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DEFLECTION CRITERIA FOR CONCRETE PAVEMENT STRUCTURAL DESIGN AND EVALUATION

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This paper focuses on a mechanistic-empirical analysis procedure to develop the deflection criteria for concrete pavement structural design and rehabilitation alternatives. By calibrating of existing concrete pavement standard structures with FEM analysis, the allowable design deflection values are proposed according to traffic classification and critical load position. Next, the critical deflection criteria for concrete pavement rehabilitation are recommended, which are based on the concept of erosion damage analysis and the investigation of FWD deflections measured from in-service concrete pavements.

Key Words: *jointed concrete pavement, allowable deflection, erosion damage, critical condition*

1. INTRODUCTION

Concrete pavement designs are generally done by flexural stress analysis to avoid fatigue cracking. However, in addition to fatigue cracking, the in-service concrete pavements also have many other types of distress such as pumping, joint faulting and corner breaking[1),2)]. Apparently, most of those distresses are more closely relevant to pavement deflections rather than flexural stresses. It is also recognized that limiting deflections of the pavement system is essential to improve its performance, especially for heavy traffic highway. Compared with slab edge stress, critical deflection occurs at the slab corner load case, which is mainly affected by foundation moduli, joint load transfer efficiency, as well as slab thickness. Therefore, deflection criteria may be used effectively for comprehensive design of slab-foundation-joint system. On the other hand, FWD has been widely used for pavement evaluation recently. As deflection criteria be added into pavement design procedure, there will be consistent criteria for new construction pavement design, in service pavement evaluation and rehabilitation design.

As early as 1960s, AASHO Road Test demonstrated that deflections were well related to pavement performances by their influence on pumping[1)], as following:

For slab edge load $\log W_{2.5}=5.18-3.15\log d_e$ (1)

For slab corner load $\log W_{2.5}=5.57-3.29\log d_c$ (2)

Where: $W_{2.5}$ = number of accumulated wheel load until pavement reaches the present serviceability index of 2.5; d_e and d_c = slab edge and corner static deflection (mm) corrected to a constant temperature condition, respectively. However, these equations did not included pavement structural parameters. They might be only suited for the conditions of AASHO Road Test, for example, the pavement structure and environment.

In 1984 PCA Design Specification[3)], the erosion criterion is included in pavement design procedure, in addition to the traditional fatigue analysis. The concept of erosion analysis was based on a great number of pavement performance data (including AASHO test in 1960s and in-service pavements in 1970s), as well as slab corner deflections computed from FEM. PCA's studies indicated that to predict pavement performances, different values of deflection criteria would be applied to different slab thickness, and to a small extent, different foundation moduli. Following useful correlation was obtained by multiplying the computed corner deflection values with computed pressure values at the slab-foundation interface:

$$\log N = 14.524 - 6.777(c_1 p - 9.0)^{0.103} \quad (3a)$$

$$p = power = 268.7 \frac{k^{1.27} d_c^{\ 2}}{h} \quad (3b)$$

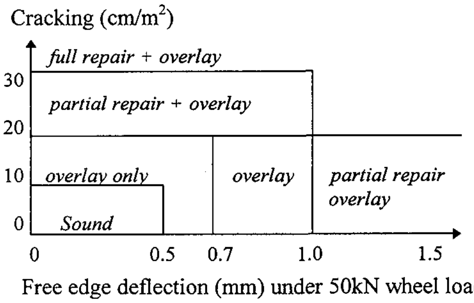


Fig.1 Rehabilitation alternatives (JRA-1978)

where: k=foundation reaction modulus (pci), h=slab thickness (inch), d_c=slab corner deflection (inch), N=allowable load repetitions to end of design period, and c_1= adjustment factor of base type, which is 1.0 for untreated base and 0.9 for stabilized base.

In 1996 JSCE Concrete Pavements Design Specification[4)], deflection criterion was directly recommended. The suggested allowable deflection values were introduced from ACI Committee Report of prestressed concrete pavement[5)], as following:

For highway pavement (under 90kN of vehicle single axle load), allowable free edge deflection $[d_e]$ was 0.75mm; and for airfield pavement (under 712kN of aircraft tandem axle load), allowable slab interior deflection $[d_i]$ was 1.25mm.

However, for prestressed slab, the failure load is much higher than that produces the first crack at the bottom of the slab. Meanwhile, the slab thickness of prestressed concrete pavement suggested by ACI is only 60%~65% of the thickness of conventional jointed concrete pavement.

As for pavement evaluation and overlay design, in Japan Road Association's pavement maintenance manual[6)], it is recommended that rehabilitation methods could be selected on cracking index and free edge deflection measured by Benkelman beam (BB), as shown in **Fig.1**. It can be found that the free edge deflection de<0.7mm is one of the critical condition for rehabilitation alternatives.

When using asphalt overlay on jointed concrete pavement, the Asphalt Institute (AI) Rehabilitation Manual[7)] also suggested that the differential deflection (under 98kN of single axle load measured by BB) at the joints should be d_1-d_2<0.05mm, and the mean deflection should be $(d_1+d_2)/2<0.36$ mm, in which d_1 and d_2 refer to deflections in the loaded and unloaded slabs, respectively. In case of such criteria are not met, foundation stabilization and undersealing are required.

Finite element modeling of edge and corner load case indicated that[8),9)] total edge and corner deflection, (d_1+d_2), remains a relative constant, regardless of available joint load transfer efficiency, and d_1+d_2 is approximately equal to d_{free} (free edge/corner deflections). Utilizing this concept, the mean deflection criterion of AI could be rewritten as:

$$\text{At joints edge} \quad (d_1+d_2)/2<0.36\text{mm} \qquad (4)$$

$$\text{At free edge} \quad d_{free} \approx d_1+d_2<0.72\text{mm} \qquad (5)$$

It can be found that AI and JRA have a similar rehabilitation deflection criterion as following: the free edge deflection under 100kN (or 98kN) single axle load should be d_{free}<0.70~0.72mm. These criteria were developed from Westergaard deflection equation and a lot of Benkelman beam test data, meaning that high deflections (e.g., d_{free}>0.72mm) identify loss of support or void beneath concrete slab.

Above literature review revealed that JSCE's allowable deflection values appear too high for pavement design, and more research is needed in this area. This paper focuses on a mechanistic-empirical analytical procedure to discuss the suitable deflection criteria for jointed concrete pavements structural design and rehabilitation.

2. ANALYSIS OF JOINTED CONCRETE PAVEMENT DEFLECTION

(1) Standard axle load and critical load positions

For concrete pavement deflection analysis, the following standard loads were selected in this study: a) FWD single circular load 50kN, load circular radius a=15cm; b) Single axle load 100kN, wheel distance L=1.9m; c) Tandem axle load 200kN, wheel distance L=1.9m, axle distance B=1.3m.

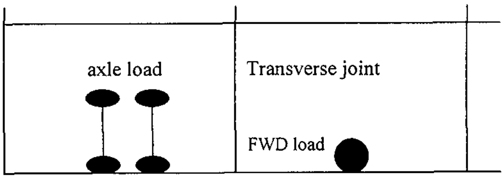
According to FEM analysis results [8),9)] and PCA's studies[3)], the most critical pavement stresses occurred while the truck wheels are placed at or near the pavement edge and midway between the joints, and the most critical pavement deflections occurred at the slab corner while an axle load is placed at the joint with the wheels at or near the corner. Otherwise, because asphalt shoulder is generally used in Japan[10)], the pavement slab can be modeled as a longitudinal free slab, as shown in **Fig.2**.

Table 1 Pavement deflections under slab corner loading case (when transverse joint load transfer efficiency E_w=0)

slab thickness h, cm	deflec-,mm / load	Foundation reaction moduli k_{75}-values, kg/cm^3						
		3	5	7	10	12	15	18
20	a	1.91/1.61	1.42/1.18	1.17/0.96	0.95/0.76	0.85/0.68	0.74/0.59	0.67/0.52
	b	2.16/1.87	1.55/1.31	1.24/1.03	0.98/0.80	0.87/0.71	0.76/0.60	0.67/0.53
	c	2.71/2.41	1.84/1.61	1.43/1.23	1.10/0.93	0.96/0.80	0.82/0.67	0.72/0.58
23	a	1.59/1.37	1.19/1.01	0.98/0.82	0.80/0.65	0.72/0.58	0.63/0.51	0.56/0.45
	b	1.88/1.64	1.34/1.15	1.07/0.91	0.85/0.71	0.76/0.62	0.65/0.53	0.58/0.47
	c	2.45/2.20	1.67/1.47	1.29/1.13	0.99/0.85	0.86/0.74	0.73/0.62	0.64/0.53
25	a	1.43/1.24	1.07/0.91	0.88/0.74	0.72/0.60	0.65/0.53	0.57/0.46	0.51/0.41
	b	1.72/1.52	1.23/1.07	0.99/0.84	0.78/0.66	0.69/0.58	0.60/0.50	0.53/0.44
	c	2.31/2.09	1.57/1.40	1.21/1.07	0.93/0.81	0.81/0.70	0.68/0.59	0.60/0.51
28	a	1.23/1.08	0.92/0.79	0.76/0.65	0.62/0.52	0.56/0.47	0.49/0.41	0.44/0.36
	b	1.54/1.37	1.10/0.96	0.88/0.76	0.69/0.59	0.62/0.52	0.53/0.45	0.47/0.40
	c	2.13/1.94	1.45/1.30	1.12/1.00	0.85/0.75	0.74/0.65	0.63/0.55	0.55/0.47
30	a	1.13/0.99	0.84/0.73	0.70/0.60	0.57/0.48	0.51/0.43	0.45/0.38	0.41/0.34
	b	1.43/1.29	1.02/0.90	0.82/0.72	0.65/0.56	0.57/0.49	0.50/0.42	0.44/0.37
	c	2.02/1.85	1.37/1.24	1.06/0.95	0.81/0.72	0.71/0.62	0.60/0.52	0.52/0.45
33	a	1.00/0.89	0.75/0.65	0.62/0.53	0.50/0.43	0.45/0.39	0.40/0.34	0.36/0.30
	b	1.30/1.18	0.93/0.83	0.74/0.66	0.59/0.51	0.52/0.45	0.45/0.39	0.40/0.34
	c	1.88/1.73	1.28/1.17	0.99/0.90	0.76/0.68	0.66/0.59	0.56/0.49	0.49/0.43

*Load type: a--50kN FWD load, b--100kN single axle load, c--200kN tandem axle load; Number at left is the maximum deflections at the most corner point, and number at right is the deflections at load center (distance from corner=15cm).

(a) Slab edge load position



(b) Slab corner load position

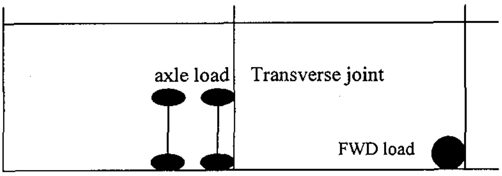


Fig.2 Critical axle load (and FWD load) positions

(2) Pavement deflections computed from FEM

Pavement structures are characterized as a slab on Winkler foundation, in which the standard slab is 10.0m long, 5.0m wide, and the elastic modulus of concrete (Ec) is 3×10^5 kg/cm^2. In the finite element program, the modeling of joint is represented by a shear spring$^{9)}$. To improve the calculation accuracy, the fine mesh (20~30cm) is used near the load, rather coarse mesh (50~70cm) is only used far away from the load. When transverse joint load transfer efficiency E_w=0 (E_w defined as d_2/d_1, where d_2 and d_1 have been defined above), the results of calculated deflections are presented in **Table 1** and **Table 2**. For another E_w-values, the corner deflection in the loaded slab (d_1) can be conveniently obtained by following equation$^{8)}$:

$$d_1 = \frac{d_{(E_w=0)}}{(1+E_w)} \tag{6}$$

Followings are main results deduced from the FEM analysis:

a) Transverse joint load transfer mechanism has a substantial effect on the magnitude of corner deflections, but has very little effect on the deflections at the center of longitudinal free edge;
b) Pavement stress is mainly depended on slab thickness, and on a small extent of foundation moduli (k-values), but pavement deflection is heavily influenced by k-values;
c) The maximum stress caused by tandem axle load may be greater or smaller than that caused by single axle load, but maximum deflection under tandem axle load is constantly greater than which is under single axle load and FWD circular load.

Table 2 Pavement deflections under longitudinal free edge load case

slab thcik-ness h,cm	deflec-,mm load	Foundation reaction moduli k_{75}-values, kg/cm^3						
		3	5	7	10	12	15	18
20	a	0.73/0.65	0.55/0.49	0.45/0.40	0.37/0.32	0.33/0.29	0.29/0.25	0.26/0.23
	b	0.77/0.71	0.56/0.51	0.45/0.41	0.36/0.33	0.33/0.29	0.28/0.25	0.25/0.22
	c	1.24/1.15	0.85/0.78	0.66/0.61	0.51/0.46	0.45/0.40	0.38/0.33	0.33/0.29
23	a	0.60/0.55	0.45/0.41	0.38/0.34	0.31/0.27	0.28/0.24	0.25/0.21	0.22/0.19
	b	0.67/0.62	0.48/0.44	0.39/0.35	0.31/0.28	0.28/0.25	0.24/0.22	0.22/0.19
	c	1.12/1.05	0.76/0.71	0.60/0.55	0.46/0.42	0.40/0.36	0.34/0.31	0.30/0.27
25	a	0.54/0.49	0.41/0.37	0.34/0.30	0.28/0.25	0.25/0.22	0.22/0.19	0.20/0.17
	b	0.62/0.58	0.44/0.40	0.35/0.32	0.28/0.26	0.25/0.23	0.22/0.20	0.20/0.18
	c	1.05/0.99	0.72/0.67	0.56/0.52	0.43/0.39	0.38/0.34	0.32/0.29	0.28/0.25
28	a	0.47/0.43	0.35/0.32	0.29/0.26	0.24/0.21	0.22/0.19	0.19/0.17	0.17/0.15
	b	0.55/0.52	0.39/0.36	0.31/0.29	0.25/0.23	0.22/0.20	0.19/0.17	0.17/0.16
	c	0.97/0.91	0.66/0.62	0.51/0.48	0.39/0.36	0.34/0.32	0.29/0.27	0.25/0.23
30	a	0.43/0.39	0.32/0.29	0.26/0.24	0.22/0.20	0.20/0.18	0.17/0.15	0.16/0.14
	b	0.52/0.49	0.36/0.34	0.29/0.27	0.23/0.21	0.20/0.19	0.18/0.16	0.16/0.14
	c	0.92/0.87	0.62/0.59	0.48/0.45	0.37/0.35	0.32/0.30	0.28/0.25	0.24/0.22
33	a	0.38/0.35	0.28/0.26	0.23/0.21	0.19/0.17	0.17/0.16	0.15/0.14	0.14/0.12
	b	0.48/0.46	0.33/0.31	0.26/0.25	0.21/0.19	0.19/0.17	0.16/0.15	0.14/0.13
	c	0.86/0.82	0.58/0.55	0.45/0.42	0.35/0.32	0.30/0.28	0.26/0.24	0.22/0.21

* Load type: a--50kN FWD load, b--100kN single axle load, c--200kN tandem axle load; Number at left is the maximum deflections at the most edge, and number at right is the deflections at load center (distance from slab edge=15cm).

Table 3 Concrete pavement standard structural parameters for each traffic classification[10)]

Traffic Classification	Design traffic volume N_{20} (10^6)	Slab thickness h(cm)	Reaction modulus k_{75} (kg/cm^3)	Slab size L×B (m×m)	Transverse joint	Shoulder type
L-traffic	<0.7	15	≥ 6.0	10.0 ×5.0	dowel joint	asphalt
A-traffic	0.7~1.8	20	≥ 6.0	10.0×5.0	dowel joint	asphalt
B-traffic	1.8~7.3	25	≥ 8.0	10.0×5.0	dowel joint	asphalt
C-traffic	7.3~22	28	≥ 8.0	10.0×5.0	dowel joint	asphalt
D-traffic	>22	30	≥ 8.0	10.0×5.0	dowel joint	asphalt

*The design traffic volume is the accumulated heavy vehicles of 20 years design period.

3. ALLOWABLE DEFLECTIONS FOR JOINTED CONCRETE PAVEMENT STRUCTURAL DESIGN

(1) Calibration of existing standard structures

a) Standard structures & performances

The existing concrete pavement design method[10)] is a mechanistic-empirical design procedure, for 20 years design life, the standardization structural parameters are presented in **Table 3**.

With regard to the validity of existing standard structures, the current field investigation conducted by Public Works Research Institute[11)] indicated that: (1) In Japan, all most of concrete pavements are in excellent structural conditions, the average cracking index is below than 5cm/m^2 for 15~25 years of heavy traffic load; (2) Only some of 20cm slabs (for A traffic pavements) have cracking index above than 10cm/m^2. These results demonstrated that the existing standard pavement structures are reliable and quite adequate.

b) Allowable design deflection values at slab corner and longitudinal free edge

For above standard structural design parameters, the deflections under standard loads (see **Fig.2**) were comprehensively analyzed with FEM program. The calibration longitudinal free edge critical design deflection values for each traffic classification are summarized in **Table 4**. As for slab corner load case, transverse joint load transfer efficiency (E_w) has a significant effect on corner deflections. According to the summarized test data of reference 4), here consider E_w=d_2/d_1= 75~80% as the design values at corner loading case, the corner allowable deflections from FEM results are presented in **Table 5**.

Table 6 Slab corner erosion damage estimated from PCA erosion equations

Traffic classification	Heavy vehicle volume N_d (10^6)	Allowable number of standard axle loads (10^6)		Percentage of erosion damage (%)
		Single axle N_s	Tandem axle N_t	$C_2(0.75N_d/N_s+0.25N_d/N_t)$
A	0.7~1.8	0.25	0.1	23~59
B	1.8~7.3	4.0	0.63	6~26
C	7.3~22	unlimited	2.0	6~17
D	22~50	unlimited	4.0	8~19

*C_2 is the lateral distribution factor of heavy vehicles, for pavement without concrete shoulders C_2=0.06.

Table 4 Longitudinal free edge allowable design deflections

Traffic class-	d_{FWD} (mm)	d_S (mm)	d_T (mm)
A	0.40	0.41	0.61
B	0.30	0.32	0.52
C	0.26	0.29	0.48
D	0.24	0.27	0.45

Table 5 Slab corner allowable design deflections

Traffic class-	d_{FWD} (mm)	d_S (mm)	d_T (mm)
A	0.54	0.59	0.70
B	0.42	0.48	0.62
C	0.36	0.44	0.58
D	0.33	0.41	0.49

*d_{FWD}--deflection under 50kN FWD load, d_S--deflection under 100kN single axle load, d_T --deflection under 200kN tandem axle load.

(2) Comparison with PCA erosion criteria

As indicated earlier, the 1984 PCA erosion criteria correlated well to a wide range of the in-service performance data, with which the reasonableness of the proposed allowable deflection values can be examined. The PCA erosion analysis is based on Miner's law using actual single and tandem loads3). On the national highways of Japan, the single axle trucks are approximately 75%, most of others are tandem axle trucks12), however, the investigated vehicle loads were usually considered as the wheel loads13), with no actual distribution of axle loads presented. For above standard structural parameters and the suggested corner allowable deflection values, the slab corner erosion damage under standard axle loads computed from PCA equations (3) & (4) are summarized in **Table 6**.

It can be noted that for pavements carrying a normal mix of axle weights, tandem axle loads usually control the slab corner erosion damage. The estimated erosion damages of each traffic classification are all less than 100%, means that the suggested allowable deflections are adequate to control erosion distress.

It should be indicated that the erosion damage of **Table 6** was obtained on the simple hypothesis that the heavy vehicles are all have the standard axle loads with 75% single- and 25% tandem-axle. Actually, the investigated average axle loads were only 52kN for single- and 95kN for tandem-axle12), so that, the potential erosion damage should be much less than that of **Table 6**.

4. FWD DEFLECTION CRITERIA FOR PAVEMENT STRUCTURAL EVALUATION AND REHABILITATION

(1) Critical deflection values based on the concept of erosion damage analysis

For jointed concrete pavements, the common types of distress are pumping, faulting and cracking, these are all concerned with erosion damage. As the traffic load and age of service increasing, the foundation erosion and joint deterioration increase gradually, thus resulting in greater pavement deflections under edge/corner loading. This damage procedure may be mechanically explained as loss of foundation support and joint load transfer capacity. In 1986 AASHTO Guide14), a factor of loss of support (LS) was suggested to account for the potential foundation erosion, which was considered by diminishing the effective k-value based on the size of void that may develop beneath the slab. For stabilized base material, which being widely used in Japan, the recommended value of LS is 0.0 to 1.0.

In this study, the design k-value is 6~8kg/cm^3, when low severity void is considered as a potential erosion, the effective k-value based on AASHTO LS correction curve is about 3.5kg/cm^3. As for joint transfer efficiency, by comprehensively considering the summarized research results of reference 4) and

Table 7 Critical deflection values under 50kN FWD load for rehabilitation alternatives

Traffic classi-fication	Longitudinal free edge d_f(mm)	Transverse joint edge d_t (mm)	Slab corner d_c (mm)
A	0.63	0.38	0.98
B	0.47	0.28	0.72
C	0.39	0.24	0.61
D	0.36	0.22	0.56

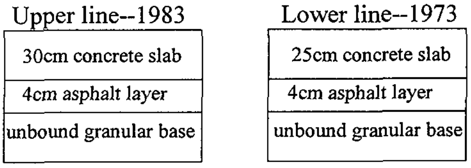


Fig.3 Structures of TB concrete pavements

Table 8 Surveyed results of TB concrete pavements[15)]

50kN FWD deflections and pavement performances data	Upper line	Lower line
Joint edge deflection d_0 (mm)	0.13	0.21
Joint load transfer efficiency E_w	88%	82%
Maintenance condition index MCI	7.2	6.3
Cracking index (cm/m^2)	0.7	2.9
Roughness index (mm)	3.1	4.0
Rutting depth (mm)	10	13

Table 9 Performances of TK concrete pavement[2)]

Average cracking index (cm/m^2) Cracking index of c-box (cm/m^2)	3.1 7.9
Average faulting (mm) Maximum faulting (mm)	5.2 20
Rutting depth (mm)	17

a number of in-service pavement's FWD measurements discussed in the next section, the loss of 10%~15% is assumed as a limited E_w-value for rehabilitation criteria analysis.

According to above mechanistic concept and parameters hypothesis, the critical deflection values computed from FEM are presented in **Table 7**. In practical evaluation procedure, if FWD deflections of the in-service pavement exceed these critical values, rehabilitation (for example, stabilization, underselling and overlay) may be required.

(2) Investigation of FWD measurements

The critical deflection values for concrete pavement rehabilitation suggested in **Table 7** were based on the concept of erosion damage. However, it should be noted that the effective k-values (3.5kg/cm^3) and limited transfer efficiencies are all from empiricism or assumptions. In this section, FWD deflection data measured on in-service pavements will be investigated to examine above rehabilitation criteria.

a) TB concrete pavements

The jointed concrete pavements were constructed in 1973 (lower line lane) and 1984 (upper line lane), concrete slab is 10.0m in length, 5.4m in width, and the cross-sections are shown in **Fig.3**. The concrete pavements have been subjected to D traffic load over 10~20 years, field surveys showed that lighter distresses have occurred at joints and corners (see **Table 8**). For conducting rehabilitation and overlay design, FWD tests were carried out at transverse joint and cracking edge in October 1996, when the air temperature was 20~24°C and the recorded temperature gradient of slab was approximately zero. The average deflection and load transfer efficiency under 50kN FWD load were summarized in **Table 8**.

It can be found that the joint transfer efficiency (measured at center of joint edge, but not corner) seems higher, but the joint edge deflection of lower lane is not much smaller than the suggested critical rehabilitation deflection values (see **Table 7**). In general, these pavement slabs appear in normal support conditions, which may be explained as the contribution of 4cm asphalt interlayer.

b) TK concrete pavement

This concrete pavement was constructed in 1974, which consisted of 30cm concrete slab over 15cm cement treated aggregate base layer. As a result of heavy traffic (D-classification) and environmental conditions more than 20 years, medium severity distresses have occurred on this old existing concrete pavement (see **Table 9**).

Transverse joint edge deflections under 100kN FWD load were measured in October 1994, when the pavement surface temperature was 25~30°C. It can be seen from **Fig.4** and **Table 10** that the loaded edge deflections of a number of joints are large to 0.8mm, and joint load transfer efficiency is as lower as 65%. If consider twice standard deviations, the representative slab edge deflections under 50kN standard load are: drj=($\bar{d}$+2S)/2 =0.32mm for outer lane, and 0.28mm for inner lane, which are much greater than the suggested critical values of **Table** 7. Meanwhile, the deflections on outer lane (heavy traffic lane) are greater than that on inner lane, which indicates that

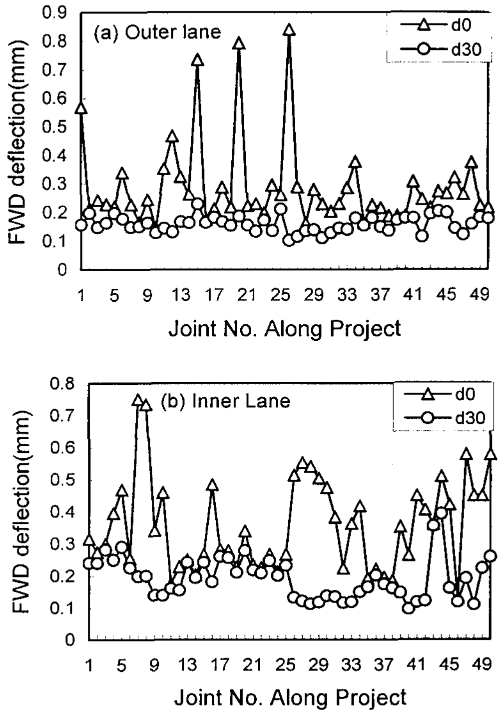


Fig. 4 Transverse joint-edge deflections under 100kN FWD load of TK concrete pavement

Table 10 FWD deflections of TK concrete pavement

FWD measurements under 100kN load	Outer lane		Inner lane	
	$\bar{d}$	S	$\bar{d}$	S
Loaded edge d_0 (mm)	0.36	0.14	0.28	0.14
Unloaded edge d_{30} (mm)	0.20	0.07	0.16	0.03
E_w=d_{30}/d_0	63%	28%	65%	20%

* $\bar{d}$--average value, S--standard deviation

as traffic load increasing, pavement deflections increase. Field destructive survey also shows that the high deflections and low load transfer capacity are caused mainly by loss of foundation support and eroded of dowel bars2). These results demonstrate that the concept of erosion damage used for critical rehabilitation deflection analysis may be feasible.

c) TH and SY concrete pavements

TH concrete pavement was constructed in 1986. The slabs were 25cm thick placed on 15cm cement treated aggregate base course. After 8 years of service, no evidence of distress was occurred on this pavement. At the transverse joint edge, FWD tests were conducted in the morning 9:30~10:30 (October 19,1994), when air temperature was about 20°C.

Table 11 FWD measurements of TH and SY pavements

FWD measurements under 100kN load	TH		SY	
	$\bar{d}$	S	$\bar{d}$	S
loaded edge d_0(mm)	0.45	0.17	0.21	0.10
unloaded edge d_{30}(mm)	0.39	0.16	0.17	0.11
transfer efficiency E_w=d_{30}/d_0	86%	3.6%	74%	14%

* $\bar{d}$--average value, S--standard deviation

SY concrete pavement was built in 1982. The design consisted of 30cm thick concrete slab placed over a 15cm cement treated aggregate base layer. Field surveyed average cracking index was 2.1cm/m^2 after 10 years of D-traffic. The FWD deflections were measured in the afternoon 14:00~15:00 (November 14, 1994, air temperatures were 12~14°C).

It can be observed from **Table 11** that the joint load transfer efficiencies are close to the limited E_w-values. Considering two standard deviations, the representative loaded edge deflections under 50kN load are 0.40mm for TH of 25cm concrete slab, and 0.21mm for SY of 30cm concrete slab. The former is much greater than the corresponded critical rehabilitation deflection, whereas the later are approximately equal to the proposed critical values.

Brief summary: In this section, a number of in-service pavement's FWD measurements were evaluated. These pavements have been serviced for 10~20 years, and some of them are approached critical repair conditions. In general, the representative edge deflections are close to or greater than the suggested critical deflection values. It reveals that the proposed critical deflections based on the concept of erosion damage may be suitable.

5. CONCLUSION

By using mechanistic-empirical analytical method, the allowable deflections for concrete pavement structural design and critical FWD deflection criteria for pavement rehabilitation alternatives were proposed in this study. Compared with the existing design procedure, the proposed deflection criteria can be effectively used.for comprehensive design of slab-foundation-joint system. For example, if the initial slab design is not adequate to control deflection below the allowable value, revisions may be made to the base features and/or load transfer system. However, in the full design procedure, the proposed deflection criteria should be reconsidered by system analyzing the total cost and long term performances.

For the deflection criteria to be of ultimate utility to pavement design procedure, further research is needed to investigate the correlation between FWD deflections and pavement long term performances. Meanwhile, the temperature and temperature gradient within the slab have a significant effect on FWD measurements. This complex influence is also a future research subject.

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コンクリート舗装の構造設計および構造評価のためのたわみ指標に関する一検討

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本研究は，理論的解析手法と経験的評価手法に基づいて，コンクリート舗装の構造設計および維持修繕のためのたわみ指標を検討し，その規準値を提案するものである．供用中のコンクリート舗装版を FEM 解析することによって，許容設計たわみが交通量区分と荷重位置に依存することを明らかにし，そのたわみ値を求めた。また，エロージョンによるダメージ解析と現場で測定した FWD たわみデータに基づいて，維持管理のための指標となり得る限界たわみ値についても検討した．