THE LOSS OF LOAD—TRANSFER CAPACITY AT JOINTS OF AIRFIELD CONCRETE PAVEMENTS UNDER REPETITIVE LOAD

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ABSTRACT

Joints are the weak parts of the airfield concrete pavement structure. When joints are working in better state, they have a fairly high capacity of load transfer. Generally, the load transfer capacity decreases with the increase number of repetition of loads, which leads to the loss of design bearing capacity of pavement. This process is called the loss of load transfer capacity. of joint. This may result the increase of edge stress and then the edge cracks, pumping. Then loss of support will appear. It is important to study deeply the loss of load—transfer capacity for several joints types under repetitive loads, and this is very important for improving the performance and durbility of concrete pavement of airfield. For this purpose, Transportaion Research Institute of Southeast University and China Airport construction company, Guangzhou Branch have made an experimental pavement which has five types of joints and is constructed in circular track road test platform in laboratory of Southeast University. The Falling Weight Deflectometer (FWD) is used to measure the loss of load transfer capacity of joint under loads. Through test and analysis, we have found the relationships of the loss of load transfer capacity of joints and the edge displacement with the loading repctetition numbers. And also the analysis indicates that the dowelled joint and the engaged joint are the best types of joints among the five.

1. INTRODUCTION

As early as 1936, L. W. Teller and E. C. Sutherland have measured the deflections and strains of different types of concrete pavement joints, in Arlington road test in USA and they have evaluated their load transfer capacities. In 1941, they have further indicated some key factors influencing the load transfer capacity of joints such as aggregate type and size; dowel bar type and size; joint width etc. , and also indicated that dowelled joint has the best stability in load transfer capacity [1]. In 1938, based on the research work of R. D. Braudbury, B. F. Fribery made a further study and indicated that it was very important to improve the load transfer capacity of joint by increasing the diameter of dowel bar and decreasing the width of joint. In 1958, based on the results of laboratorial test, L. W. Teller indicated that during the operation of run—way, the wavering of the dowel bar was the main factor of the loss of load tranfer capacity of joint and the repetitve number or load was the main reason of the appearing of this wavering [2].

Considering the analyzing method of stress in jointed concrete pavement with certain load transfer cpacity, Y. H. Huang, and S. T. Wang of Kentucky University and X. J. Deng a Chinese visiting scholar, have developed the finite element analysis program for concrete pavement with multiple slabs and multiple functions. Y. H. Huang and X. J. Deng have presented"A Simplified Method for Analyzing Concrete Pavements Composed of Multipie Jointed Slabs", and Y. T. Chou, EWET, US Army, has developed the programs WESLAYER and WESLIQUID [3],[4],[5], [6]. Although the programs mentioned above are perfect for analysing the load transfer capacity of joints of concrete pavement ,but they can not be used for analysing the loss of it. In fact, the load transfer cpacity is not a constant value. Generally, at the begining , as soon as the road pavement is just completed in construction, the joints have better transfer capacity. After applying a great number of repetitional load, the joint transfer capacity would be

decreased and the decrement of the transfer capacity is dependent on the traffic volume and the exle weight of truck.

The loss of load transfer capacity of joint would lead to increase the working stresses in concrete pavement. It is very important to accurately evaluate the load transfer capacity of joints and working stress of pavement in different periods in the pavement design system and pavement management system.

The purposes of this paper are to discover the relationship between the repetion numbers and the loss of load transfer capacity under the repetive of aircraft wheel in a circular track road test platform, to evaluate the loss of load transfer capacity for five types of joints, to analyze the pavement stress by finite element method and to give for improveing the pavement design method for airfield concrete pavemend in consideration of repetitive load action and the loss of load tranfer capactityof joints.

2. TEST MODEL AND INSTRUMENT

2.1 Circular track road test platform

Circular track road test platform(in Southeast University) is a special instrument for testing the performance under repetive loading. It consists of three main parts: circular road test trough, loading operation system and control system. the depth of circular trough is 200cm, the outside diameter of circular trough is 950cm, the inside diameter is 550cm, and width of the circular test pavement is 200cm. Loading operation system, has two loading arms, at the ends of which, there are two groups of full scale standard wheel load with counter weights. J — 7 type aircraft is adopted as the standard wheel load, a single wheel load of J—7 is 45KN, and the tire pressure of wheel is 1.08MPa. The control system in a special room commands all activeties of test, including start、stop、regulating velocity of load operation system and recording the load repetion numbers automatically.

2.2 Model of structure

To emphasize the differences among all joint types in loss of load — transfer capacity, and identical pavement structure is adopted for all joint types. The first group of test was done from Mar. 29, 1991 to Sept. 23, 1991;and the second one was done from Apr. 24, 1992 to May. 28, 1992. Fig. 1 shows the cross — section of pavement structure for test, the thickness of concrete slab is 20cm, and the thickness of sand cushion is 15cm.

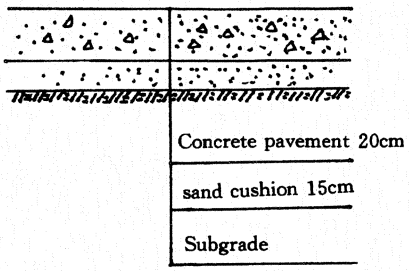


Fig. 1 Pavement structure in circular trough

The circular pavement is divided into 13 uniform sections by 12 joints. Each angle between two nearby joints is 27.5° (Fig. 2), Fig. 3 shows the detail of joint structure. In the first group of test, four joint types, thin and thick key joint, dummy joint and dowelled joint, are adopted. In the second group of test, five joint types are adopoted, thin and thick key joint, dummy joint, dowelled joint and engaged joint. Table 1. shows the serial numbers of different joint types.

Table 1. Number of five kinds of joints

group	dowel	engage	dummy	thin key	thick key
first	7#,8# 9#	—	1#,2# 3#,10# 11#,12#	—	4#,5# 6#
second	5#,6# 7#	8#,9#	10#,11# 12#	3#,4#	1#,2#

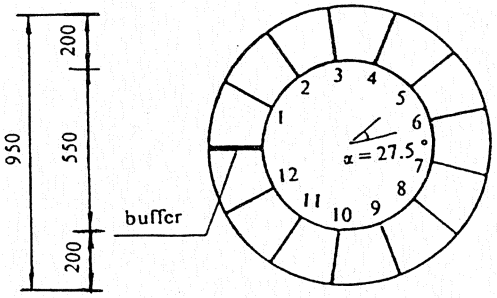


Fig. 2 Position of joints circular track road test platform

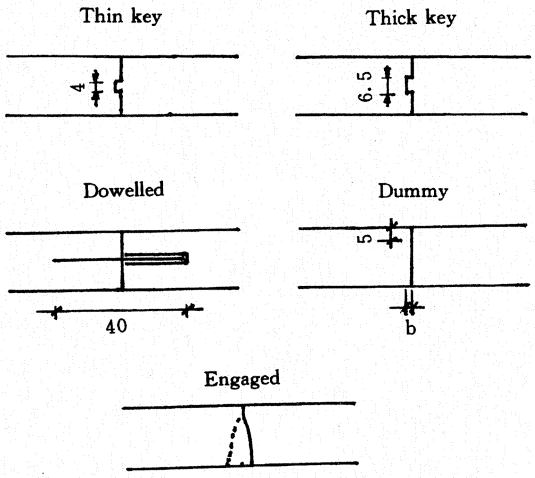


Fig. 3 Detail structure of different types of joints

The resilience modulics of subgrade is 286MPa, which was determined by a circular plate, 30cm in diameter. Other parameters of concrete pavement and materials separately as shown in Table 2.

Table 2. Parameters of concrete in test

W/C	Cement (kg/m³)	Sand (kg/m³)	Aggregate (kg/m³)	Slump (cm)	Modulus of elastic (MPa)	Strength of rupt (MPa)
0.44	356	600	1311	1.56	3.4×10^4	4.52

2. 3 Measurement of dynamic deflections of joints with FWD

The dynamic deflections of pavement can be measured by the FWD at multiple points in a very short time. The instrument FWD used in this project was developed by TRI, Southeast University. The FWD system can apply a load of 30 to 70KN, In this case, a constant load of 50KN, as a standard dynamic load, is adopted.

The dynamic load is applied at one side of a joint by the falling weight, and the deflections at both sidess of joint are collected by sensors, which were set on measurement points. Fig. 4 shows the positions of bearing plate and sensors of FWD. The whole process is controled by a microcomputer fixed to the FWD. All the measurement data were stored disks, and could be shown on screen or printed out (7).

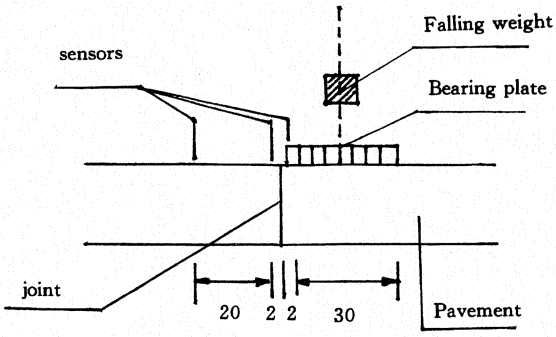


Fig. 4 Position of FWD in testing

2. 4 Mathematical model of load — transfer capacity of joints

The capability of transfering the wheel load from one side of concrete pavement joint to the other is called "load — transfer capacity". The direct index expressing the load — transfer capacity of joint is the ratio of bearing loads at both sides of concrete pavement joint. But, in fact, these bearing loads are difficult to be measure and to be analyzed. So other indirectly indices expressing this capacity are presented, deflection method and stress or strain method[7].

(1) Deflection method: The load—transfer capacity is expressed in terms of deflections values at both sides of slab joint. There are two forms of expression by this method

$$E_w = \frac{2W_2}{W_1 + W_2} \times 100\% \tag{1}$$

$$E_w = \frac{W_2}{W_1} \times 100\% \tag{2}$$

in which:

E_w——load transfer coefficient of joint;

W_1——edge deflection of loading slab;

W_2——edge deflection of near side nonloading slab.

(2) Stress or strain method: In stress method the load —transfer capacity is expressed by stress valuces at both sides of slab joint, and in strain method it is expressed by strain values at both sides of slab joint. There are three forms of expressions by this method:

$$E_\epsilon = \frac{2\epsilon_2}{\epsilon_1 + \epsilon_2} \times 100\% \tag{3}$$

$$E_\epsilon = \frac{\epsilon_2}{\epsilon_1} \times 100\% \quad (4)$$

$$E_\sigma = \frac{\sigma_{fe} - \sigma_j}{\sigma fe - \sigma_i} \times 100\% \quad (5)$$

in which:

E_ϵ or E_σ——load fransfer coefficient of joint

ϵ_1——edge strain of loading slab;

ϵ_1——edge strain of near side nonloading slab;

σ_{fe}——edge stress of slab at free edge (edge load);

σ_i——central stress of slab (central load)

σ_j——edge stess of slab at joint edge (edge load)

In Eq. 3 and Eq. 4 , if $\epsilon_1 = \epsilon_2$, the joint has a load transfer coefficent of 100%. In Eq. 5 if the edge stress is reduced to central stress, due to the central loading, the joint has a load transfer coefficient of 100%.

Analyzing these two methods, in the view of practical purpose, deflection method is better than the stress or strain method. deflection easiert to be and to be controled than stress and strain. Some computer programs, listed in references, adopt deflection ratio, as Eq. 2, to express the load—transfer capacity of joint of concrefs pavement;[4], [5],[6], and the deflecttion ratio method is also adopted in "Specification of Pavement Design in Airfield of Chinese [8]. So in this paper, deflection method Eq. 2 is adopted as the mathematical model of load — transfer capacity of joint of concrete pavement.

3. TEST REUSLT ANALYSIS

3.1 Transfer coefficient and loading numbers

Test work started from March of 1991 and completed at May of 1992. 24 joints of 5 types are applied by aircraft wheel load in 60, 000 repefltive times. After certain repetitive of load, the load transfer coefficient for all joints are measured by FWD. The numbers of repetition are:0, 1000, 2400, 3400, 5000, 7500, 10000, 15000, 20000, 25000, 40000. Each measurement of deflection ran three times by FWD. The relations between load transfer coefficient and the repetitive numbers of load for all typesof joint are shown in Fig. 5.

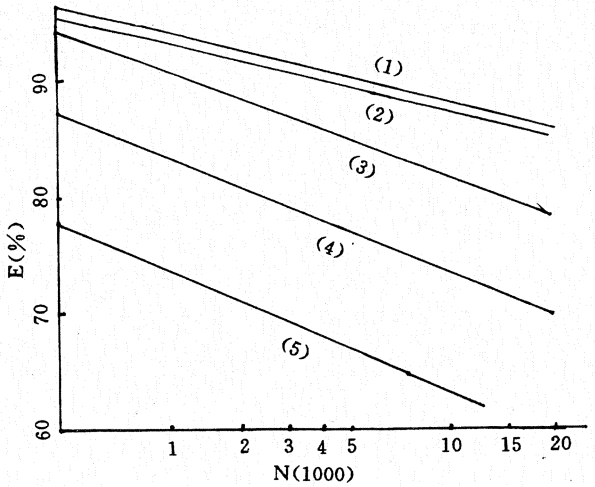


Fig. 5 Loss of load transfer coefficient of all joints due to N

notes:

N——repetitive numbers of wheel load

E——coefficient of load—transfer of joint

(1)Engaged;(2)Thin key;(3)Dowelled;

(4)Thick key;(5)Dummy joint.

As shown in Fig. 5, the engage joint has the best load transfer capacity, after 1000 repecttions of loading, E = 97. 8%, after 40,000 times of repetition, E = 82. 0%; The thin key joint is the second one, the loss of load transfer capacity is very slow, and after 40,000 times of repetion of loading, its E=82. 0%; and the dowelled joint has E = 77. 0% after 40,000 repetitive time of loading. After 5,000 of loading times, these three types of joint mentioned above are kept in a stable state, and the loss of load transfer capacity is very slow. Also from Fig. 5, the dummy joint has the lowest load transfer capacity, the loss of E is considerably quick. After 1000 repectition of loading ,E=77. 0%, after 4,000 repetitions of loading E =55. 0%.

Considering characteristics of joint structure, the engageed joint has excellent properties, the slabs on both sides of the joint are kept closely contact in all times, the deformations are not obvious in either vertical or horizontal direction. So the engaged joint is the best type of joint. It may be used broadly. The load transfer capacity of dowelled joint depends upon the tightness of the contact between dowel bar and pavement concrete, If the concrete around the dowel bar is crushed or a gap is appeared around the dowel bar, the load transfer capacity of joint would be reduced progressively.

As shown in the result of test, because the inter locking action of aggregate in concrete is reduced, dummy joint has the lowest load transfer capacity and the loss of this acpacity is considerably quick.

3. 2 Influence of width of dummy joint on loss of load —transfer

During the test, different widths of dummy joint are arrranged to study the influence of joint width on loss of load transfer capacity. The widths are b=0,2;0. 8;2. 0; 4. 0mm. After applying wheel loading, dummy joints of different widths have different properties of loss of load—transfer capacity as shown in Fig. 6.

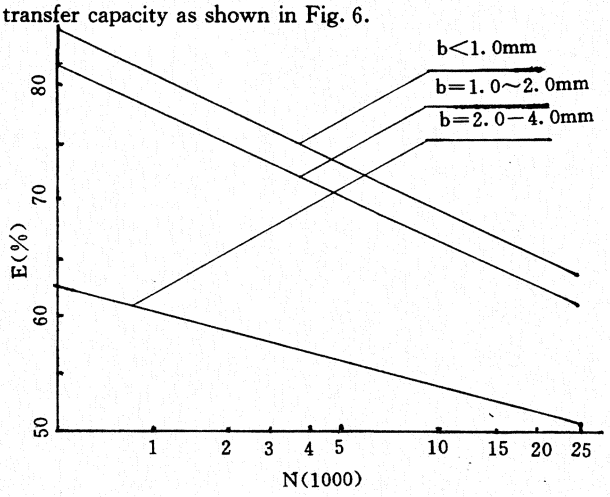


Fig. 6 Relations of E and N for dummy joints with different widths

b——width of dummy joints(mm)

As shown in Fig. 6, influence of width of dummy joint on loss of load transfer capacity is obvious, the wider the joint is, the quicker the loss is. So measures should be taken to prevent the dummy joint from its developing wider. Comparing the curves in Fig. 6, we can see if the width of dummy joint is less than 1. 0mm, the loss of load transfer capacity is slow, after 40,000 of load repetitiom ; E=60. 00%; if the width equal to 4. 0mm, after 40,000 of load repetition, E reduces from 64. 0% to 48. 0%. if the width of dummy joint is more than 5mm, the reduction of the load transfer coefficient E would be much quick. So for concrete pavement used for road or airfield runway with heavy vehicles or air crafts, the tie bars should be used in dummy joint structure to keep the joint closely, and to prevent it from reducing the load transfer capacity.

3. 3 Mathematical model of load transfer coefficient with load repetition number

Though 40,000 times of repetitive load, a group of regression functions of load transfer coefficient E with load repetion number N is developed A loglinear regression function with two parameters is adopted as the mathematical model expressing the functional relation.

$$E = A - BlgN \tag{6}$$

in which,

A,B——regression coefficient

E—coefficient of load transfer by deflection method (%)

N—repetitve load number

A. Dummy joint:

group	number	width (mm)	A	B	R	S
1	1	0. 1	95. 37	5. 25	0. 80	0. 51
1	2	0. 2	96. 56	5. 62	0. 82	0. 50
1	3	0. 25	87. 98	3. 99	0. 73	0. 49
1	10	1. 30	86. 77	4. 73	0. 85	0. 40
2	10	4. 00	64. 34	2. 49	0. 81	0. 23
2	11	2. 00	82. 91	3. 07	0. 97	0. 12
2	12	0. 80	88. 06	4. 20	0. 97	0. 13

B. Dowelled joint:

group	number	width	A	B	R	S
1	7	—	93. 46	5. 00	0. 75	0. 58
1	8	—	93. 57	4. 15	0. 67	0. 60
1	9	—	87. 20	3. 22	0. 65	0. 49
2	5	—	94. 66	3. 58	0. 99	0. 44
2	6	—	96. 99	3. 26	0. 92	0. 18
2	7	—	91. 46	3. 76	0. 98	0. 82

C. Engaged joint:

group	number	width	A	B	R	S
2	8	—	96. 31	2. 04	0. 66	0. 31
2	9	—	96. 65	2. 76	0. 86	0. 22

D. Key joint

group	number	width	A	B	R	S
1	4	0.50	76.75	1.96	0.72	0.25
1	5	0.30	86.06	3.03	0.76	0.34
1	6	0.40	87.61	3.54	0.79	0.39
2	1	0.20	88.58	4.13	0.98	0.97
2	2	0.20	87.59	3.28	0.98	0.87
2	3	0.20	95.78	2.11	0.75	0.24
2	4	0.20	96.05	2.54	0.95	0.10

notice:

R——correlation coefficient

S——standard deviation

After sorting out the data, the regression funcitions of load transfer coefficient with load repetition numbers are presented for each joint types.

Dummy joint:

$$\begin{cases} E = 87.41 - 4.46 logN (R = 0.91)(b = 1.0mm) \\ E = 82.91 - 3.97 logN (R = 0.97)(b = 1.0 - 2.0mm) \\ E = 64.35 - 2.49 logN (R = 0.81)(b = 2.0 - 4.0mm) \end{cases} \quad (7)$$

Dowelled joint:

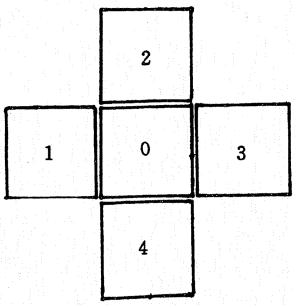
$$E = 94.47 - 3.54 logN \quad (R = 0.96) \quad (8)$$

Engaged joint:

$$E = 96.48 - 2.40 logN (R = 0.76) \quad (9)$$

Key joint:

$$\begin{cases} E = 87.46 - 3.50 logN \quad (R = 0.88)(thick\ key) \\ E = 95.90 - 2.32 logN (R = 0.85)(thin\ key) \end{cases} \quad (10)$$



0: central slab

1,2,3,4: side slab

Fig. 7 Configuration of simplified method for analyzing stress in jointed concrete pavement

3.4 Comparison with the test in airfield

From 1986 to 1988, the author has tested the load transfer capacity of joint of concrete pavement at six airfields in China, the age of the pavements is from 20 to 30 years. The loads in field testing are the same as that in laboratory. Table 3 shows the comparative results.

Table 3. Tests of load transfer coefficient of joints

Name of airfield	Time of opening	Life (years)	joint type	coef. tested(%)	coef. cal. (%)	accu. (%)
Changchun	1959	27	key	83.30	68.98	−20.7
Siping	1958	28	key	42.70	68.80	38.7
Changsha	1966	20	key	66.50	69.48	4.1
Laiyan	1960	26	key	69.30	69.00	−0.4
			key	71.20	69.38	−2.6
Xian	1966	20	doweled	91.00	76.19	−19.4
			key	50.00	69.46	−28.0
Yinchuen	1967	19	felt	8.40	—	—

The average number of the passing load on all the six airfields each year is estinated to be 7300. Using the life of the airfields the load transfer coefficatent of joint E can be cauculated by Eq. 7 to Eq. 10. The results are shown in Table 3, the last column of which shows the comparative accuracy between calculated and tested results, It is evident taht they agree with each other quite well.

4. ANALYSIS OF STRESS IN CONCRETE PAVEMENT CONSIDERING THE LOSS OF LOAD TRANSFER CAPACITY AT SOINTS

Considering the load—transfer capacity of joints, lot of models for analying the stress in concrete pavement were presented in past decades, The key of the problem is how to treat the boundary conditions of the edges of pavement slab. In 1982, the author, Deng Xue Jun, and Y. H. Huang have presentede a paper "A Simplified Method for Analyzing Conrete Pavement Composed of Multiple Jointed Slabs". With a little modification, this methodcan also be used in this paper to analyze the stress in concrete pavement [5]. Fig. 7 shows the confgiuration of the simplified method. The load is applied at the central or main slab, and then transmit to the four side slabs through different types of joint.

Using the well known displacement method, the equilibrium equation of slab can be expressed as

$$[K]\{\delta\} = \{P\} \quad (11)$$

in which:

[K]——stiffness matrix

{δ}——deflection including one vertical deflection and two rotations for each node

{P}——force including one vertical force and two moments for each node.

Considering the boundary conditions, the reduced stiffness matrix of side slabs are substituted into the stiffness matrix of the main slab. In the side slab

$$[K']_n\{W'\}_n = \{P'\}_n \quad (12)$$

in which:

$[K']_n$——reduced stiffness matrix of sided slab;

$\{W'\}_n$——deflection vector of side slab along joint n;

$\{P'\}_n$——vertical force vector of side slab along joint n;

According to the definition of load — transfer coefficient

$$E_n = \{W'\}_n/\{W\} \quad (13)$$

the deflection of side slab $\{W'\}_n$ can be substituted to the deflection of the main slab $\{W\}$

$$\{W'\}_n = E_n\{W\} \quad (14)$$

Eq. 12 can be expressed as

$$E_n[K']_n\{W\} = \{P'\}_n \quad (15)$$

Substitute Eq. 15 into Eq. 11 considering effect of all the side slabs,

$$[K]\{\delta\} = \{P\} - E_n[K']_n[W] \quad (16)$$

or

$$([K] + E_n[K']_n)\{\delta\} = \{P\} \quad (17)$$

Eq. 17 can be used to solve the unknown nodal displacement {δ} and the stress in concrete pavement considering E_n.

Subsitiing Eq. 6 into Eq. 17 the following equation is obtainted which can be used to solve and analyze the stress of pavement slab for different passing numbers of aircraft and for different joint types.

$$([K] + (A_n - B_n lgN)[K']_n)\{\delta\} = \{P\} \quad (18)$$

5. SUGGESTIONS TO IMPROVE THE DESIGN METHOD OR AIRFIELD CONCRETE PAVEMENT

The design method of airfield concrete pavement assigned in the current specification is based on the theory of elastical thin plate on a semispace foundation, considering the boundary conditions of edge of slab and using the finite element method. Fig. 8 shows the design chart in this specification, and this chart can be used to analyze the stress of slab [8].

Using this design chart, the new suggestied airfield concrete pavement design method consists of following steps:

(1) Predict the total passing number of aircrafts during the design periods of airfield;

(2) According to the selected joint type of slab, calculate the minimum value of load—transfr coefficient of joint by the respective equation from Eq. 7 to Eq. 10.

(3) Using the allowable working stress of concrete, load type, resilience modulus of foundation and load — transfer coefficient of joint, the required thickness of concrete pavement of runway by design chart shown in Fig. 8

Example of the improve design method:

Design a concrete pavement for an airfield runway, All design data are as the follows: design load is Boeing 737 — 200, resilience modulus of foundation $E_0 = 292$MPa; elastic modulus of concrete $E_c = 35,000$MPA; allowable working stress of concrete $[\sigma] = 2.25$MPa; the total passing number of aircraft $n = 3,000$ each year; design period is 30 years; the longitudinal joint is of thick—key type and the transveers joint is of the dowelled type.

$[\sigma] = 2.25$MPa

$E_c/E_0 = 35,000/292 = 120$

$E_1 = 87.46 - 3.50\lg(3000 \times 30) = 70.12\%$

$E_2 = 97.47 - 3.54\lg(3000 \times 30) = 76.93\%$

Min. $E = 70.0\% = 0.7$

From the chart in Fig. 8, the required thickness H = 31cm.

6. CONCLUSIONS

(1)Circular track road test platform is an applicable facility

for testing and investigating the loss of load — transfer caqpacity of concrete pavement joint, and the test result is in good keeping with the actual condition of pavement performance characteristics.

(2)It is successful to use FWD as an instrument for measuring the load — transfer capacity of concrete pavement joint under dynamic loads, and it has good measuring accuracy.

(3)Test results illustrate that load—transfer cacacity of joint decreased as the load repetition number increases, the velocity of loss of load—transfer capacity depends upon the joint type. the width of joint and the load repetion numbers. It is found, in this test, that the engage joint is the best one to resist the loss of load—transfer capacity, dowelled joint is the second one, and the key joint is the next one after dewelled joint. For dummy joint, the load—transfer capacity decreases rapidly as the load repetition number increase. The width of dummy joint is the main infulence factor on loss of load transfer capacity. When the width is more than 4mm load transfer capacity decreases rapidly.

(4) Through regression analysis, it is found that the loss of load—transfer capacity of joint corresponds to the mathematic model of log—linear. In this paper, several mathematic models of log — linear are presented for different types of joints respectively. With the semodels, the loss of load transfer capacity of joint can be evaluated. The conclution and the models mentioned agree quite well with the tests at six airfields in China

(5)In calculating the stress in concrete pavement with joints of different load transfer capacity, the suggested formulce (7) to (12) in this paper can be used, and it is possible to calculate the stress in concrete pavement with dirferent joint structures for different design periods.

(6) The improved design method suggested in this paper could be adopted in the specification of airfield concrete pavement design, and the pavement thickness could be determined for different passing numbers of aircrafts and for different joint types of pavement.

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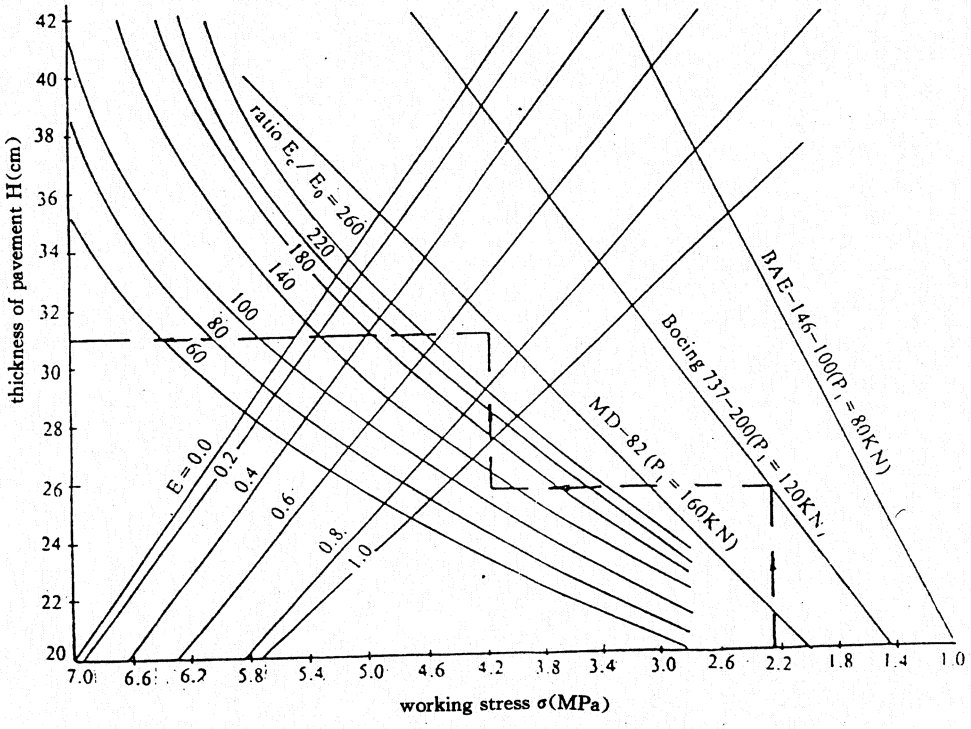


Fig. 8 Design chart for concrete airport pavement
(including coefficient of load—transfer)