project documents and the assistance in the preparation of this Paper.

TABLE TITLES

TABLE 1 Percentage of Pavement having Friction Coefficients Larger than those shown

TABLE 2 Solutions for Overlaying the Existing Pavement

TABLE 3 Needed Repairs to Existing Pavement

TABLE 4 Life-cycle strategies

TABLE 1 Percentage of Pavement having Friction Coefficients Larger than those shown

	Right carriageway		Left carriageway	
Friction Coefficient	Left lane	Right lane	Left lane	Right lane
.50	-	-	-	98
55	-	98	-	-
60	-	-	96	
65	99	-	-	-

(-) Missing data

TABLE 2 Solutions for Overlaying the Existing Pavement

Number	Description	Thickness (cm)	Cost[1] (1995 million pesetas)	Life (years) to next rehabilitation
#1	Intensive repair	0	0	10
#2	Bituminous surface rehabilitation	8	140	10
#3	Bonded concrete overlay	10	151	20
#4	**AC** overlay	16	306	20
#5	**JPCP** overlay	28	528	30
#6	**CRCP** overlay	24	634	35

[1] Including overlay of outer shoulder

TABLE 3 Needed Repairs to Existing Pavement

		Slab repairs		Joint repairs			
Solution	Cold milling[1]	Min. rating	Number	Min. rating	Number	Sealing	Cost[2]
#1	Surface	4	1,436	4	857	Type 2	122
#2	Yes	5	282	4	857	Type 2	96
#3	Deep[3]	5	112	5	351	Type 2	57
#4	Deep[3]	5	112	6	97	No	21
#5	None	6	94	6	97	No	17
#6	None	6	94	6	97	No	17

[1] 93,000 m^2

[2] 1995 million pesetas

[3] 4 cm

TABLE 4 Life-cycle strategies

		Following rehabilitation			
		First		Second	
Strategy No.	Initial solution	Type	Year	Type	Year
A	#1	#2	10	#2	20
B	#1	#2	10	#4	20
C	#1	#2	10	#5	20
D	#1	#2	10	#6	20
E	#1	#3	10	+	*
F	#1	#4	10	+	*
G	#1	#5	10	+	*
H	#1	#6	10	+	*
I	#2	#2	10	#2	20
J	#2	#2	10	#4	20
K	#2	#2	10	#5	20
L	#2	#2	10	#6	20
M	#2	#4	10	+	*
N	#2	#5	10	+	*
O	#2	#6	10	+	*
P	#3	#2	20	+	*
Q	#3	#4	20	+	*
R	#3	#5	20	+	*
S	#3	#6	20	+	*
T	#4	#2	20	+	*
U	#4	#4	20	+	*
V	#4	#5	20	+	*
W	#4	#6	10	+	*
X	#5	+	*	+	*
Y	#6	+	*	+	*

(+) Not necessary

(*) Not applicable

FIGURE CAPTIONS

Fig. 1 Existing Pavement

Fig. 2 Compressive Strength of Concrete of Existing Pavement

Fig. 3 Flexural Strength of Concrete of Existing Pavement

Fig. 4 Pavement Widening

Fig. 5 Slab Rating System

Fig. 6 Transverse Joint Rating System

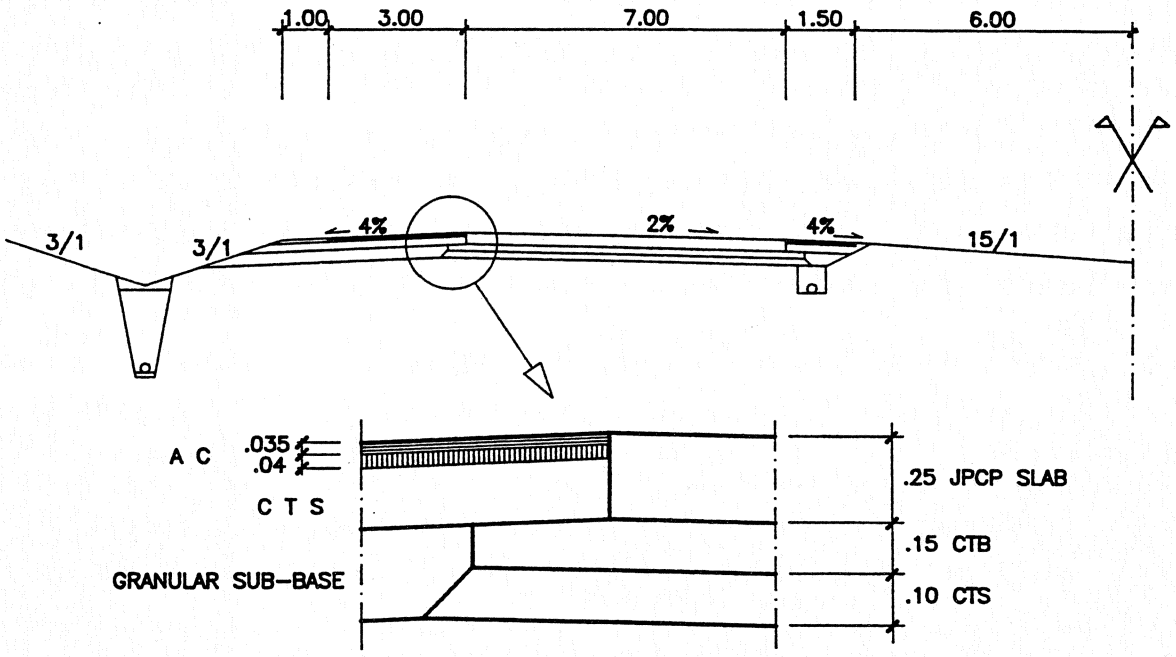
Fig. 7 A Comparison of Joint Condition 1988 - 1997

Fig. 8 A Comparison of Slab Condition 1988 - 1997

Fig. 9 Chosen Widening and Overlay Solution

Fig. 10 Traffic Management During Construction

Fig. 1 Existing Pavement



(Figures shown are in meters)

Fig. 2 Compressive Strength of Concrete of Existing Pavement

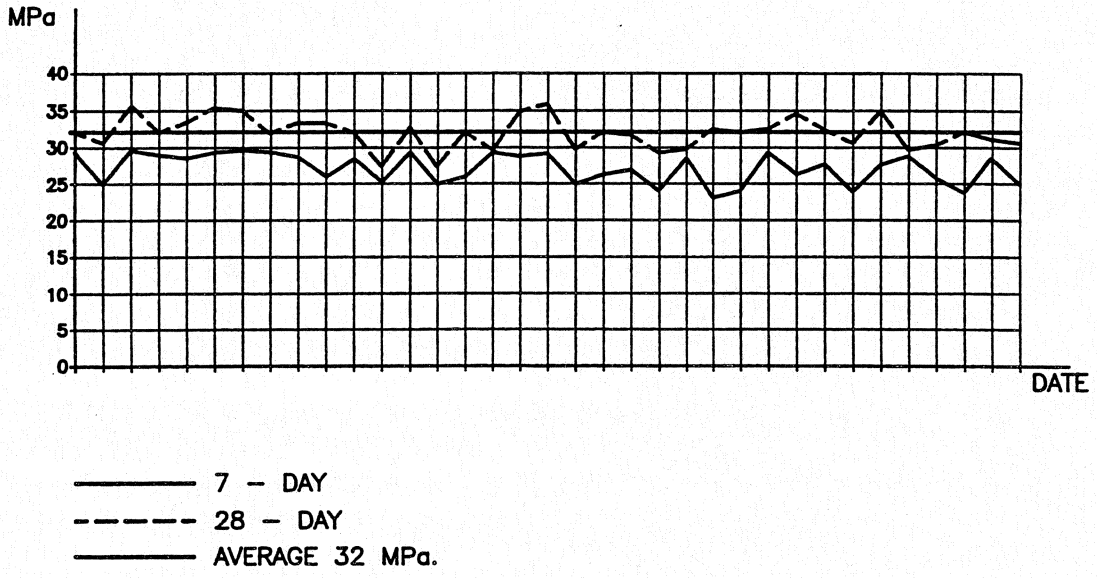


Fig. 3 Flexural Strength of Concrete of Existing Pavement

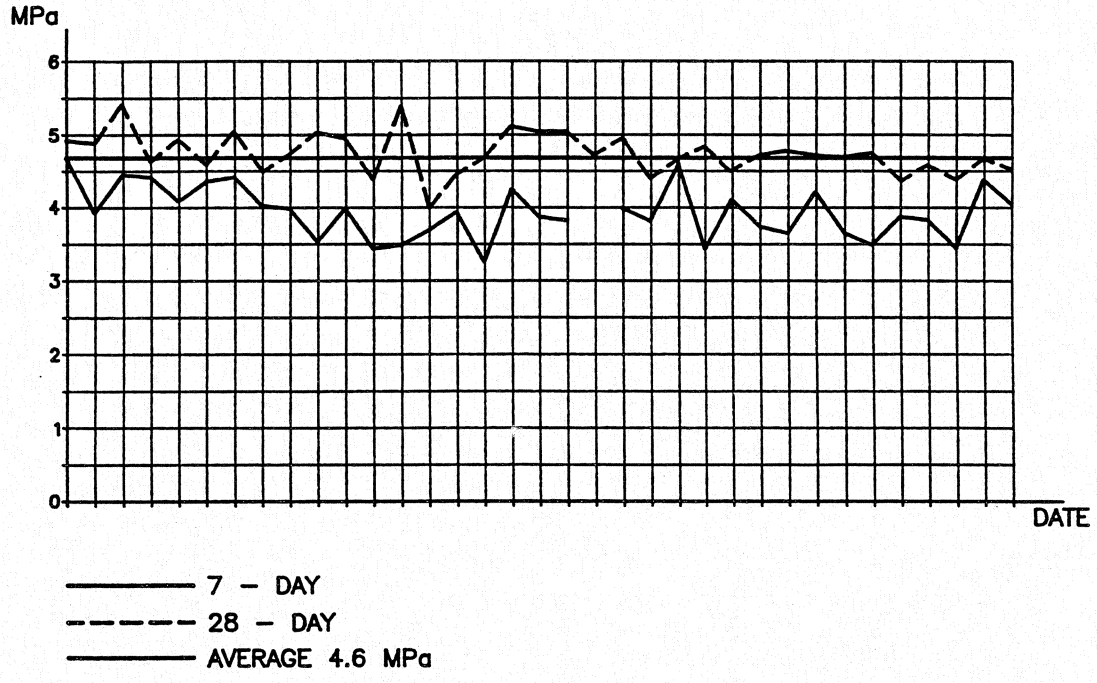


Fig. 4 Pavement Widening

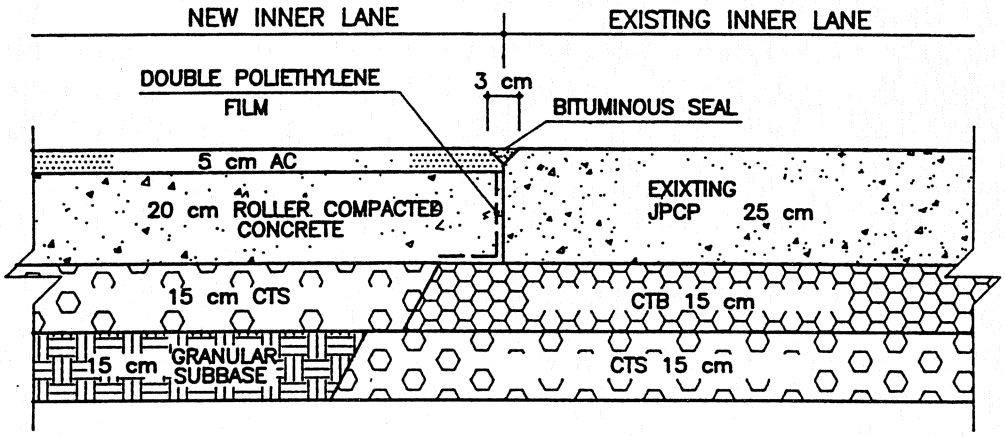
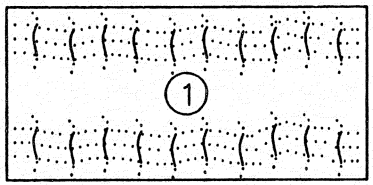
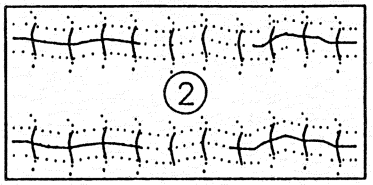


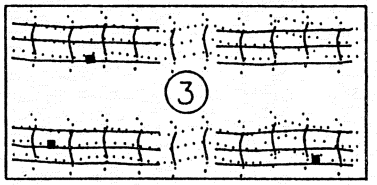
Fig. 5 Slab Rating System



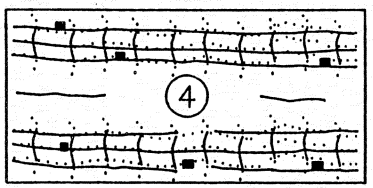
FINE GRID CRACKS



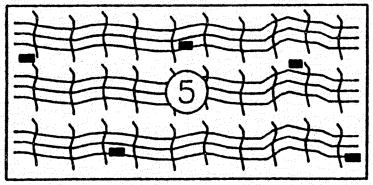
< 1mm IN WHEELPATHS
< 2m



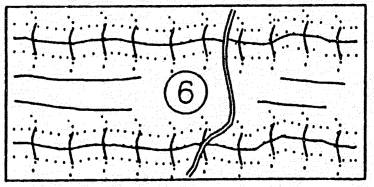
< 1.5mm IN WHEELPATHS.
SPALLS



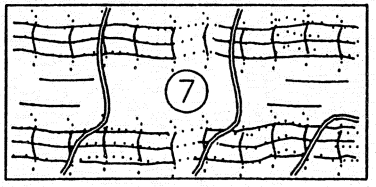
< 2mm, SERPENTINE CRACKS,
MOSTLY IN WHEELPATHS,
OVERALL SPALLING



OVERALL GRID CRACKING
< 2mm

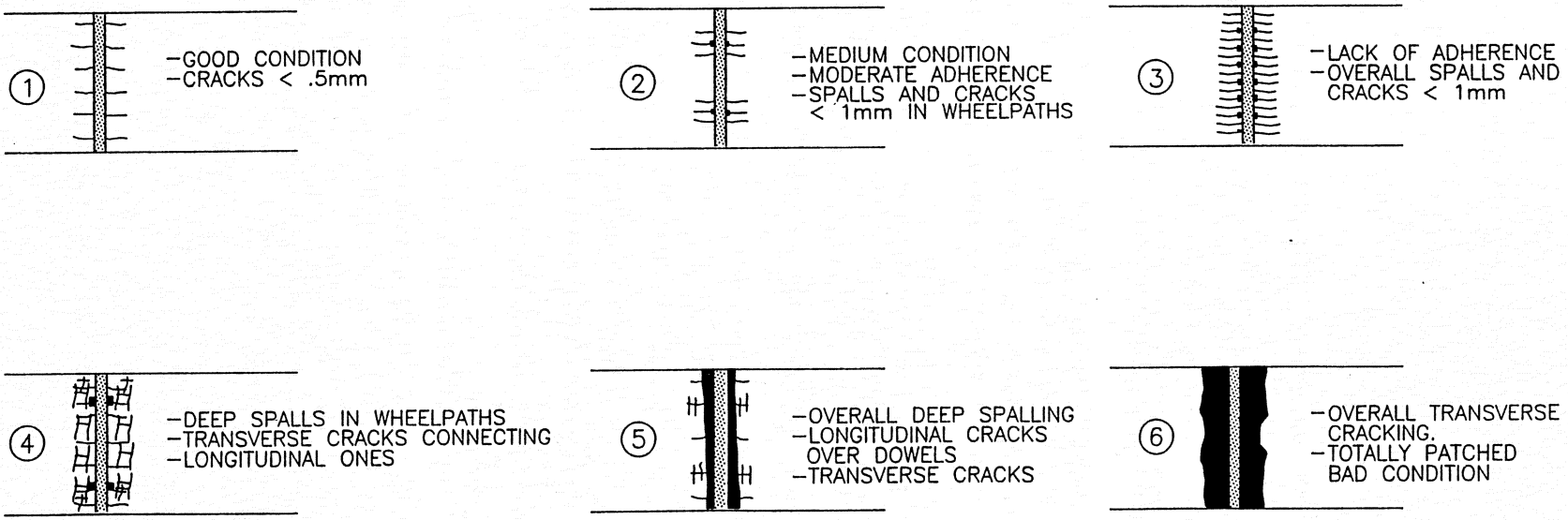


ONE STRUCTURAL CRACK.
REPAIR IN POOR CONDITION



MORE THAN ONE
STRUCTURAL DISTRESS

Fig. 6 Transverse Joint Rating System



0: UNCRACKED

1: LONGITUDINAL CRACKS 25cm TO EITHER SIDE

2: CRACKS PROGRESS TOWARDS SLAB CENTER

0: UNREPAIRED OR REPAIR IN GOOD CONDITION

1: REPAIR IN BAD CONDITION

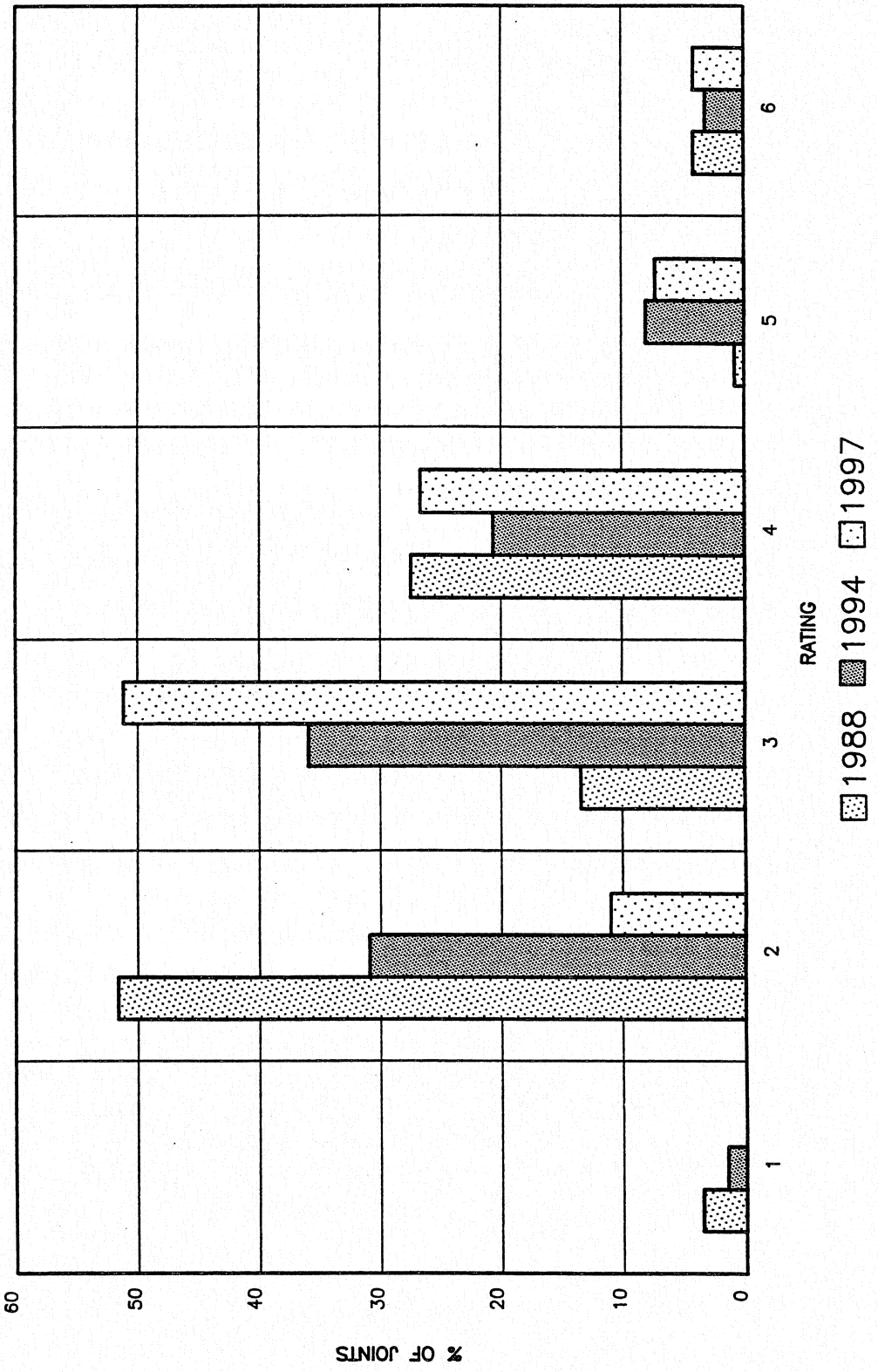


Fig. 7 A Comparison of Joint Condition 1988 - 1997

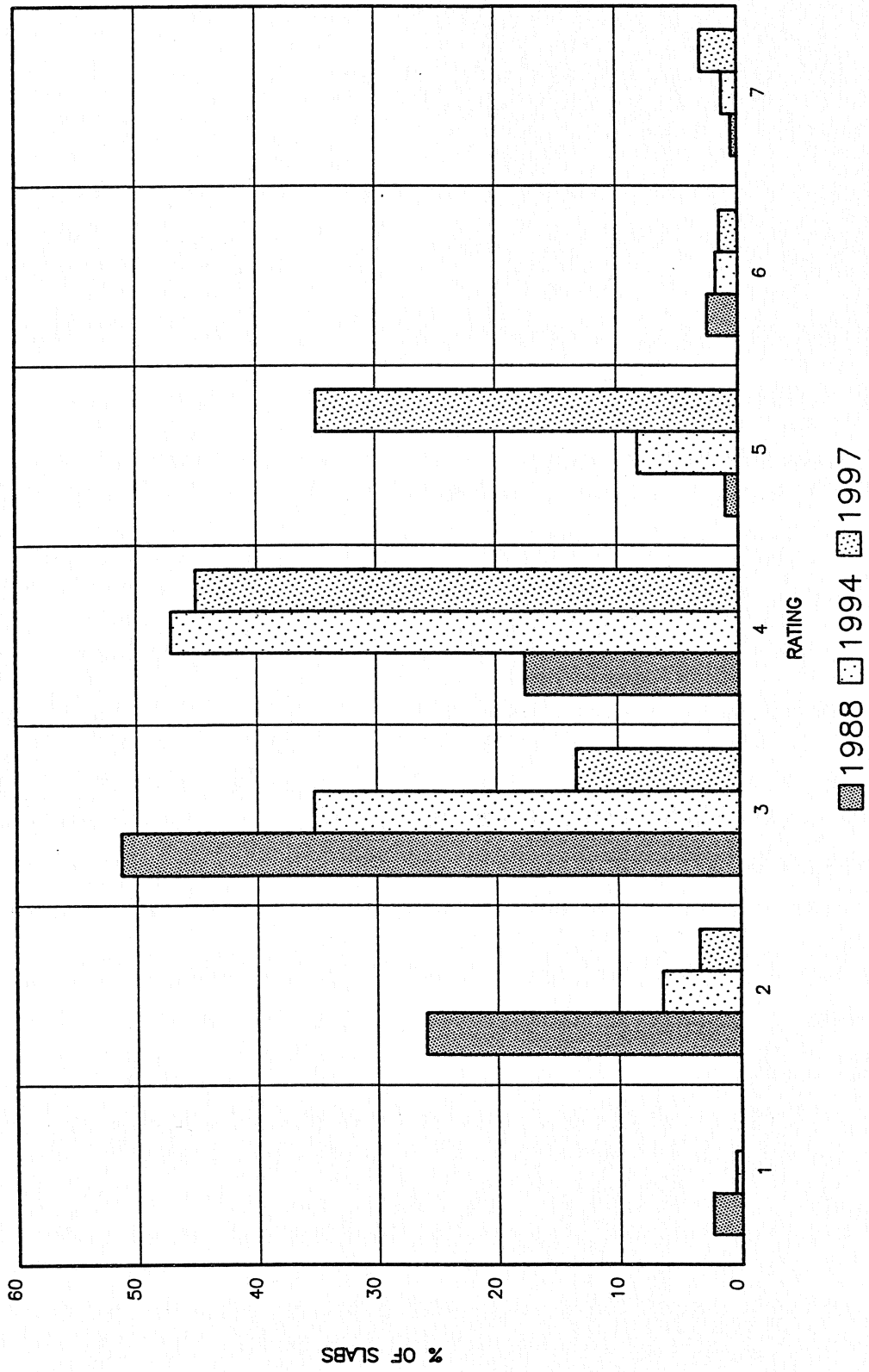
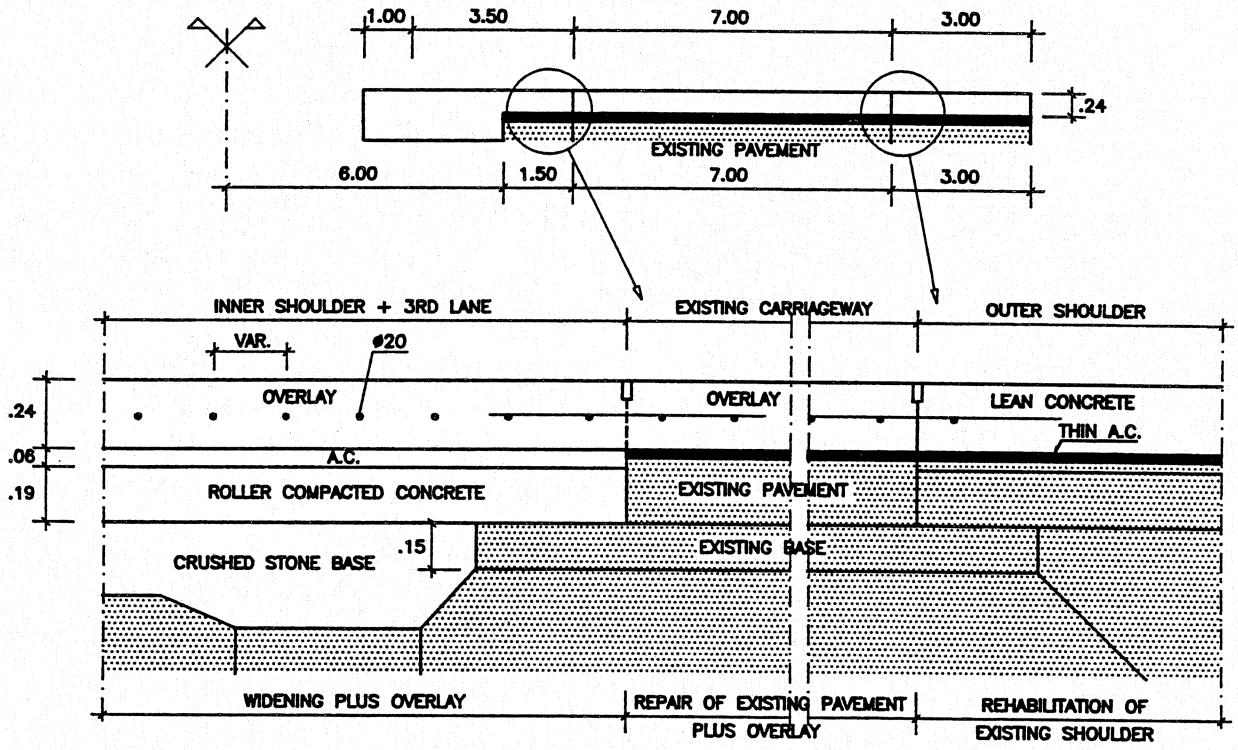


Fig. 8 A Comparison of Slab Condition 1988 - 1997

Fig. 9 Chosen Widening and Overlay Solution



(Figures shown are in meters)

Fig. 10 Traffic Management During Construction

