Thickness Planning for Rigid Pavement of Reach Stacker Lanes in the Container Yard Area of Ex-JICT 2, Tanjung Priok Port, PT Pelabuhan Indonesia

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ABSTRACT

This research discusses the planning of Reach stacker routes in the Ex-JICT 2 Container Yard area of the Tanjung Priok Port, PT Pelabuhan Indonesia. The background of this research is the increasing need for port efficiency to support domestic and international goods distribution. Reach stackers were chosen due to their flexibility in moving containers, however, the movement of this equipment requires routes that meet standards to ensure safety and efficiency. This research uses a structural design method for port pavement designed to withstand Reach stacker loads for 20 years using Interpave, British Precast Standard. The analysis includes wheel loads, wheel proximity factors, dynamic loads, and optimal pavement thickness. The results show that C35/45 concrete material is more recommended than C8/10 CBGM pavement with CBP, as it has higher compressive strength and better resistance to heavy loads.

Keywords: Container yard, Pavement, Reach stacker

1. INTRODUCTION

Based on the 2012 Tanjung Priok Port Master Plan (RIP), the Ex-JICT 2 Terminal is designated as a container terminal for both the short and long term[1] .In the design and build project for the improvement of the Ex-JICT 2 Terminal infrastructure at Tanjung Priok Port, the container yard area has a planned concrete elevation of +2.850 m, with the existing elevation at +1.60 mLWS due to the increase in the maximum draft of ships berthing at the wharf area. With the increase in maximum vessel draft, there will be an increase in the number of containers that can support domestic and international goods distribution. Efficiency in container management will play a vital role at this terminal, necessitating the use of heavy equipment to support such efficiency, one of which is the Reach Stacker[2].

Reach stackers offer flexibility in lifting and moving containers; however, during operations, proper route planning in accordance with standards is required to ensure efficient and safe movement of the reach stacker [3]. The use of optimal and safe routes can support time savings in container movement and help reduce congestion in the container yard area, thereby increasing port productivity [13].

This study aims to design an optimal pavement route for reach stacker operations at the Ex-JICT 2 Container Yard, Tanjung Priok Port, considering the loads generated by the equipment. Proper pavement planning is expected to ensure durability and safety for the planned 20-year lifespan [14].

2. THEORY AND METHODS

2.1 Theory

The map in Figure 1 shows the location of the study, where data collection was carried out during the period from August to September 2024[4].

Figure 1. Location Teminal Ex-JICT 2

This study uses the reference method The Structural Design of Heavy Duty Pavements for Ports and Other Industries. Interpave, British Precast Concrete Federation, 4th edition[5]. In addition, the data used in this study is secondary data listed in the Technical Work Plan and Requirements (RKS) for the Ex-JICT 2 project in 2023.

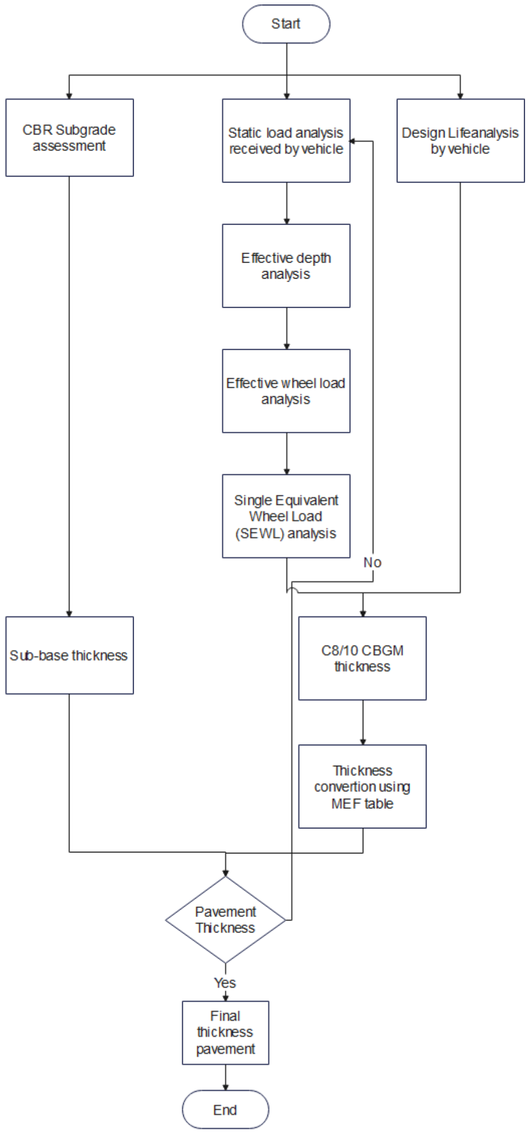

Figure 2. Research flowchart

2.2 Methods

Wheel Loading on Reach Stackers

Loading on reach stackers can be analyzed using Equations 1 to 6.

$$W_1 = fd \times \frac{A_1 \times W_c + B_1}{M} \tag{1}$$

$$W_2 = fd \times \frac{A_2 \times W_c + B_2}{M} \tag{2}$$

$$A_1 = \frac{-X_2}{X_1 - X_2} \tag{3}$$

$$A_2 = \frac{-X_1}{X_2 - X_1} \tag{4}$$

$$B_1 = \frac{W_T\,(X_T - X_2)}{X_1 - X_2} \tag{5}$$

$$B_2 = \frac{W_T\,(X_T - X_1)}{X_2 - X_1} \tag{6}$$

Description:
W1 = Load on front wheels (kg)
W2 = Load on rear wheels (kg)
Wc = Container load (kg)
WT = Empty vehicle load (kg)
Fd = Dynamic factor
M = Number of front wheels (2, 4, or 6)

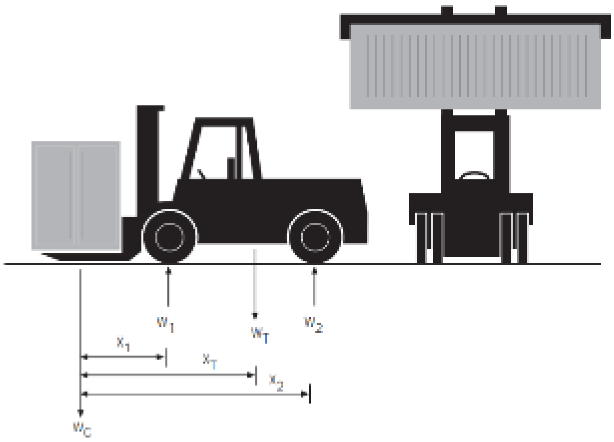

Figure 3. Wheel load of reach stacker

Wheel Proximity Factor

Wheel proximity analysis requires an understanding of the California Bearing Ratio (CBR) of the subgrade soil. Wheel loads are adjusted according to the proximity factor obtained from Table 1. If there are more than two wheels in close proximity, the radial stress under the critical wheel may need to be increased to account for the tangential stress contribution from the other wheels[5]. This proximity factor depends on the distance between wheels and the effective plate depth, which is calculated using Equation 7 to estimate the theoretical plate depth if made from subgrade soil material. This analysis ensures that the pavement can adequately support multiple wheel loads without excessive deformation or failure [12].

$$Depth_{eff} = 300 \times \sqrt[3]{\frac{3500}{CBR \times 10}} \tag{7}$$

Description:
$Depth_{eff}$ = Effective Depth (mm)
CBR = CBR subgrade (%)

Table 1. Dynamic load factors (fd)

Condition	Vehicle Type	fd
Braking	Reach Stacker/Front Lift Truck	± 30%
	Straddle Carier	± 50%
	Side Lift Truck	± 20%

Condition	Vehicle Type	fd
	Tractor dan Trailer	± 10%
	Rubber Tyre Gantry Crane (RTG)*	± 10%
Cornering	Reach Stacker/Front Lift Truck	± 40%
	Straddle Carier	± 60%
	Side Lift Truck	± 30%
	Tractor dan Trailer	± 30%
	Rubber Tyre Gantry Crane (RTG)*	zero
Acceleration	Reach Stacker/Front Lift Truck	± 10%
	Straddle Carier	± 10%
	Side Lift Truck	± 10%
	Tractor dan Trailer	± 10%
	Rubber Tyre Gantry Crane (RTG)*	± 5%
Uneven Surface	Reach Stacker/Front Lift Truck	± 20%
	Straddle Carier	± 20%
	Side Lift Truck	± 20%
	Tractor dan Trailer	± 20%
	Rubber Tyre Gantry Crane (RTG)*	± 10%

If two or three of these conditions apply simultaneously, then fd must take into account several dynamic effects.

Design Life

Design life is defined as the duration of time or number of load cycles during which the pavement can function without requiring significant repairs. In container yard areas, the pavement must be designed to withstand loads from heavy vehicles such as reach stackers. Equation 8 is the formula for calculating [11].

$$D_{life} = UR \times 365 \times n_{vehicles} \quad (8)$$

Description:
D_{life} = Design life (traffic)
$n_{vehicles}$ = Number of vehicles in operation (vehicles/day)
UR = Planned lifespan (years)

Pavement Foundation Design

In general, the design thickness of the pavement layer for port terminal construction is greater than that for highways [15]. The thicknesses in Table 2 are designed to ensure that when the CBR value of the subgrade soil falls below 5%, the stress on the subgrade material remains stable, and the pavement deflection remains virtually unchanged. However, it should be noted that it is not possible to maintain stress and deflection at a CBR value of 5% simultaneously. When the CBR decreases below 5%, the deflection at the center of the wheel field increases according to the values listed in Table 3[5].

Table 2. Thickness of unbound sub-base and capping for various subgrade CBR values

CBR Subgrade	Capping Thickness (mm)	Sub-base Thickness (mm)
1.0%	0.9	0.15
2.0%	0.6	0.15
3.0%	0.44	0.15
4.0%	0.25	0.15
5.0% and greater	Not required	0.15

Table 3. Increase in wheel deflection when the subgrade CBR falls below 5%

Subgrade CBR Design Stress	Tensile Stress in base (N/mm2)	Deflexion of pavement surface (mm)
1.0%	2.00	0.81
2.0%	2.01	0.81
3.0%	2.01	0.79
4.0%	2.00	0.76
5.0%	2.00	0.75

Pavement Thickness

Figure 4 shows a similar graph, but with additional information regarding the number of load passes or the number of cycles expected during the design period. The lines in the graph indicate the number of load cycles from 250,000 to 25 million passes. Pavement thickness needs to be increased as the number of load passes increases to prevent damage such as rutting or cracking in the pavement layer [5].

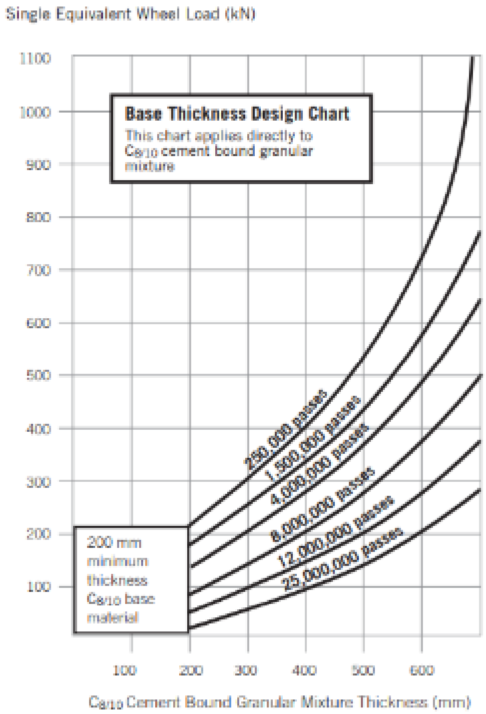

Figure 4. Graph showing the relationship between SEWL and pavement thickness in the reach stacker area

Table 4 contains the Material Equivalence Factor (MEF) for various types of materials used in basic road pavement construction. These materials are grouped based on the type of hydraulic mixture, concrete[6], traditional materials bound with cement, materials bound with asphalt, unbound materials, and concrete paving blocks.

Table 4. Material compatibility factors linking C8/10 CBGM with other materials

Material Grouping	**Preferred Pavement Base Construction Material**		**Material Equivalence Factor (MEF)**
	Material Strength	**Relevant standard**	
Hydraulically Bound Mixtures	C1.5/2	BS EN 14227-1	1.74
	C3/4	BS EN 14227-1	1.38
	C5/6	BS EN 14227-1	1.16
	C8/10	BS EN 14227-1	1.00
	C12/15	BS EN 14227-1	0.87
	C16/20	BS EN 14227-1	0.79
	C20/25	BS EN 14227-1	0.74
	C1.5/2	BS EN 14227-2&3	1.74
	C3/4	BS EN 14227-2&3	1.38
	C6/8	BS EN 14227-2&3	1.10

Material Grouping	**Preferred Pavement Base Construction Material**		**Material Equivalence Factor (MEF)**
	Material Strength	**Relevant standard**	
	C9/12	BS EN 14227-2&3	0.95
	C12/16	BS EN 14227-2&3	0.85
	C15/20	BS EN 14227-2&3	0.79
	C18/24	BS EN 14227-2&3	0.76
	C21/28	BS EN 14227-2&3	0.72
	C24/32	BS EN 14227-2&3	0.68
	C27/36	BS EN 14227-2&3	0.63
Concrete	C8/10	BS8500-1	1.00
	C12/15	BS8500-1	0.87
	C16/20	BS8500-1	0.79
	C20/25	BS8500-1	0.74
	C25/30	BS8500-1	0.65
	C25/30	BS8500-1 including 20 kg/m3 steel fibre	0.60
	C25/30	BS8500-1 including 30 kg/m3 steel fibre	0.55
	C25/30	BS8500-1 including 40 kg/m3 steel fibre	0.50
	C28/35	BS8500-1	0.62
	C32/40	BS8500-1	0.60
	C32/40	BS8500-1 including 20 kg/m3 steel fibre	0.55
	C32/40	BS8500-1 including 30 kg/m3 steel fibre	0.50
	C32/40	BS8500-1 including 40 kg/m3 steel fibre	0.45
	C 35/45	BS8500-1	0.58

Material Grouping	**Preferred Pavement Base Construction Material**		**Material Equivalence Factor (MEF)**
	Material Strength	**Relevant standard**	
Traditional Cement Bound Materials	CBM 1		1.60
	CBM 2		1.20
	CBM 3		1.00
	CBM 4		0.80
	CBM 5		0.70
	No-fines Lean Concrete for permeable paving		1.00
Bitumen Bound Materials	HDM as define by SHW		0.82
	DBM as define by SHW		1.00
	HRA as define by SHW		1.25
Unbound Materials	Crushed rock sub-base material CBR > 80%		3.00
Concrete Block Paving	Concrete Block Paving as surfacing (80mm blocks and 30mm laying course)		1.00

Reinforcement Planning

Equation 9 can be used to calculate the cross-sectional area of reinforcement [7].

$$A_s = \frac{\mu \times L \times g \times h}{2 \times f_s} \qquad (9)$$

Description:

A_s = Cross-sectional area of steel reinforcement (mm^2/m')

f_s = Allowable tensile strength of reinforcement (MPa)

g = Gravity (m/s^2)

h = Concrete slab thickness (m)

μ = Coefficient of friction between concrete slab and foundation

3. RESULTS AND DISCUSSION

Wheel Loading on Reach Stackers

Based on laboratory [8] and field CBR tests [9], the fill soil has a CBR value at 10%. The following data was used in designing the pavement for the reach stacker area with a CBR subgrade of 10% [4]:

The total load of the Reach stacker in the loaded condition is 121 tons, with a front wheel load of 90 tons and a rear wheel load of 31 tons. Therefore, the static load applied through each front wheel is 90/4 = 22.5 tons, and the static load on each rear wheel is 31/2 = 15.5 tons. The largest load, 22.5 tons or 225 kN, is used.

Wheel Proximity Factor

To calculate the effective depth of the base, the following calculation is used:

$$Effective\ depth = 300 \times \sqrt[3]{\frac{3500}{10 \times 10}}$$

$$Effective\ depth = 2114.19$$

To calculate the effective wheel load depth assuming wheel proximity factors of 600 mm, 3100 mm, and 3700 mm, the following interpolation is obtained:

Table 5. Wheel Proximity Factors

Wheel Spacing (mm)	**Proximity Factor for Effective Depth to Bottom**		
	2000	**2114.19**	**3000**
600	1.8200	1.8303	1.9100
2400	1.0200	1.0485	1.2700
3100	1.0083	1.0216	1.1242
3600	1.0000	1.0023	1.0200
3700	1.0000	1.0021	1.0183
4800	1.0000	1.0000	1.0000

In analyzing the effective wheel load, the following formula can be used:

$$B = 1 + 0.83 + 0.022 + 0.0021 = 1.854$$

$$Wheel\ load_{effective} = 1.854 \times 225$$

$$Wheel\ load_{effective} = 417.13\ kN$$

So, the effective wheel load is 417.13 kN.

Vehicle Dynamic Load

In analyzing dynamic load, it is assumed that the dynamic load of the reach stacker occurs during braking and acceleration conditions as shown in Table 1.

$$SEWL = fd \times Beban\ roda_{effective}$$

$$SEWL = (1 + 0.3 + 0.1) \times 417.13$$

$$SEWL = 583.99\ kN$$

Therefore, the Single Equivalent Wheel Load (SEWL) value is 583.99 kN.

Design Life

In analyzing the design life of the Reach stacker vehicle, it is assumed that the Reach stacker vehicle operates 373 vehicles/day with 746 trips/day and a design life of 20 years[10].

$$Design\ life = UR \times Lintasan \times 365$$

$$Design\ life = 20 \times 746 \times 365$$

$$Design\ life = 5445800 = 5.4 \times 10^6$$

Therefore, the design life of the Reach stacker is 5.4 million.

Pavement Foundation Design

Based on Table 2, it can be concluded that with an assumed soil CBR of 10%, no capping is required, and a sub-base layer thickness of 150 mm is needed using crushed stone material with CBR ≥ 80%.

Pavement and Reinforcement Design

In planning the thickness of the pavement surface, the SEWL value and design life value are required using Figure 5 with material consisting of C8/10 Cement Bound Granular Mixture (CBGM) concrete strength.

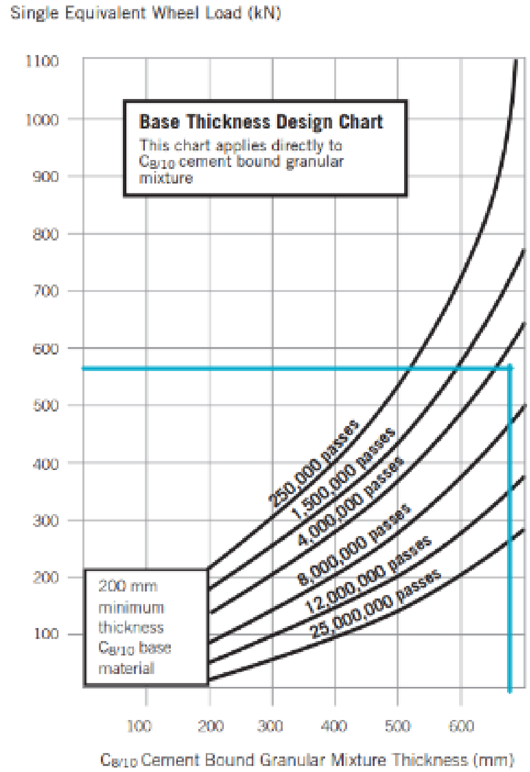

Figure 5. C8/10 CBGM Thickness

Based on the analysis results, the thickness of the base course using C8/10 CBGM was determined to be 680 mm with a laying course thickness of 30 mm and Concrete Block Paving with a thickness of 80 mm, as shown in Figure 6.

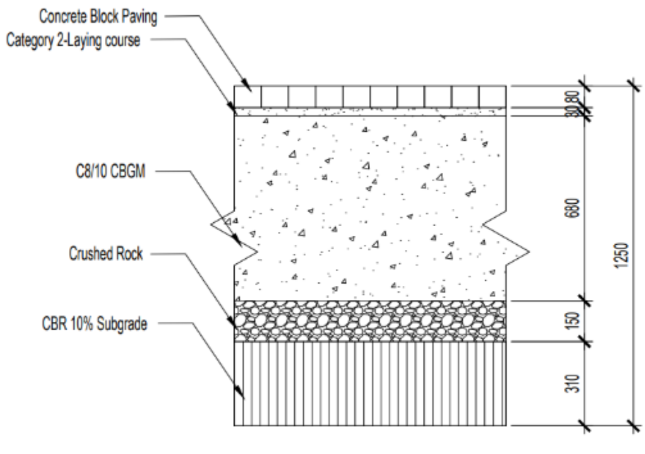

Figure 6. Thickness of pavement in the C8/10 CBGM reach stacker area with CBP

Based on the results of the base course, laying course, and concrete block paving thicknesses, a thickness value of 790 mm was obtained. According to Table 4, if the designer uses alternative materials, these are multiplied by the Material Equivalent Factors (MEF), resulting in a thickness of 460 mm for C35/45 in situ concrete and 360 mm for C32/40 concrete with a 40 kg/m³ fiber steel mixture.

Calculation of C35/45 In situ Reinforcement Material

The following specifications are used in planning continuous concrete pavement:

Plate thickness	=46 cm
Plate width	=40.625 m
Plate length	=10 m
Friction coefficient between plates	=1.5 (paraffin bond)
Allowed tensile strength of steel	= 240 MPa
Concrete density	= 2400 kg/m³
Gravity	= 9.81 m/s²

Based on the above specifications, the analysis of the continuous concrete pavement with reinforcement is as follows:

1. Longitudinal Reinforcement

The following is an analysis of pavement with continuous concrete with longitudinal reinforcement:

$$As = \frac{\mu \times L \times g \times h}{2 \times f_s}$$

$$As = \frac{1.5 \times 10 \times 9.81 \times 0.46}{2 \times 240}$$

$$As = 338.445\, mm^2/m'$$

$$As_{min} = 0.1\% \times tebal\, pelat \times 10 \times 1000$$

$As_{min} = 0.1\% \times 46 \times 10 \times 1000 = \frac{460mm^2}{m'}$>AsPlan ($As_{min}$ used)

The diameter and spacing of reinforcement used are specified as follows:

$$As_{terpakai} = \frac{1000}{S} \times \pi \times r^2$$

$$As_{terpakai} = \frac{1000}{400} \times 3.14 \times 16^2 = 502.4\, mm^2/m' > As_{min}$$

So, reinforcement bars with a diameter of 16 mm and a spacing of 400 mm were used.

2. Transverse reinforcement

The following is an analysis of pavement with continuous concrete with transverse reinforcement:

$$As = \frac{\mu \times L \times g \times h}{2 \times f_s}$$

$$As = \frac{1.5 \times 40.625 \times 9.81 \times 0.46}{2 \times 240}$$

$$As = 1374.93\, mm^2/m'$$

$$As_{min} = 0.1\% \times tebal\, pelat \times 10 \times 1000$$

$As_{min} = 0.1\% \times 46 \times 10 \times 1000 = 460mm^2/m'$<AsPlan (AsPlan used)

The diameter and spacing of reinforcement used are specified as follows:

$$As_{terpakai} = \frac{1000}{S} \times \pi \times r^2$$

$$As_{terpakai} = \frac{1000}{200} \times 3.14 \times 19^2 = 1416.93mm^2/m' > As_{Plan}$$

So, reinforcement bars with a diameter of 19 mm and a spacing of 200 mm were used. This results in the following thickness of reinforced pavement:

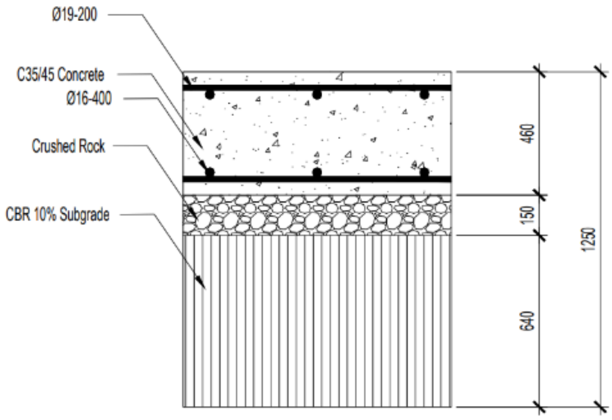

Figure 7. Thickness of pavement in the C35/45 In-situ reach stacker area

3. CONCLUSIONS

The analysis concludes that for the Reach Stacker route, the C35/45 concrete pavement requires a 460 mm slab with 16-400 mm longitudinal and 19-200 mm transverse reinforcement. Based on pavement engineering principles, C35/45 concrete is recommended due to its higher strength and quality[6].

4. ACKNOWLEDGEMENTS

Acknowledgments are extended to PT Pelabuhan Indonesia (Persero) for providing data to support this research.

REFERENCES

[1] K. P. Sekretariat Jenderal, *Keputusan Menteri Perhubungan Republik Indonesia Nomor KM 11 Tahun 2024 tentang Plan Induk Pelabuhan Tanjung Priok dan Marunda Terintegrasi*, no. 8. 2024.

[2] T. Bambang, *PePlanan Pelabuhan*, no. 112. 2010.

[3] B. S. H, *Port Terminal Operation*, vol. XIII. 2015.

[4] P. P. Indonesia, *Plan Kerja dan Syarat-Syarat Teknis Proyek Pekerjaan Perbaikan Infrastruktur Terminal Ex-JICT 2 Pelabuhan Tanjung Priok*, vol. 11, no. 1. 2019.

[5] J. Knapton, *THE STRUCTURAL DESIGN OF HEAVY DUTY PAVEMENTS FOR PORTS AND OTHER INDUSTRIES*, vol. 9, no. 2. 1987.

[6] Badan Standardisasi Nasional, "Persyaratan Beton Struktural untuk Bangunan Gedung," *Sni 2847-2019*, no. 8, p. 720, 2019.

[7] D. P. dan P. Wilayah, "PePlanan Perkerasan Jalan Beton Semen (Pd T-14-2003)," *Book*, p. 51, 2003.

[8] Badan Standardisasi Nasional, "Metode uji CBR laboratorium Badan Standardisasi Nasional," *Badan Stand. Nas.*, pp. 1–28, 2012, [Online]. Available: www.bsn.go.id.

[9] Badan Standardisasi Nasional, "SNI 1738:2011 Cara uji CBR (California Bearing Ratio) Lapangan," 2011.

[10] K. P. Direktorat Jenderal Perhubungan Laut, "Peraturan Kepala Kantor Otoritas Pelabuhan Utama Tanjung Priok tentang Standar Kinerja Pelayaran Operasional Pelabuhan Pada Pelabuhan Tanjung Priok." .

[11] Y. H. Huang, Pavement Analysis and Design, 2nd ed. Upper Saddle River, NJ, USA: Prentice Hall, 2004.

[12] AASHTO, Guide for Design of Pavement Structures, Washington, DC, USA: American Association of State Highway and Transportation Officials, 1993.

[13] Han, Yongbin & Lee, Loo Hay & Chew, Ek Peng & Tan, Kok Choon. (2008). A yard storage strategy for minimizing traffic congestion in a marine container transshipment hub. OR Spectrum. 30. 697-720. 10.1007/s00291-008-0127-6.

[14] Di Mascio, P., Loprencipe, G., & Moretti, L. (2019). Technical and Economic Criteria to Select Pavement Surfaces of Port Handling Plants. Coatings, 9(2), 126. doi:10.3390/coatings9020126

[15] Takashi KOBAYASHI, Keizo KAMIYA, VALIDATION OF JAPAN'S DESIGN METHOD OF PAVEMENT THAT RELATES ITS THICKNESS INDEX, WHEEL LOAD AND SUBGRADE *CBR*, Journal of Japan Society of Civil Engineers, Ser. E1 (Pavement Engineering), 2019, Volume 75, Issue 1, Pages 53-58, Released on J-STAGE October 20, 2019, Online ISSN 2185-6559, https://doi.org/10.2208/jscejpe.75.53