

CONCRETE PAVEMENT DESIGN PROCEDURE FOR CONTAINER TERMINALS

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This paper presents the development of a concrete pavement design procedure for container terminals under an overall consideration of the operational conditions and the functional requirements of container handling areas. Two different design criteria are adopted for areas with different usage or loading conditions. Stress analysis was based upon a solution for a free-edged rectangular thick plate on a Winkler foundation, taking into account the transverse shear deformation and the edge effect, and a comprehensive computer program was developed to produce simplified design charts and tables for stress calculations.

There has been a rapid growth of container terminals in China over the past decade. The major functions required of the pavements by container operations are (1) strength under high wheel loads, (2) intense "point" load bearing capacity, (3) planarity, (4) resistance to lubricant spillage, and (5) little maintenance. Since concrete pavement has the advantage of meeting all these requirements, it has been the preferential surfacing type in China for container handling areas with minor or negligible adverse settlements.

The concrete pavement design procedure for highways has often been used for container terminals. Although the basic elements of pavement design for container handling areas are very similar to those for highways, there are also distinct differences, especially as regards the nature of loads and the operational conditions. The container operations may be divided into three phases: transfer, movement and storage, and the usage of the site will be such that the loads are both dynamic (as a result of mobile transport equipment) and static (due to storage and stationary equipment). The wheel loads and the contact pressures of vehicles for transfer and movement operations are usually much higher than traffic loads on highways, so that the designer would have to resort to extreme extrapolations, while using the design curves for highway pavements. In storage, the principal operation is container stacking. The corner post castings that bear all the container stack weight have a bearing area of only $4 \times 288 \text{ cm}^2$. Thus they exert intense contact pressures on pavements, a maximum

of about 13 MPa under a five-high stack of 12 m (40 ft) containers, which may cause overestimated design thicknesses, if ignoring the large transverse shear deformations induced in pavement slabs. These major differences set containerisation pavement design beyond the scope of highway pavement design.

This paper describes the development of a concrete pavement design procedure for container terminals which considers the special functional requirements of the container operations. Ample attention has been paid to the loading characteristics of the stacked containers and the container handling vehicles, the adoption of design criteria, the solution for stress analysis, as well as the layout of the site.

Loads

Designing pavements for container handling areas requires special attention to the characteristics of loading conditions. Pavement loading occurs from container stacking, as well as container handling vehicles.

Design Loads for Containers

There are two types of container, 6 m (20 ft) and 12 m (40 ft) in use, with a limited maximum gross weight of 200 kN and 300 kN respectively. The design load for such container is not to be based upon its limited maximum gross weight, since the actual loading weight is usually lower than the maximum. The ratio of the actual weight to the maximum gross weight is referred to as load factor ξ . Statistic results of the load factor data collected from four ports (Tianjin, Shanghai, Xiamen and Guangzhou) are depicted in figures 1 and 2 which indicate the probability distribution of load factor for 6 m and 12 m containers respectively (1). Based on the lower bound of these observed data, the recommended probability distribution of the load factor $P(\xi)$ is listed in Table 1.

Stackunits of 4 up to 5-high loaded containers are not uncommon in stack areas, and the stackunit is usually composed of containers with various load factors. It is uneconomic, therefore, to take the total maximum gross weight of containers in a

stackunit as the design load. The probability distribution of the load factor η for stackunits with n -high containers, $P(\eta \leq a, \eta = \xi_1 + \xi_2 + \dots + \xi_n)$, can be derived by applying assumption of equal probability to stacking process and taking advantage of Table 1, which is shown in Tables 2 and 3.

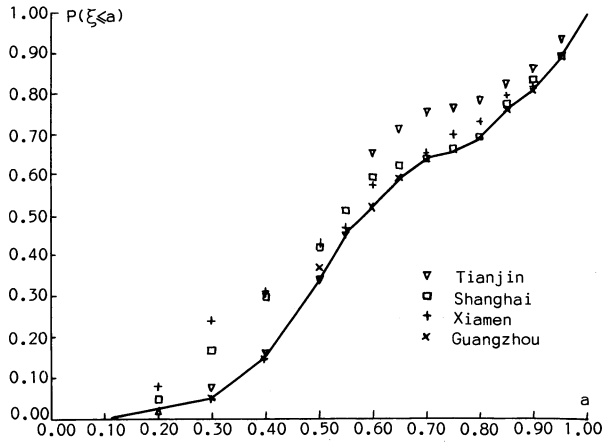


Fig.1 Probability Distribution of Load Factor ξ for 6 m Container

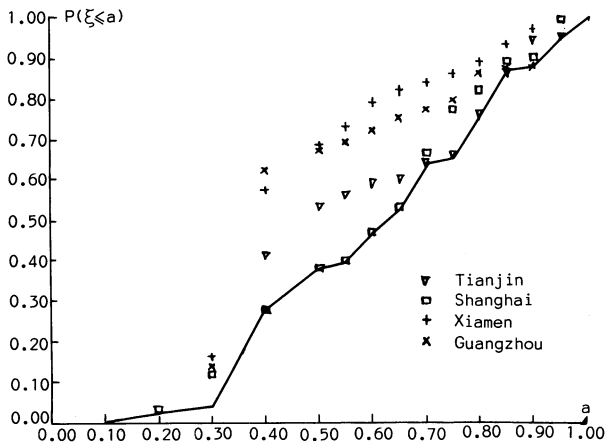


Fig.2 Probability Distribution of Load Factor ξ for 12 m Container

Table 1 Recommended Probability Distribution of the Load Factor $P(\xi)$ for 6 m and 12 m Containers

Load Factor ξ		≤ 1.00	≤ 0.95	≤ 0.90	≤ 0.85	≤ 0.80
Type of Container	6 m	1.00	0.89	0.81	0.76	0.69
	12 m	1.00	0.95	0.88	0.87	0.76
Load Factor ξ		≤ 0.75	≤ 0.70	≤ 0.60	≤ 0.50	≤ 0.40
Type of Container	6 m	0.66	0.64	0.52	0.34	0.15
	12 m	0.66	0.64	0.47	0.38	0.28

Table 2 Probability Distribution of the Load Factor $P(\eta)$ for Stackunits of 6 m Container

Load Factor η		≤ 1.00	≤ 0.95	≤ 0.90	≤ 0.85	≤ 0.80
Levels	2	1.00	0.970	0.930	0.893	0.841
	3	1.00	0.991	0.972	0.941	0.875
	4	1.00	0.997	0.987	0.958	0.899
	5	1.00	0.999	0.993	0.973	0.923
Load Factor η		≤ 0.75	≤ 0.70	≤ 0.60	≤ 0.50	≤ 0.40
Levels	2	0.755	0.634	0.415	0.215	0.049
	3	0.780	0.666	0.376	0.144	0.022
	4	0.802	0.660	0.330	0.091	0.005
	5	0.826	0.678	0.312	0.060	0.005

Table 3 Probability Distribution of the Load Factor $P(\eta)$ for Stackunits of 12 m Container

Load Factor η		≤ 1.00	≤ 0.95	≤ 0.90	≤ 0.85	≤ 0.80
Levels	2	1.000	0.991	0.972	0.929	0.857
	3	1.000	0.998	0.990	0.964	0.914
	4	1.000	1.000	0.996	0.979	0.938
	5	1.000	1.000	0.998	0.989	0.948
Load Factor η		≤ 0.75	≤ 0.70	≤ 0.60	≤ 0.50	≤ 0.40
Levels	2	0.784	0.695	0.480	0.232	0.090
	3	0.835	0.724	0.440	0.178	0.045
	4	0.858	0.733	0.381	0.126	0.011
	5	0.883	0.755	0.384	0.085	0.008

Table 4 Design Loads for the Container Corner Post P_c (kN)

Type of Container		6 m (20 ft)			12 m (40 ft)		
Reliability Level		0.90	0.95	0.98	0.90	0.95	0.98
Levels	1	50	50	50	75	75	75
	2	86	93	97	124	131	138
	3	123	130	138	178	188	198
	4	160	169	178	233	244	256
	5	197	207	217	286	301	315

By choosing the load factors under the same level of probability, the design loads for containers can be determined with various reliability level, as shown in Table 4.

Design Loads for Container Handling Vehicles

The transfer of a container may be performed by forklift, straddle carrier or mobile wheeled gantry crane. The forklift and straddle carrier with unladen wheel loads of 78.8 kN and 72.5 kN respectively are selected as typical loaders used at container terminals in China. The unladen wheel load of a typical mobile wheeled gantry crane is assumed to be 180 kN. Using the probability dis-

tribution of load factor (Table 1) for 12 m container, the load spectrum for the three types of vehicle can be determined (Table 5). Based on the 16-th power relationship of equivalent fatigue damage for concrete pavements (2), the weighted mean wheel loads, i.e. the design wheel loads, of the vehicles can be specified as shown in Table 6.

Table 5 Idealised Load Spectrum for 3 Types of Vehicle

Percent of Total Passes	Load per Wheel (kN)		
	Forklift	Straddle Carrier	Wheeled Gantry Crane
28	108.8	87.5	210.0
10	116.3	91.3	217.5
9	123.8	95.0	225.0
17	131.3	98.8	232.5
12	138.8	102.5	240.0
12	146.3	106.3	247.5
12	153.8	110.0	255.0

Table 6 Design Wheel Loads for Vehicles

Vehicle Type	Design Wheel Load (kN)	Contact Pressure (MPa)	Contact Area (m ²)	Wheel Configuration	Wheel Distance (m)
Forklift	140	0.76	0.1842	dual	0.60
Straddle Carrier	102	0.70	0.1457	single	
Wheeled Gantry Crane	237	0.74	0.3202	single	

Layout of the Site

Within the site there are often areas to be distinguished with a different usage or load pattern. Containers are usually stacked in the stack area at fixed positions with specified clearances, and the arrangement of transfer areas depends upon the type of container handling vehicles being adopted. Typical configurations of these two areas for forklift, straddle carrier and mobile wheeled gantry crane operations are schematically shown in Figures 3, 4 and 5.

It can be inferred from these figures that the layout of pavement slabs may affect the loading condition of these slabs, thus influence the bending stresses significantly. As indicated in Figure 5, three types of slab, ABCD, EFGH or IJKL, may be figured on. Each of three is subjected to different loading pattern (see Figures 6, 7 and 8), including different loading stresses. The comparison of maximum stress for three types of slab is listed in Table 7 which obviously indicates that the maximum stress induced in the slab decreases as the number of container corners applied on the

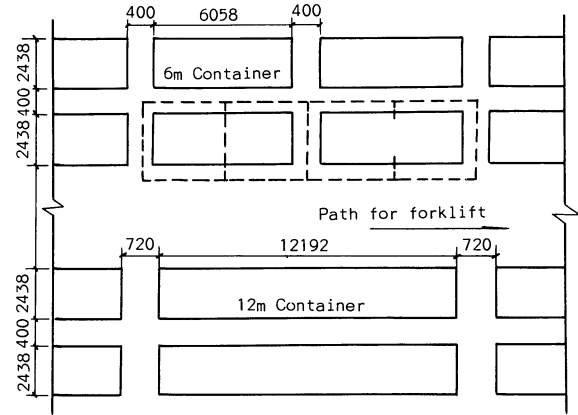


Fig. 3 Configuration of the Site with Forklift

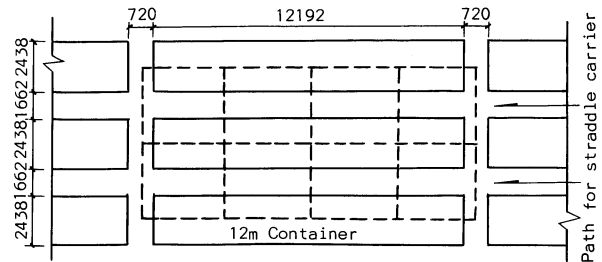


Fig. 4 Configuration of the Site with Straddle Carrier

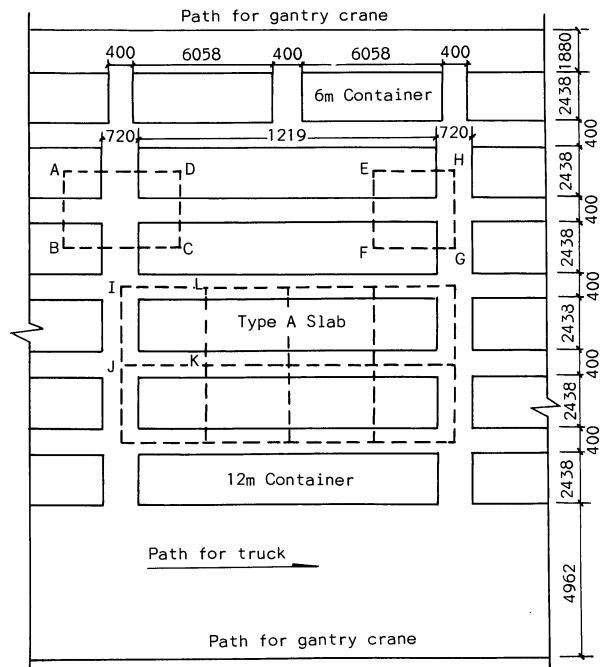


Fig. 5 Configuration of the Site with Mobile Wheeled Gantry Crane

slab decreases and the clearance from the corners increases (3).

After comparing alternative layouts of pavement slabs, two types of slab which have relatively low maximum stresses induced by the container corners are proposed. The type A slab, with its dimension shown in Figure 8 and subjected to two corner loads of a container, is available to the site using forklifts or mobile wheeled gantry cranes as the transfer vehicles. The type B slab, acted by two corner loads from two containers (Figure 9), is available for the site with straddle carriers as the handling vehicles.

The layouts of these two types of slab in the site with three typical container handling vehicles are also shown in Figures 3, 4 and 5.

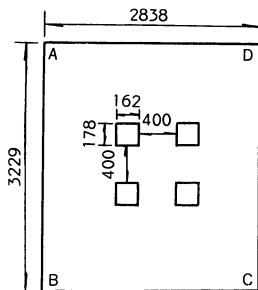


Fig. 6 Loading Pattern of Slab ABCD

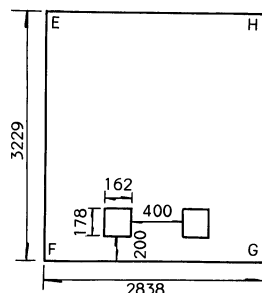


Fig. 7 Loading Pattern of Slab EFGH

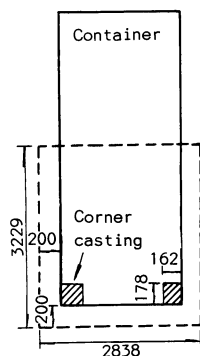


Fig. 8 Loading Pattern of Type A Slab

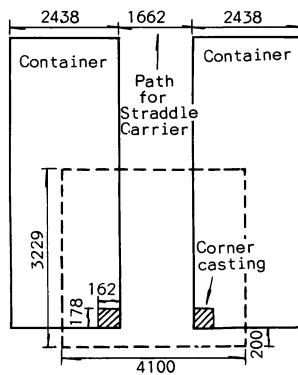


Fig. 9 Loading Pattern of Type B Slab

Table 7 Variation of Stresses with the Clearance of Container Corners

Type of Slab	Maximum Bending Stress (MPa)
Slab ABCD	4.639
Slab EFGH	3.765
Slab IJKL	2.288

Notes: Modulus of elasticity $E = 35000 \text{ MPa}$,
reaction modulus of foundation $K = 49 \text{ MN/m}^3$,
3-high container stack load,
Poisson's ratio $\mu = 0.15$

Design Criteria

Cracking is the major failure mode in concrete pavements for container terminals which is induced by stacked containers and (or) container handling vehicles.

The stacked containers exert static loads on pavements which may stay at the storage areas for several days or even couple of weeks, therefore, it can be referred to as sustained loads. It has been shown that the flexural strength of concrete will decline as the duration of sustained loads increases, as a result of the creep deformation induced in concrete. Consequently, the concrete pavement for storage area has to limit its flexural stress due to stacked containers below the sustained strength of concrete. That is

$$\sigma_p \leq \sigma_s \quad (1)$$

where σ_p is the maximum pavement stress due to the design loads of containers determined from Table 4, and σ_s is the sustained strength of concrete which may be assumed to be $0.75 \times \sigma_r$ (28-day flexural strength of concrete) based on the test results from H. Rusch (4) and other researchers (5).

As for container handling vehicles, the wheel loads are strictly channelised in the transfer areas for operational purposes with a relatively short duration and certain number of repetitions. Therefore, it is appropriate to limit the fatigue damage induced by repeated loading stresses. By using the same fatigue equation for highway pavements (2), the design criterion for moving wheel loads may be written as follows:

$$\sigma_p \leq \sigma_r \times (0.944 - 0.077 \times \log N_s) / K_1 \quad (2)$$

in which σ_p is the maximum stress due to design wheel loads, and σ_r is the 28-day flexural strength of concrete, and K_1 is a safety factor for the dynamic effect of vehicles which can be taken as 1.2, and N_s is the total number of repetitions of the design wheel loads during the design life.

If handling vehicles used for container operations are different from those adopted as standard design wheel loads (Table 6), their number of applications can be approximately converted into number of applications of the design wheel load by following equation (2):

$$N_s = N_i \times (P_i / P_s)^{16} \quad (3)$$

where P_s and N_s are the design wheel load and its number of repetitions, P_i and N_i are the wheel load to be converted and its number of repetitions.

Stress Analysis

The small bearing area and the intense contact pressure of container corners, when imposed on concrete pavements, may cause large transverse shear deformations in slabs. The conventional Westergaard's stress formula, based on classical thin plate theory, often leads to excessive loading stress, thus overestimating pavement thickness, due to ignoring the transverse shear deformation and the edge effect. Therefore, an elastic thick

plate on a Winkler foundation is selected as the stress analysis model in this procedure.

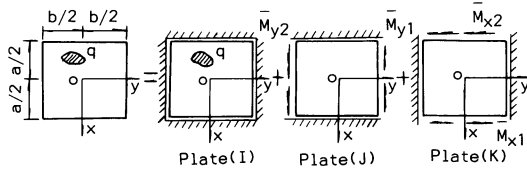


Fig.10 Elemental Plates

The solution of a rectangular free-edged thick plate on a Winkler foundation is developed by means of Reissner thick plate theory and superposition method (6). A plate with four free edges can be substituted by three elemental plates (Figure 10), plate (I) with four slip shear edges, and the other two plates (J) and (K) with two slip shear edges and two edges acted upon by distributed unknown bending moments, M_{x1} , M_{x2} , M_{y1} and M_{y2} . By assuming the solution as double trigonometric series for plate (I) and single trigonometric series for plate (J) and (K), the solutions for three elemental plates are able to be derived through solving the Reissner thick plate equations. The unknown bending moments, M_{x1} , M_{x2} , M_{y1} and M_{y2} in the solutions of plate (J) and (K) are then determined by using following free edge boundary conditions:

$$\begin{aligned} M_x(I) + M_x(J) + M_{x1} &= 0, \quad x = a/2 \\ M_x(I) + M_x(J) + M_{x2} &= 0, \quad x = -a/2 \\ M_y(I) + M_y(K) + M_{y1} &= 0, \quad y = b/2 \\ M_y(I) + M_y(K) + M_{y2} &= 0, \quad y = -b/2 \end{aligned} \quad (4)$$

where $M_x(I)$ and $M_y(I)$, $M_x(J)$, $M_y(K)$ are the bending moment for plates (I), (J) and (K) respectively. The solution of the free-edged plate can finally be obtained by superposing the solution of the elemental plates (I), (J) and (K).

The comparisons of the maximum bending moments at various loaded areas obtained from the thick plate solution and the Westergaard's formula are shown in Table 8 (interior loading case) and Table 9 (edge loading case), in which R is the radius of the loaded area and h is the thickness of the plate. It can be seen that the bending moments from the Westergaard's formula are higher than those from the thick plate solution. The difference increases as the loaded area becomes smaller in the interior loading case, and it reaches 12% over at R/h smaller than 0.3 which is the usual case for concrete slabs in stack area. As for edge loading case, the differences lay 35% over in the R/h range considered. Accordingly, it is more reasonable to adopt the thick plate solution as the stress analysis model.

By using this free-edged thick plate solution, extensive computational work has been carried out for various loading types and pavement structure parameters. The maximum pavement stresses due to containers with its loading pattern shown in Figures 8 and 9 can be obtained by following equation:

$$\sigma_p = \sigma_0 \times P_c \quad (5)$$

where P_c is the design load of container corners (Table 4) and σ_0 is the stress coefficient which is tabulated in Tables 10 and 11 for slabs in Fig-

Table 8 Comparison between Thick Plate Solution and Westergaard's Formula (Interior Loading Case)

R/h	Maximum Bending Moment (N-m/m)		Differences between Two Solution (%)
	Westergaard's Formula	Thick Plate Solution	
0.2	3773	3069	23
0.3	7650	6860	12
0.4	12296	11745	5
0.5	17917	17902	0.08

Notes: Modulus of elasticity $E = 29400$ MPa,
reaction modulus of foundation $K = 19.60$ MN/m³,
intensity of load $q = 0.98$ MPa,
Poisson's ratio $\mu = 0.15$

Table 9 Comparison between Thick Plate Solution and Westergaard's Formula (Edge Loading Case)

R/h	Maximum Bending Stress (N-m/m)		Differences between Two Solution (%)
	Westergaard's Formula	Thick Plate Solution	
0.2	561	416	35
0.3	1262	928	36
0.4	1963	1418	38
0.5	2804	2099	34

Notes: Modulus of elasticity $E = 29400$ MPa,
reaction modulus of foundation $K = 19.60$ MN/m³,
intensity of load $q = 0.98$ MPa,
Poisson's ratio $\mu = 0.15$

Table 10 Stress Coefficient σ_0 (1/m²) for Type A Slab in Figure 8

Thickness of Slab (cm)	Composite Reaction Modulus of Subgrade-Subbase (MN/m ³)						
	60	80	100	140	180	220	260
22	29.92	28.67	27.52	25.50	23.77	22.28	20.94
24	25.94	25.06	24.24	22.76	21.46	20.31	19.25
26	22.63	22.00	21.41	20.31	19.33	18.45	17.63
28	19.87	19.41	18.97	18.16	17.41	16.73	16.09
30	17.55	17.22	16.89	16.27	15.70	15.17	14.67
32	15.60	15.35	15.10	14.63	14.19	13.78	13.38
34	13.95	13.76	13.57	13.20	12.86	12.53	12.23
36	12.54	12.39	12.24	11.96	11.68	11.43	11.17
38	11.32	11.20	11.09	10.86	10.65	10.44	10.24
40	10.27	10.18	10.09	9.91	9.73	9.57	9.41
42	9.36	9.28	9.21	9.07	8.92	8.79	8.65
44	8.56	8.50	8.44	8.32	8.21	8.09	7.99

Table 11 Stress Coefficient σ_0 (1/m²) for Type B Slab in Figure 9

Thick- ness of Slab (cm)	Composite Reaction Modulus of Subgrade-Subbase (MN/m ³)						
	60	80	100	140	180	220	260
22	36.17	35.47	34.91	34.07	33.43	32.91	32.47
24	31.23	30.66	30.21	29.50	28.96	28.53	28.15
26	27.29	26.83	26.46	25.86	25.41	25.04	24.72
28	24.10	23.73	23.42	22.92	22.53	22.22	21.94
30	21.46	21.17	20.91	20.49	20.17	19.89	19.65
32	19.27	19.03	18.82	18.47	18.19	17.96	17.74
34	17.42	17.23	17.06	16.77	16.53	16.32	16.14
36	15.85	15.70	15.55	15.31	15.11	14.93	14.77
38	14.51	14.38	14.26	14.06	13.89	13.74	13.60
40	13.35	13.24	13.14	12.97	12.83	12.70	12.58
42	12.34	12.25	12.17	12.03	11.90	11.79	11.69
44	11.46	11.38	11.32	11.20	11.09	10.99	10.91

Table 12 Maximum Pavement Edge Stress σ_p (MPa) due to Design Wheel Load of Forklifts

Thick- ness of Slab (cm)	Composite Reaction Modulus of Subgrade-Subbase (MN/m ³)						
	60	80	100	140	180	220	260
22	7.22	7.05	6.84	6.49	6.19	5.94	5.72
24	6.25	6.09	5.94	5.68	5.45	5.25	5.09
26	5.45	5.31	5.20	5.00	4.82	4.67	4.53
28	4.78	4.66	4.58	4.42	4.29	4.17	4.05
30	4.22	4.12	4.05	3.93	3.83	3.74	3.64
32	3.74	3.66	3.61	3.52	3.44	3.37	3.29
34	3.34	3.28	3.24	3.17	3.10	3.04	3.00
36	3.00	2.95	2.91	2.87	2.81	2.76	2.72
38	2.69	2.67	2.65	2.60	2.56	2.52	2.48
40	2.45	2.43	2.41	2.37	2.34	2.31	2.27
42	2.23	2.22	2.20	2.17	2.14	2.12	2.08
44	2.05	2.03	2.02	2.00	1.97	1.95	1.93

Table 13 Maximum Pavement Edge Stress σ_p (MPa) due to Design Wheel Load of Straddle Carriers

Thick- ness of Slab (cm)	Composite Reaction Modulus of Subgrade-Subbase (MN/m ³)						
	60	80	100	140	180	220	260
22	3.91	3.74	3.60	3.38	3.22	3.10	2.98
24	3.39	3.25	3.13	2.96	2.82	2.72	2.62
26	2.96	2.85	2.75	2.61	2.49	2.40	2.32
28	2.60	2.51	2.43	2.31	2.22	2.14	2.06
30	2.30	2.23	2.17	2.06	1.98	1.92	1.86
32	2.04	1.99	1.94	1.85	1.78	1.73	1.67
34	1.83	1.78	1.74	1.67	1.61	1.56	1.52
36	1.64	1.60	1.57	1.51	1.46	1.42	1.38
38	1.48	1.45	1.42	1.37	1.33	1.29	1.27
40	1.34	1.31	1.29	1.25	1.21	1.18	1.16
42	1.21	1.19	1.17	1.14	1.11	1.08	1.06
44	1.10	1.09	1.07	1.04	1.02	0.99	0.98

ures 8 and 9 respectively. The maximum pavement edge stresses σ_p due to the design wheel loads of forklift, straddle carrier and mobile wheeled gantry crane (Table 6) can be obtained from Tables 12, 13 and 14 respectively.

Table 14 Maximum Pavement Edge Stress σ_p (MPa) due to Design Wheel Load of Mobile Wheeled Gantry Cranes

Thick- ness of Slab (cm)	Composite Reaction Modulus of Subgrade-Subbase (MN/m ³)						
	60	80	100	140	180	220	260
22	6.72	6.52	6.33	6.01	5.75	5.52	5.32
24	5.75	5.61	5.47	5.24	5.03	4.86	4.70
26	4.97	4.86	4.76	4.58	4.43	4.29	4.17
28	4.32	4.24	4.17	4.04	3.92	3.81	3.71
30	3.79	3.73	3.67	3.57	3.48	3.40	3.32
32	3.34	3.30	3.26	3.18	3.11	3.04	2.98
34	2.97	2.93	2.90	2.84	2.78	2.73	2.69
36	2.65	2.62	2.60	2.55	2.51	2.47	2.43
38	2.38	2.36	2.34	2.30	2.27	2.23	2.21
40	2.15	2.13	2.11	2.08	2.06	2.03	2.01
42	1.95	1.93	1.92	1.90	1.87	1.85	1.83
44	1.77	1.76	1.75	1.73	1.71	1.69	1.67

Subsoil and Subbase

Concrete pavements are sensitive to differential settlements. As a matter of fact many ports are situated in estuarine areas, where the sites have been formed by filling. Consequently, one will often have to deal with settlement and differential settlement problem of the subsoil. A survey of pavement performance has been conducted at container terminals with different subsoils, which were characterised by static-probing test. It has been found that the pavement slabs with subsoil having low probestrength exhibited severe subsidence while those with high probestrength performed well. Based on these test data, a criterion of probe-strength is proposed to identify the needs for deep-seated treatment of subsoils (7). That is, the normal probe-pressure of subsoil σ_e at 5 m depth has to satisfy:

$$\sigma_e (h = 5 \text{ m}) \geq 1.5 \text{ MPa} \quad (6)$$

In order to mitigate the differential settlement induced stresses in concrete slabs, it is preferable to use cement hydrated soil or granular material as the subbase. The composite reaction modulus of subgrade and subbase can be determined by bearing plate test in situ, or obtained from Table 15. It is recommended that the composite reaction modulus of subgrade and subbase K_c has to satisfy:

$$K_c \geq 80 \text{ MN/m}^3 \quad (7)$$

Design Procedure

The design procedure discussed herein may be

Table 15 Composite Reaction Modulus of Subgrade and Subbase Kc (MN/m³)

Types of Subbase	Cement Stabilized Granular Material				Cement Stabilized Soil				Granular Material		
Thickness of Subbase (cm)	15	20	30	40	15	20	30	40	20	40	
Reaction Modulus of Subgrade (MN/m ³)	20	60	84	111	138	28	50	66	90	40	60
	40	101	140	182	236	55	90	132	170	80	130
	60	140	189	246	/	82	140	197	260	120	190
	80	/	/	/	/	100	180	263	/	160	260

summarised step by step as follows:

1. Determine the design loads for containers and vehicles from Tables 4 and 6, according to the type of container and number of levels specified, and the type of transfer vehicles adopted.

2. Collect traffic data, forecast numbers of repetitions of various vehicles during design life, and convert into number of repetitions of design wheel load by equation 3; calculate accumulative repetitions of design wheel load during design life.

3. Identify the necessity of deep-seated treatment for the subsoil by using equation 6.

4. Assume a pavement structure with subbase type and thickness and slab thickness.

5. Use bearing plate test results or tabulated values (Table 15) to evaluate the composite reaction modulus of subgrade and subbase, and regulate subbase type or thickness if the composite modulus does not meet the requirement suggested in equation 7.

6. Prepare concrete mix design, and determine the 28-day flexural strength of concrete.

7. Estimate the loading stress σ_p due to containers by means of Table 10 or 11 and equation 5, and compare with the design criterion for sustained load (equation 1); estimate the loading stress σ_p due to forklifts, straddle carriers or mobile wheeled gantry crane by Table 12, 13 or 14, and compare with the design criterion for moving vehicles (equation 2). If assumed structure is overstressed, repeat the analysis with a new slab thickness, until the criteria are satisfied.

8. Compare the estimated slab thicknesses required for containers and moving vehicles, and adopt a larger one as the design pavement thickness for the site using forklifts or straddle carrier as container handling vehicles. As for the site using mobile wheeled gantry crane, the estimated thickness for containers is accepted as the design pavement thickness for stack areas, as well as for crane path. It is recommended, however, to reinforce the concrete slabs for crane path with higher induced stresses.

Summary

A study of the nature of loads and the operational conditions associated with pavements for container terminals has indicated that it is necessary to develop a specific concrete pavement design procedure for container handling areas. The procedure proposed here provides a possibility to substitute a more reasonable approach than the conventional highway pavement design procedure.

The major features of this procedure are:

1. Limiting the fatigue damage of repeated loading stresses due to moving vehicles and the creep damage of static loads due to stacked containers.

2. Using a solution of free-edged thick plate on Winkler foundation, derived by means of Reissner thick plate theory and superposition method, to calculate the load induced stresses.

3. Zoning the site as stack areas and transfer areas, providing reasonable layout of slabs.

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