

Loads and Road Design for Intermodal Container Terminals with Untypical Heavy Load Traffic

Stanisław Majer, Bartosz Budziński, Przemysław Gardas
West Pomeranian University of Technology Szczecin, Poland

There is a high demand in Poland for new intermodal container terminals. Increased rate of freight transport requires however new solutions for durable roads. Intermodal operations are carried out by swap bodies, trailers or most often containers. The intermodal terminals play the function of a storage, transportation and handling of the containers. The road surfaces within the terminals are exposed to different types of loads due to untypical types of transportation that operates on them. New types of roads demand new design methods that consider loads applied by special types of vehicles (container cranes, types of forklifts called reach-stackers). They also need to consider the method of container stacking, where the local forces can reach up to 1400 kN. The article presents typical loads that can be found in intermodal terminals, including the storing area and maneuvering aisles. The article presents also typical materials used for road construction, as well as method of dimensioning that incorporates different exposure factors. The method allows to design load-bearing and durable road surfaces. The calculations were performed for materials typically used in road construction, as well as in industrial flooring. The study presents a case study calculation of a parking lot designed for heavy load trucks.

Keywords: intermodal terminals; heavy load vehicles; road design, intermodal terminals, heavy load vehicles

1. INTRODUCTION

The increase of the total handling volume shows the need for constructing additional handling infrastructure. Additionally, the development of companies that require inner transportation of heavy load elements adds up to the general need for new infrastructure. This leads to necessity for designing roads for untypical loads caused by containers, RTG cranes or forklifts. Existing Polish Codes do not include any easy and comprehensive methods of designing the road surfaces, resistant to untypical loads.

Such loads do not exist on a typical road. General methods do not even consider the use of concrete blocks pavings or fiber reinforced concretes for the construction of roads. Empirical and mechanical designing methods such as **CBR** [1], **OSŻD** [1,2,3] and others found in the literature do not take a holistic approach in designing intermodal road surfaces. Therefore, the study tries to introduce a rather simple method of designing such type of road surfaces, that was also included in “*The Structural Design Of Heavy Duty Pavements For Ports and Other Industries*”. The method, known as HDPFP, allows to design very heavy loaded roads with frequent local loads.

2. THE CHARACTERISTICS OF THE LOADS ON ROAD SURFACES IN INTERMODAL TERMINALS

2.1 CONTAINER LOAD

The first and main load applied on the roads in intermodal terminals is the load from stacks of containers. A single container applies huge concentrated forces in its corners. The values of the force depend mostly on the number of containers and method of stacking. Containers are stacked as a single stack, rows or blocks. The load values are presented in Table 1. The values incorporate the reduction of the load with increased level of the pile.

Tab. 1 The loads transferred to the road surface in relations to stacking method and number of containers [4]

Container stack	Force reduction	surface load [kN]		
		single stack	row	block
1	0	76.2	152.4	304.8
2	10%	137.2	274.3	548.6
3	20%	182.9	365.8	731.5
4	30%	213.4	426.7	853.4
5	40%	228.6	457.2	914.4
6	40%	274.3	548.6	1,097.0
7	40%	320.0	640.0	1,280.0
8	40%	365.8	731.6	1,463.0

2.2 HANDLING VEHICLES LOAD

One of the first types of untypical loads in the handling areas is the load applied by the Rubber Tyred Gantry (RTG). The size and transferred loads on the surfaces depend mostly on the height of handled container stack. Depending on the type of stacking (height) the work area of the RTG might require different thickness of the surface. The gantries move only on a pre-determined routes.

In case of other vehicles and handling devices the operator decides on the driving path (or in case of automated vehicle, the computer). Those types of cranes are used for handling or setting the shipment. The loads applied by the moving vehicles and the static values are presented in Table 2. The design of a reach-stacker vehicle is visible in Figure 1.

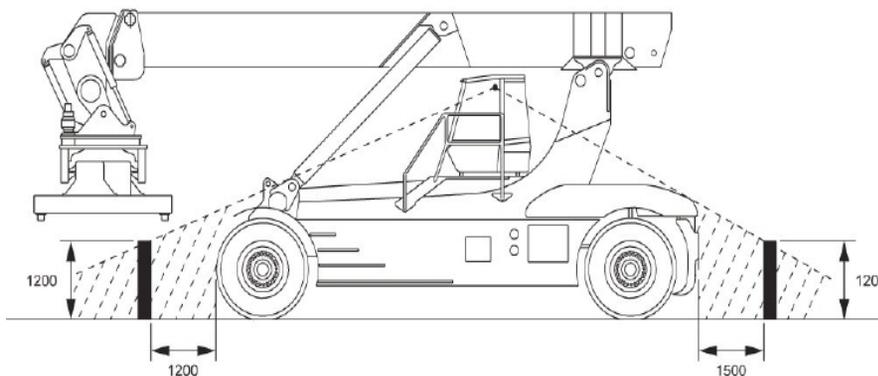


Fig. 1. Reach-stacker design – promotional leaflet of the Linde company [producer’s data]

2.3 TRANSPORTATION LOADS

The last type of the loads are the loads applied by the transportation vehicles for the containers. Those are not only the vehicles used for the internal transportation, but also trucks that bring and pick up the shipment. In the latter case the vehicles are adjusted and entry into service on public roads. The maximum permissible weight must be less than 44 t. In this case it is not the load that is regarded as damaging to the surface, but the frequency of loading.

Tab. 2 Examples of static point loads from different vehicles [based on producer's data]

Type of a vehicle	Point load (per wheel)
RTG (e.g. Kalmar)	205 kN
Container crane „reach-stacker“	600 kN
Forklift Hoist P350	150 kN
heavy load truck with maximum permissible weight of 44 t	57.5 kN
port crane „Gottwald“ – while moving	300 kN

3. MAIN MATERIALS FOR ROAD SURFACE CONSTRUCTION

Several different materials are used in a road construction for heavy loaded roads. The base can be done with mechanically compacted gravel, but mostly is constructed from cementitious materials. In case of the surfaces, the most prevalent are concrete blocks or cementitious concretes, including fibre reinforced concretes. The road surfaces exhibit high strength and durability. In case of road surfaces constructed with small size pre-cast concrete elements (concrete blocks) the costs of repairs are low. The concretes are mostly reinforced with steel fibres, due to high improvement of mechanical strength. The influence of the fibres addition can be found in [5] and is presented in Table 3.

Tab. 3 Changes in concrete properties after addition of fibres [5]

Property	effect of fibre addition
compressive strength	0/+
tensile strength	+
bending tensile strength	+
fatigue tensile strength	++
residual tensile strength	++
impact energy strength	++
Elastic modulus	0
+ improvement, ++ significant improvement, 0 no change	

The road surfaces constructed with use of bituminous mixes are also permitted for use, however are not often considered. The reason lies in the type and period of loading, as well as frequent maneuvers of vehicles. The horizontal forces during the latter can cause a plastic deformation of the mix.

4. HDPFP METHOD

The HDPFP method has similar steps as the traditional CBR method. Based on the vehicle and container loads nomograms the thickness of the base layer can be indicated. The value corresponds to the thickness of a mix with cementitious binder with C8/10 strength class. In the CBR method the substitution thickness was presented as the layer of gravel. The thickness should be incremented with an additional layer (11 cm) of road surface, made from concrete blocks and sand-cement foundation. Respective coefficients are presented in Table 4.

Tab. 4 Chosen coefficients used in port and industrial road design [4]

Material group	Material	material coefficient
bounded mixes/ cementitious concrete	C1,5/2,0	1.74
	C3/4	1.38
	C5/6	1.16
	C8/10	1.00
cementitious concrete	C12/15	0.87
	C25/30	0.65
	C25/30 reinforced with steel fibres (20kg/m ³)	0.60
	C25/30 reinforced with steel fibres (30kg/m ³)	0.55
	C25/30 reinforced with steel fibres (40kg/m ³)	0.50
	C32/40	0.60
	C32/40 reinforced with steel fibres (20kg/m ³)	0.55
	C32/40 reinforced with steel fibres (30kg/m ³)	0.50
	C32/40 reinforced with steel fibres (40kg/m ³)	0.45
	C35/45	0.58
unbounded material	aggregate with CBR>80%	3.00
concrete blocks	8 cm concrete brick 3 cm base	1.00

The coefficients table includes vast range of cementitious mixes used for the road construction. It allows to perform detailed calculations for different variants of strength class and other characteristics. This is particularly useful in designing the fiber reinforced concretes. Table 4 includes 6 types of FRC with different amount of fibres (20-40 kg/m³) and different strength class. It is worth noticing that in this method the coefficient ratio for C8/10 concrete and stabilized crushed aggregate is 1:3, while in the classic CBR method was 1:1.7.

The asphalt mixes are not represented in Table 4, but their coefficients range between 0.82-1.25.

The HDPFP method also includes a solutions for composing the foundation and stabilized layers. It can be simply assumed that the upper layers should be constructed on the base of at least G1 class (CBR \geq 10%). The load-bearing capacity can be designed based on the original method or [6]. In case of soils with CBR lower than 5% the replacement is recommended for a material with CBR higher than 15%. Depending on the base, the layer thickness can range from 25 cm (CBR=4%) to 90 cm (CBR=1%). Such assumption allows to construct a G2 class base in accordance to Polish Standards. Such base allows for sub-base with thickness of 15 cm, composed from a bound and hydraulically unbound mixes or stabilized soils. The methods, besides of loads and materials takes also into consideration dynamic coefficients from vehicle maneuvers (Table 5).

Tab. 5 Dynamic coefficients for different types of maneuvers and vehicles[4]

Manoeuvre	Vehicle	fd
breaking	Reach-Stacker	±30%
	container handler with trailer	±10%
	RTG	±10%
turning	Reach-Stacker	±40%
	container handler with trailer	±30%
	RTG	0%
accelerating	Reach-Stacker	±10%
	container handler with trailer	±10%
	RTG	±5%
uneven surface	Reach-Stacker	±20%
	container handler with trailer	±20%
	RTG	±10%

5. USE OF HDPFP METHOD FOR DIMENSIONING OF ROAD SURFACES AND MANOEUVRE AREAS

The presented method can be successfully used to design road surfaces and manoeuvre areas exposed to increased loads from heavy trucks, particularly in the rest areas (RA). There are currently no guidelines and acts in operation regarding the road surfaces and parking lots constructed from concrete blocks. In 2015 the amendment to the Technical Conditions caused the 5th Appendix to cease to apply [7,8] This created some uncertainty between the designer on how to design the surfaces on parking lots, especially in rest areas.

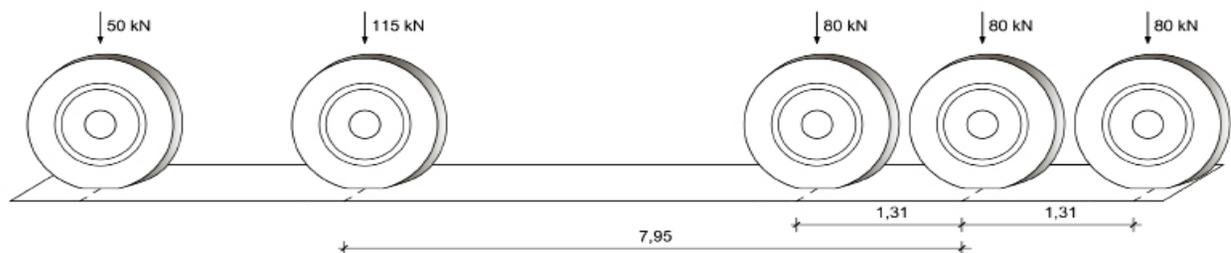


Fig. 2. Axial load schematic of the surface used in the calculations (cm)

To determine the required surface thickness, authors assumed the load from a semi-truck with a trailer. The total assumed load was 405 kN. The load system is presented in Figure 2. Based on the assumptions the authors determined the coefficient of the axial distance of semi-truck wheels from the trailer's wheels. In this example the coefficient was 1.44. The calculations assumed that the road will have foundation with bearing capacity G1 (CBR>10%), The calculations considered the influence of the breaking (10%) and turning (30%) that resulted in a dynamic coefficient of 1.4. The HDPFP method uses the power of 3.75 to calculate the loads applied to the surface. However, considering the experiences from Poland, the authors assumed the power of 4.0. The total conversion rate for the semi-truck with a trailer for a single wheel was 60 kN.

$$r_{C+P} = 1,4 * \left[\left(\frac{25}{60} \right)^4 + \left(\frac{57,5}{60} \right)^4 + 1,44 \left(\frac{40}{60} \right)^4 + 1,44 \left(\frac{40}{60} \right)^4 + 1,44 \left(\frac{40}{60} \right)^4 \right] = 1,70 \quad (1)$$

Considering the acquired result and conversion coefficients for equivalent axis from [6], the authors assumed that the number of reference wheelbases (100kN) for different traffic categories is approximately equal to the number of 60 kN loads. The results allow to determine the substitution thickness of the sub-base (from C8/10 concrete) based on the nomogram.

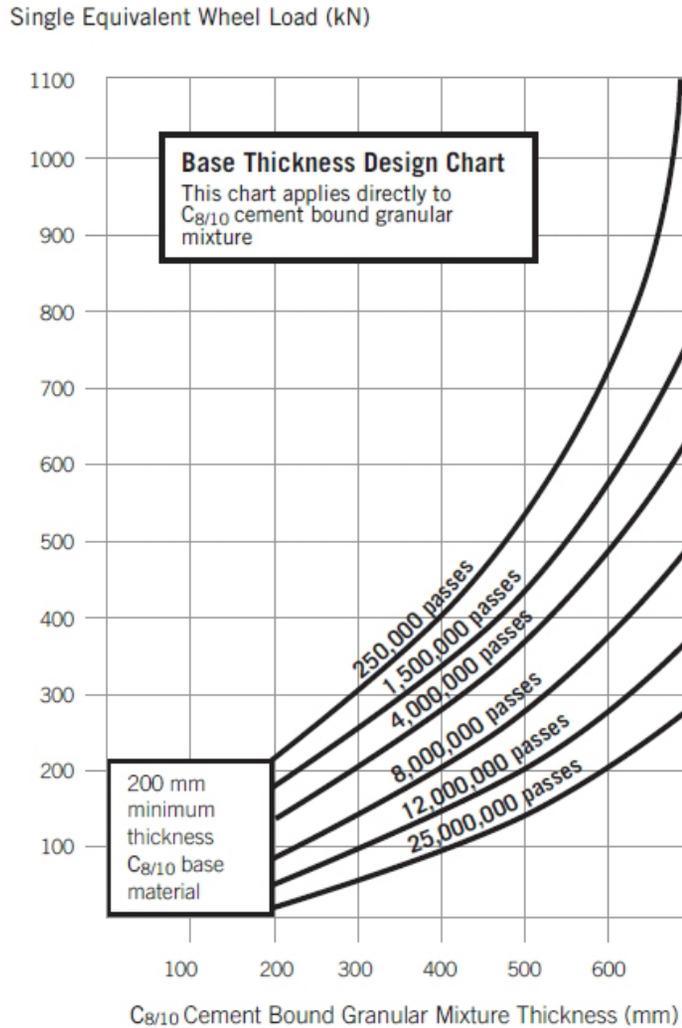


Fig. 3. Nomogram for determination of sub-base thickness expressed as a layer of bounded C8/C10 mix for different types of traffic [4] – similar nomograms exist for single loads (e.g. containers)

Despite assuming simplification while determining the equivalent loading, it appears that the increase of the traffic from KR1 to KR4 does not influence the required thickness of the designed surface road. Only in case of the KR5 traffic load (upper limit) it is required to increase the thickness of the base. It might be now assumed that the standard cross section of the parking lot and manoeuvre areas should look like the one presented in Figure 4.

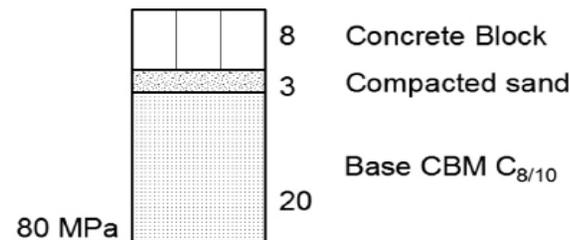


Fig. 4. Proposed cross-section of the road in parking lots and manoeuvre areas for heavy load trucks

The proposed solution is similar to the solutions presented in the non-operational 5th Appendix to the Technical Conditions [7,8]. The aforementioned solution differs in terms of required bearing capacity of the surface ($E_2 \geq 120$ MPa compared to $E_2 \geq 80$ MPa). The 5th Appendix permitted the use of stabilized crushed aggregate in the sub-base layers. The authors think that in case of KR1-KR2 traffic load different solutions can be easily applied, including stabilized aggregate. In case of surfaces exposed to KR3 and higher traffic load the sub-base should be constructed from hydraulically bound layers.

According to the [6], the included solution might be used in parking lots „under the condition of ensuring increased resistance of asphalt mixes to rutting“ (point 2.10). According to paragraph 6.7, the required traffic category on the parking lots and manoeuvre areas for heavy-load vehicles and buses should be K4 (with the exception of non-frequent parking lots, where it can be lowered to KR3). A typical cross-section with a sub-base made with hydraulically bound mix in accordance to [6] is presented in Figure 5.

Comparison of both types of constructions (Figure 4 and 5) even without a detailed economic analysis, allows to draw a clear conclusion. Based on the used materials and layer thickness it is easily visible that surface from concrete blocks designed based on the HDPPF method is far better.

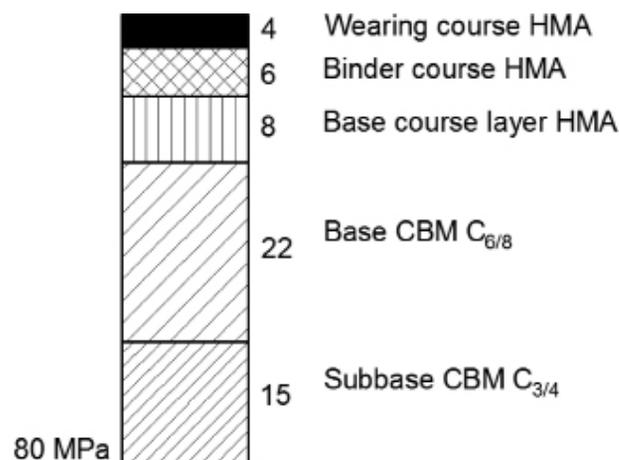


Fig. 5. An example of a solution presented in [6] for a KR4 traffic (parking lots and manoeuvre areas for heavy load trucks and buses) – includes a sub-base on a G1 foundation

6. SUMMARY AND CONCLUSION

Standard methods of designing road surfaces are not always the best choice in case of areas exposed to untypical heavy-load traffic. There is a constant need for determination of improved solutions, that include both technical and economic aspects. The presented designing method is simple and does not require any additional software. Simultaneously, it allows to design the road surface for specific heavy-load vehicles. The method can be also used in dimensioning of the concrete brick road surfaces

.REFERENCES

- [1] Kossakowski M., *Zasady Obliczenia grubości nawierzchni podatnych w projektach drogowych*, „Problemy Projektowania Dróg i Mostów”, 4 (1970).
- [2] Szydło A., *Nawierzchnie z betonu cementowego*, Polski Cement, Kraków 2004.
- [3] Hajduk P., *Projektowanie podłóg przemysłowych*, Wydawnictwo Naukowe PWN, Warszawa 2017.
- [4] Knapton J., *The Structural Design Of Heavy Duty Pavements For Ports and Other Industries*, 4th ed., Interpave, Leicester 2007.
- [5] Glinicki M., *Beton ze zbrojeniem strukturalnym*, [in:] *Materiały XXV Ogólnopolskiej Konferencji „Warsztaty Pracy Projektanta Konstrukcji”*, Szczyrk 2010, pp. 279-308.
- [6] *Catalogue of Typical Constructions of Flexible and Semi-Rigid Pavements, Annex to Regulation No. 31 of the General Director for National Roads and Motorways of June 16, 2014.* [7] Regulation of the Minister of Transport and Maritime Economy of 2 March 1999 on the technical conditions to be met by public roads and their location - published text, Journal of Laws. 1999, no.43, item. 430.
- [8] Announcement of the Minister of Infrastructure and Construction of 23 December 2015. on the publication of the uniform text of the regulation of the Minister of Transport and the Sea Economy on the technical conditions to be met by public roads and their location, Journal of Laws 2016, item 124.

Stanisław Majer
West Pomeranian University of Technology Szczecin, Poland
majer@zut.edu.pl

Bartosz Budziński
West Pomeranian University of Technology Szczecin, Poland
bbudzinski@zut.edu.pl

Przemysław Gardas
West Pomeranian University of Technology Szczecin, Poland
Przemyslaw.Gardas@zut.edu.pl