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Road and Rail Infrastructure III

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DESIGN MODEL FOR STATIC AND IMPACT LOAD AFFECTED PAVEMENTS

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Abstract

Pavements of aerodromes, container terminals, logistic terminals, areas of storage, parking lots, areas of waste utilization and etc. are affected by static and impact loads. These loads strongly influence pavement performance by causing permanent deformations and distresses in the surface and even sometimes pavement failure in the beginning of pavement exploitation. The types of structure, materials and layers thickness are the main factors relative to pavement performance. This paper aims to create a design model for static and impact load affected pavements.

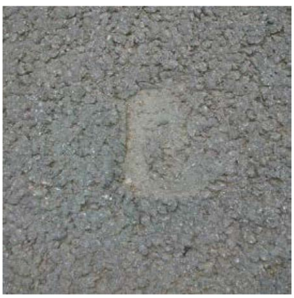
Keywords: static loading, impact loading, pavement distress, pavement structure, design model.

1 Introduction

There are many methods, procedures and guides for pavement structure design for roads or streets where usually is considered a moving heavy vehicle traffic load. There is an attitude that designed pavement is one in which there is no structural deterioration of the pavement either over time of design [1–3]. Mostly pavements are designed for 20 years according to equivalent single axle load which is accepted as 8 t, 10 t, 11.5 t or other depending on dominated traffic loads. However, pavement design procedures up for roads cannot be applied for others special objects such as parking aprons of aircraft, ports and containers terminals, logistics terminals, industrial areas, parking lots, waste recycling areas and etc., where different types of loading – static and impact loads – affect pavements.
Researchers describe wheel load as static, quasi-static or dynamic. A static load represents a constant load, which is defined by geometry of contact and mass of the load. A quasi-static load – a moving constant load, which is defined by stiffness and mass of the load without damping force in the equation of equilibrium. And a dynamic load – a changeable moving load, which involves inertia, damping, stiffness and mass terms in the equation of motion [4, 5]. From experience observed that falling object or special machineries induce impact loads. Impact load represents a force of potential energy, which is defined by multiplying object weight, drop height and acceleration of gravity. These kinds of loading produce many distresses in pavements of special objects.
Consequently, it is very important to design a stable pavement, i.e. pavement structure resistant to static and impact load. In other countries this kind of pavements are designed by using special design charts, guides, manuals and computer programs. However, in Lithuania is neither solution for design such pavements (there is regulated only design for roads (streets) pavements). Contribution to this is a lack of information about influence of different loading type to pavement structure and its performance. The aim of this article is to study types of pavement distresses, to analyze load specification and influence of climatic conditions to pavement performance and to suggest a design model for pavements affected by static and impact load.

2 Distresses of pavement structures affected by static and impact load

In general, pavement degradation is a function of pavement roughness, which is a sum of all types of distresses and increases with pavement age [6–8]. The type of pavement distress depends on the pavement structure and materials properties.
Due to easy construction and rehabilitation flexible pavements are the most common type of pavement structure using in Lithuania and in other countries. However, flexible pavement design life is shorter than rigid pavements and usually after 20 year of exploitation need full rehabilitation. Pavement distresses are classified in to: surface defects (raveling, bleeding and polishing), surface deformations (rutting, shoving, corrugation, bumps, heaves, settlements and blow ups (curling)), cracks (fatigue, thermal, longitudinal and slippage) and potholes. Though, in the asphalt pavements the most common distresses are fatigue cracking, rutting (permanent deformations) and thermal cracking, meanwhile in pavements affected by static and impact load – permanent deformations and thermal cracking.
Thermal cracking is primarily associated with cold temperatures (below 10 °C) at the surface of asphalt layer. Due to low temperature the binder film to get thinner around aggregates. When the temperature drops below the point where asphalt binder becomes brittle, thermal cracking is initiated in the surface of asphalt pavement and immediately grows down [9], [10].
Permanent deformations are associated with viscous-elastic-plastic properties of asphalt and variance of ambient temperature [3, 11, 12]. Four types of permanent deformation may occur in asphalt pavement [13, 14]: surface wear rutting, initial densification, structural deformations and plastic (flow) deformations (rutting). Bitumen binder properties decreases at high temperatures (to +60°C and more) influencing relaxation of asphalt mixture strength [15]. Examples of permanent deformation observe in pavements of special objects are shown in Figure 1. In most cases this kind of deformation develops in surface (wearing) layer of asphalt pavement.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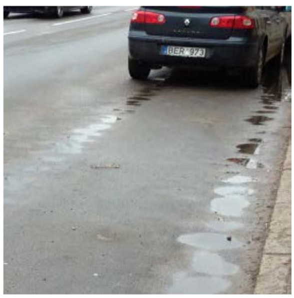
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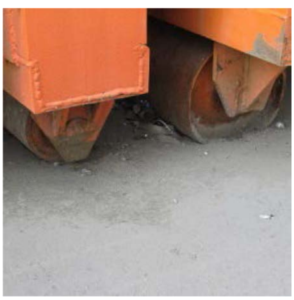
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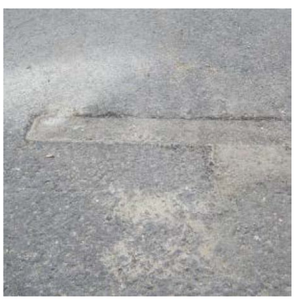
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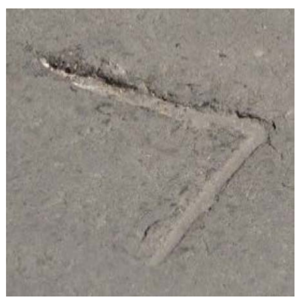
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Figure 1 Examples of permanent deformation observe in pavements of special objects: a) port; b) parking lot; c) parking apron of aircraft; d) e) f) industrial area

3 Load specification and climatic conditions

The static and impact load usually delivers from aircrafts, containers, handling equipment (rubber tire gantry cranes (RTGs), straddle carriers, reach stackers, front lift trucks, side loader lift trucks and etc.), storage goods, trucks, cars and/or falling stuff. In areas where is considerable expectation of this kind of loading, the magnitude of loads and loading time is higher comparing with traffic loads. Moreover, loads are concentrated and affect pavement within small contact area. Consequently, it leads high pressure into pavement. Contact pressure strongly depends on contact area load, which is influenced by high of stacking (if source of load is stackable). Into Table 1 is taken contact pressure considering to characteristics of the load source. It is emphasized that contact pressure to pavements affected by static and impact load is significantly higher comparing with contact pressure applied in roads pavements. On purpose to simplify calculations a tire-pavement contact area is assumed as a circle area equals to ellipse's (rectangle) area. This contact area changes by increasing/decreasing magnitude of load and/or by changing inflation pressure [16]. However, common the tire-pavement contact pressure is assumed equal to inflation pressure. Impact load is characterized by drop height and/or weight of falling object. As these characteristics increase, the negative effect of this kind of load to pavement performance increases, too.

Table 1 Contact pressure considering to characteristics of load source[a)]

Object (load source)	Contact area [mm^2]	Maximum high of stacking	Contact pressure [MPa]
Aircraft	[b)]	–	0.3-1.7[c)]
Handling equipment of ports	[b)]	–	0.7-1.7
Container	26250	6-8 (12)[d)]	2.59-12.5[e)]
Heavy vehicle	[b)]	–	0.6-1.0
Trailer dolly (wheel)	8800	–	35-40
Trailer pivot plate	33750	–	2.0
Handling equipment of industrial areas	[b)]	–	0.5-1.0
EuroPallet	116000	2-4[f)]	0.03-0.44[g)]
Car	[b)]	–	0.20-0.25

a) Sources of impact load are not included in to table due to their large variety.
b) The leg of load source is wheel. Contact area of tire-pavement depends on characteristics of tyre.
c) Contact pressure depends on type of aircraft.
d) Fully loaded containers are usually stacked up to 6 high and empty containers – 8 high. In some cases containers can be stacked up to 12 high.
e) When only 1 container is on the pavement the contact pressure is 2.59 MPa, when conteiners are stacked up to 8 high – 12.5 MPa.
f) EuroPallets are usally stacked up to 2 high for transportation and up to 4 high for storage.
g) When only 1 EuroPallet with goods is on the pavement the contact pressure is from 0.03 MPa depending on the weight of goods, when EuroPallets with goods are stacked up to 4 high – by 0.44 MPa depending on the weight of goods.

In design process of special objects should be paid attention to different loading, i.e. static (containers, standing equipment, storage goods and etc.) and slow dynamic loading (handling equipment's movements, cornering, accelerating and braking). Mostly, slow dynamic loading is assessed by applying a load multiplication factor.
Climatic conditions such as temperature, moisture, frost and number of freeze-thaw cycles strongly influence pavement performance and exploitation. Climatic conditions in Lithuania are similar to other cold regions countries. There temperature of asphalt pavement surface varieties from -22°C to +53°C [17]. Moreover, number of freezing/thawing cycles of pavement

surface exceeds 80 times and more in year [18]. Consequently, pavement structure is designed evaluating resistance to frost heave.
It is well known, that moisture influences the behavior of unbound layers, while temperature – the stiffness (elastic modulus) of bituminous layers and thermal stresses in cement layers. Pavement failures (distresses) related with high moisture content in unbound layers is common phenomenon in cold region pavements [19-21]. Increasing water content leads more permanent deformations in unbound layers [20]. Moisture content and pavement stiffness depends on season, because pore water crystallizes into ice lenses during cold season conditioning increase of stiffness of unbound layers [20, 21]. The negative influence of moisture and frost to pavement structure performance is solved by ensuring sufficient drainage and thickness of whole pavement structure, respectively.
Variations of temperature affect the viscous-elastic-plastic properties of asphalt pavement. The elastic modulus decreases as the temperature increases and increases as the temperature decreases [21]. In design process, it is assessed by including the non-linear asphalt behavior.
In the rigid pavements, daily temperature variations lead curling of the slab: the slab blows up (expansion of the pavement surface) when the top of the slab is warmer than the bottom of the slab (daytime) and the slab blows down (contraction of the pavement surface) when the top of the slab is cooler than the bottom of the slab (nighttime). Furthermore, the temperature variations give thermal stresses in the slab, which must be estimated in process of pavement design [22].

4 Pavement structure design model

All types of pavement structure are used for areas affected by static and impact load. According to pavement structure layers and materials mechanical performance pavement structures are:

- Flexible – asphalt layer(-s) or stone/concrete blocks on unbound granular base or asphalt base layer.
- Rigid – concrete layer(-s) or stone/concrete blocks on bound granular base or asphalt base layer or concrete layer.
- Composite – semi-rigid/semi-flexible – ultra-thin concrete layer or concrete paving flags on flexible pavement structure, asphalt layer(-s) on concrete pavement, pours asphalt with cement grout on flexible pavement structure.

Foreign countries practice has shown that traditionally pavements of special objects have been design using design charts. According to them the whole thickness of pavement structure and/or each thickness of pavement layer are selected. However, this design method has low accuracy. Consequently, other design model should be applied instead of design charts. In our opinion design charts could be used only for selection of whole thickness of pavement structure and the upper part of the pavement (generally wearing layer) should be analyzed separately according to development of permanent deformations and thermal cracks.
Considering to foreign countries practice and normative requirements or guides of pavement design for special objects, there is suggested a design model for pavements affected by static and impact load (Fig. 2). A design model consists of three main parts: field of application, input data and analysis procedure. Following design process step-by-step, the designer selects the best solution for new or rehabilitated pavement structure depending on environmental/climate conditions, structural conditions, design materials and loading conditions.

FIELD OF APPLICATION					
Parking aprons of aircraft	Ports and containers terminals	Logistics terminals	Industrial areas	Parking lots	Areas affected by impact load

INPUT DATA

	Characteristic	For new construction	For rehabilitation
Environmental /Climate conditions	• Environmental temperature	+	+
	• Pavement temperature		+
	• Moisture	+	+
	• Hidrothermal conditions of pavement structure		+
	• Frost heave		+
	• Depth of freeze	+	+
	• Ground water level	+	+
Structural conditions	• Pavement structure composition, condition and materials		+
	• Bearing capacity of pavement structure and separate layers		+
	• Subgrade conditions, materials (soils) and bearing capacity	+	+
	• Embankment conditions and materials (soils)	+	+
	• Distress types and levels		+
Design materials	• Asphalt mixture	+	+
	• Asphalt with cement grout	+	+
	• Portland cement concrete (PCC)	+	+
	• Concrete paving blocks, flags	+	+
	• Layer bonding materials	+	+
	• Bonded granular layer materials	+	+
	• Unbounded granular layer materials	+	+
	• Soils (subgrade/embankement)	+	+
	• Special materials	+	+
	• Special rehabilitation materials		+
Loading conditions	• Type of loading	+	+
	• Gross weight	+	+
	• Contact load	+	+
	• Load interval frequency	+	+
	• Load-pavement contact area	+	+
	• Contact pressure	+	+
	• Maximum drop weight (impact loading)	+	+
	• Maximum drop height (impact loading)	+	+
	• Forecasting (history)	+	+

ANALYSIS PROCEDURE

	Model	Criteria	For flexible/ composite pavement	For rigid pavement
Pavement response to load	• Multi-layer linear elastic model	Calculate stresses, strains, deflection	+	+
	• Multi-layer viscoelastic model		+	
	• Finite difference method		+	
	• Boundary element method		+	
	• Finite element model		+	+
Pavement response to frost heave	Empirical (from experience)	• Max. freeze depth	+	+
		• Min. pavement structure thickness	+	+
		• Allowable moisture content in structure (during thaw season)	+	+
Performance (Design) criteria	• Alligator cracking (bottom-up)	• 10-35 % lane area	+	
	• Fatigue cracking (bottom-up)	• 10-35 % lane area	+	+
	• Permanent deformation	• 10-17 mm rut depth	+	
	• Thermal cracking	• 95-133 m/km	+	+
	• Flow deformation	• 10-17 mm rut depth	+	
	• Mean joint faulting	• 4-6 mm		+
	• Slab cracking (frost heave)	• 10-20 %		+
	• Ponchouts			

Figure 2 Flow chart of pavement structure design model

5 Conclusions

In Lithuania pavement structures for special purposes are designed according to experience and standardized pavement structure catalogue for roads. There is lack of procedures, requirements, guides and/or manuals for it.

For special purposes pavement structures long-term static or short-term impact loading are assumed as most common negative factor for pavement distress. Moreover due to brittle of bitumen at low temperature thermal cracking is assumed as very significant distress, too.

Considering to specification of static and impact loading, especially to wide range of contact pressure (from 0.03 MPa up to 40 MPa), design procedures for pavement structure of roads and streets cannot be applied for pavements of special objects – terminals, aprons, parking and storage lots.

The negative influence of moisture and frost to pavement structure performance is solved by insuring sufficient drainage and thickness of whole pavement structure, respectively. While influence of temperature is assessed by different stiffness (elastic) modulus of bituminous layers and thermal stresses in cement layers.

Research represents pavement structure design model with three main objectives: field of application, input data (environmental/climate conditions, structural conditions, design materials and loading conditions) and analysis procedure (pavement response to load, pavement response to frost heave and performance (design) criteria).

The established model will be extended after pavement structure materials experimental research results analysis.

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