THE BRAKE DECELERATION OF THE FORKLIFT TRUCKS AND THE WAREHOUSE SAFETY

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Abstract
The article is comparing the braking deceleration of two front forklifts, a new and a slightly used forklift truck, with technically identical specifications. The focus of the article is on the braking effect of the new and slightly used trucks and the operational safety. The results were compared with the required braking deceleration according to the standards for granting a technical control. Later, the safety aspects in normal warehouse operation were evaluated 32% more control force was applied to the brake pedal on the forklift with the new brakes in comparison with the slightly used forklift, where about 18% less braking deceleration was achieved. Although both forklifts meet the standard norms, the difference in braking effect can create a collision situation. Such instance can be avoided if the forklift is slightly used before its normal operation.

Key words: *brake deceleration; forklift; warehouse safety.*

INTRODUCTION

Large proportion of the handling trucks' final braking deceleration is influenced by the brakes' construction, the types of materials and the condition of the individual structural elements
(Swiderski, et al., 2019). Generally, with the change of the brake linings and other friction elements, precaution and anticipation of a lower braking effect is recommended *(Arman, et al., 2018)*. This is rather common, if the brake components on an older forklift wear out and are replaced by new ones *(Liu, et al., 2014)*.
In the same way with a new handling truck, as with the road vehicles, it's often automatically expected that everything in the new handling truck functions impeccably. It is strongly recommended not to load the new vehicle with 100% weight at the beginning of its use, but to run it down slightly before *(Tretsiak, 2012)*. But what about the braking effect? Usually, no recommendations and restrictions are given. At the same time, when taking into an example the case of forklift trucks, this is a very important aspect from the warehouse safety operation point of view. Especially when considering, that multi-ton forklifts often operate with loads of similar weight to the forklifts *(Horberry et al., 2004)*. The warehouse spaces are very limited and even though the forklifts move at slower speeds, a contact with the pedestrians could be dangerous *(Lehtonen, et al., 2021)*. Therefore, the magnitude of the braking effect is an important safety parameter.
Safety in the warehouses can be improved by using slightly used forklifts.
The aim of the study is to evaluate the safety of using new forklifts in the warehouse in relations to its braking efficiency values.

MATERIALS AND METHODS

A decelerometer was used to measure braking deceleration on the forklift, which was placed next to the driver in a horizontal position. It was secured against movement with a locking screw. A CT 3010 type decelerometer with production number 16107 was used during the measurement, the current calibration was valid. The pedometer was placed on the brake pedal.


Fig. 1 Tested forklifts


Fig. 2 Pedometr location

The measurements of the forklifts braking deceleration were carried out at the premises of Toyota Material Handling CZ in Rudná u Prahy. The measurements took place in outdoor areas and then in the warehouse of the Toyota MHCZ company. During the experiment, the outside temperature was 29 °C and 24 °C in the warehouse. Both surfaces' tops were dry. In the outdoor conditions, the braking deceleration was measured on an asphalt surface, in the indoor spaces the braking deceleration was measured on a concrete surface. The measurements were carried out only on the front forklifts with a seated operator, where the presence of the decelerometer is permitted. A front four-wheel forklift with a Toyota type 02-8 FDF20 combustion engine was used for the measurements. Each measurement was performed repeatedly, at least five times. Table number 1 lists the parameters of the front carriages, which can be found from the identification labels and which must be on each handling technique. For the clarity of the differences between the forklift trucks used, the cells of the table are divided by the shades of grey colour. The forklift marked in light grey and with the letter N is a completely new forklift that was only used to test the technical condition for the under carried measurements. The data marked in dark grey are the parameters of the used forklift that was already in operation at the Toyota MHCZ rental company. The data marked in white are completely identical.

Tab. 1 Technical parameters of the forklifts

Toyota – front forklift	N	
Model	02 -8FDF20	
Series number	66719	60197
Total weight	3790 kg	
Front tire size	7.00-12/5.00	
Tire pressure	SOLID	
Back tire size	6.00 -9/ 4.00	
Year of manufacture	2018	2015
Working hours	2 mth	3640 mth

The functionality of the braking system is evaluated by using the average deceleration and the maximum force applied to the brake pedal. The applied force on the brake pedal must be checked and must not exceed the prescribed control force on the service brake table below the text. To grant a technical inspection, the braking deceleration value must correspond to the values specified in the methodology for carrying out technical inspections: NV No. 176/2008 sb., ČSN EN ISO 3691-1, and ČSN ISO 6292. The standards are given by the Engineering Testing Institute in Jablonec nad Nisou. Super elastic tires, marked SE, were used. The brands Solodeal Magnum grey colour 7.00-12/5.00 for the rear wheels and Solodeal Magnum grey colour 6.00-9/4.00 for the front wheels. The dimensions were chosen accordingly to the identification plate of the machine.

The distance was calculated from the measured deceleration according to relation number 1

$$s = \frac{1}{2}at \qquad (1)$$

where s is distance[m], a is deceleration [m/s^2], t *is* time [s]

The speed v [m/s] was calculated according to the relationship number 2:

$$v = \sqrt{2 \cdot a \cdot s} \quad (2)$$

where a is deceleration [m/s^2], s is distance [m]

The calculation of the braking force B [kN] is given in relation 3

$$B = m \cdot a \quad (3)$$

where, m is weight [kg], a is deceleration [m/s^2]

Used relationship number 4 to detect braking C_b [%]:

$$C_b = \frac{a}{g} \cdot 100\ [\%] \quad (4)$$

where a is deceleration [m/s^2], g is gravitational deceleration [m/s^2],

Braking power P_B is calculated according to the relationship number 5

$$P_B = B \cdot v \quad (5)$$

where B is braking force [kN], v is speed [m/s],

RESULTS AND DISCUSSION

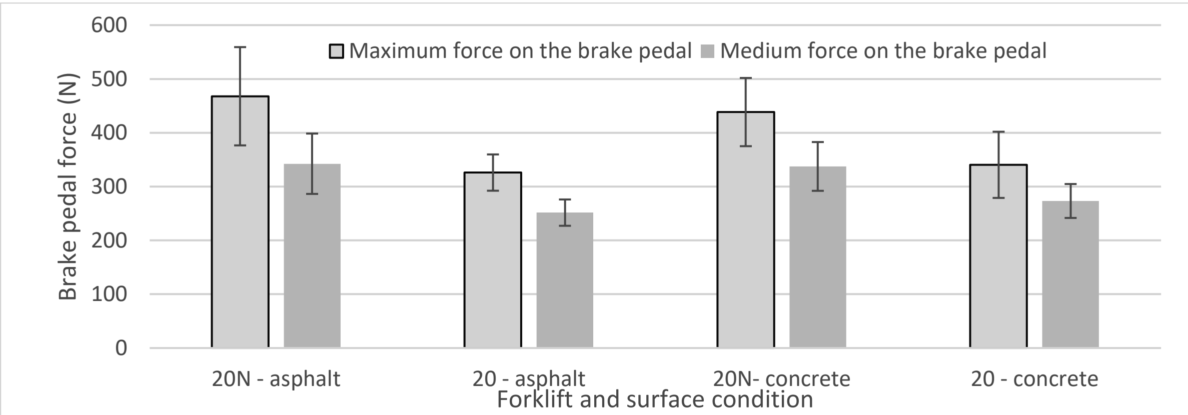

Fig. 1 Brake pedal force applied

Fig. 3 shows the amount of the brake pedal force on asphalt and concrete surfaces for a forklift with new (20N) and used brakes (20). The maximum values that were recorded during the measurements and the average values are listed. From Fig. 3, it is apparent that the truck with the new brakes used approximately 32% more control force on the pedal than the truck with the used brakes. According to ANOVA, the result is significant.

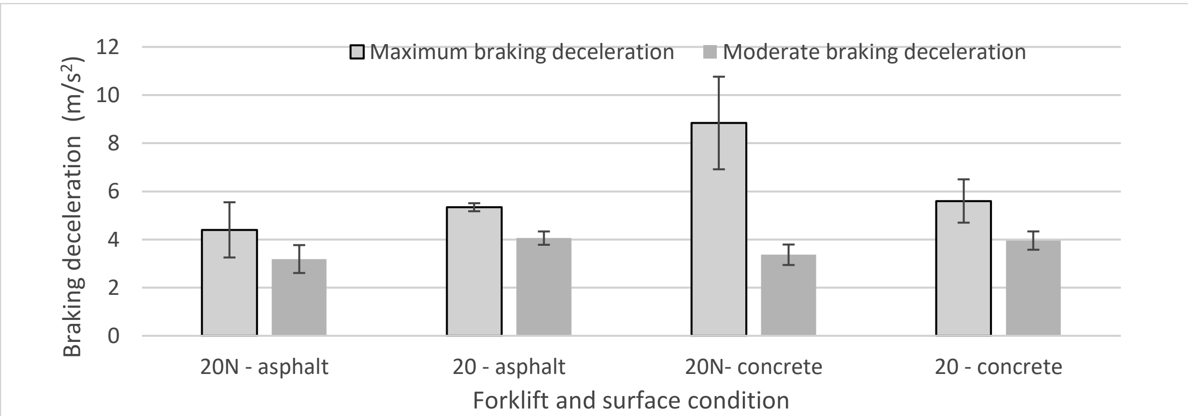

Fig. 2 Braking deceleration on different surfaces

Fig. 4 shows the achieved deceleration on asphalt and concrete surfaces for the forklift with new (20N) and used brakes (20). The maximum values that were recorded during the measurement and the average values are listed. From the Fig. 4 it is clear, that the forklift with new brakes achieved approx. 18% lower braking deceleration than the forklift with the used brakes. According to ANOVA, the result is not significant.

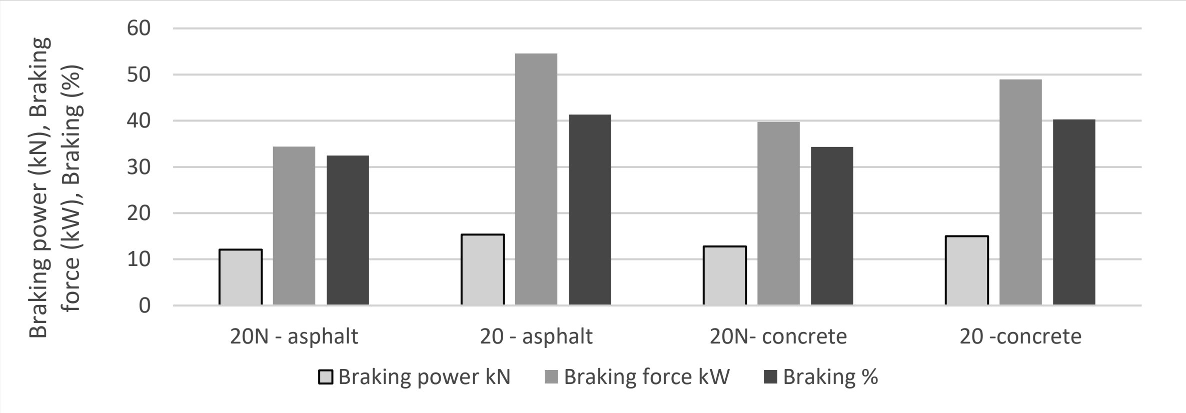

Fig. 3 Comparison of braking force, braking performance and braking

Fig. 5 shows a comparison of the achieved braking power, braking performance and braking on asphalt and concrete surfaces by a forklift with new (20N) and used brakes (20). From the Fig. 5, it is evident, that the forklift with the new brakes achieved approx. 18% lower braking force, approx. 28% lower braking power and approx. 7.5% lower braking than the truck with the used brakes *(Halawa, et al., 2020).* According to ANOVA, the result is significant.

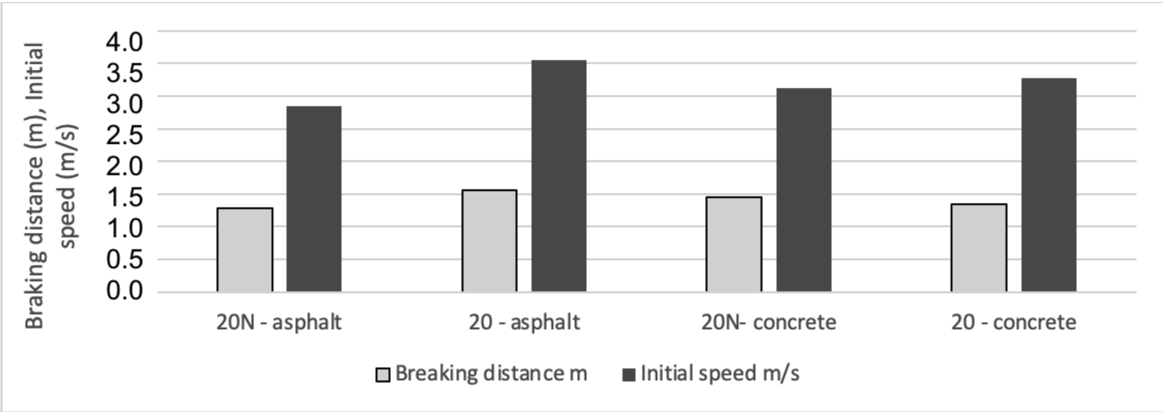

Fig. 4 Braking distance at initial speed

On basis of the collected measurements for medium power deceleration and the time of decelerating, the braking distance and the entry speed were calculated. The values are shown in the Fig. 6. The objective was to achieve a similar entry approach speed; the achieved value was 3.20 ± 0.29 m/s for all recorded measurements. The braking distance values are put into the context of the approach speed with the values of achieved deceleration (*Stein, et al.*, 2018). According to ANOVA, the result is not significant.

Fig. 7 The ratio of braking power between the new and used brakes expressed in percentage: a) asphalt, b) concrete

A comparison of the braking force values is shown in Fig. 7 on asphalt and concrete surfaces by a forklift with the new (20N) and the used brakes (20). The values of the braking force are shown on the pie chart proportionally and are presented in the percentage values. It is clear that in both cases, of asphalt and concrete surfaces, a higher braking force (by approx. 10%) is achieved by the forklift with worn brakes, despite the fact that the new forklift achieves approx. 13% higher control force on the brake pedal (Fig. 8).

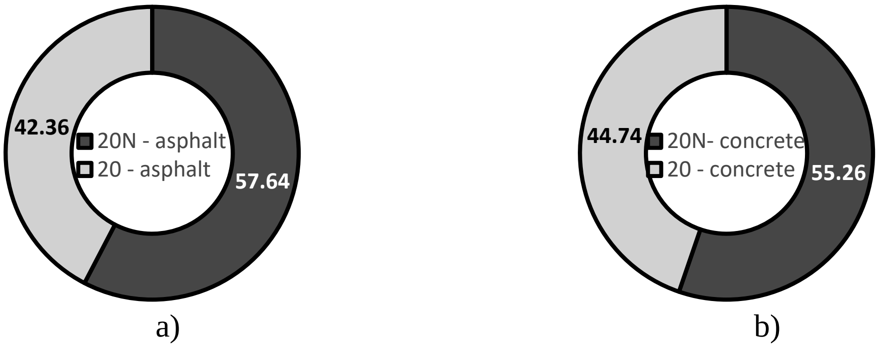

Fig. 8 Brake pedal force ratio between new and used brakes expressed as a percentage: a) asphalt, b) concrete

Braking distance and safety in warehouses also depends on many factors especially on human (*Horberry, et al., 2004*).

CONCLUSIONS

From the point of view of the forklift safety operation with new and used brakes, the following can be stated.

- From the point of the regulations view, it can be stated that the maximum developed force on the brake pedal (max. 600 N) was observed and both front forklifts met the requirements of the standard for handling technology with a maximum nominal load capacity of up to 16,000 kg and a speed in the range of 5 to 13 .4 km/h (1.39 to 3.72 m/s).
- On the forklift with new brakes, approx. 32% more control force was applied to the brake pedal than in the case of the forklift with used brakes, and yet approx. 18% lower braking deceleration was achieved.

The forklift with new brakes also achieved lower braking force (approx. 18%), lower braking power (approx. 28%) and lower braking than the truck with used brakes (approx. 7.5%).

In the case of asphalt and concrete surfaces, a higher braking force (about 10%) is achieved by the forklift with used brakes, even though the new forklift achieved about 13% higher control force on the brake pedal.

In general, it is therefore necessary to consider that during the first few hours of operation, the efficiency of the brakes will be higher with the used brakes than the new brakes. This can have a negative effect,

especially in a situation where a truck driver operating on a slightly used forklift, unexpectedly receives a forklift with the new brakes and is not advised about the situation accordingly. Although the forklift meets the standards, the difference in the braking effect can create a collision situation. The reaction of the driver and his experience is an important factor for safety in the warehouse, as has already been found *(Halawa, et al., 2020)*.
Such instance can be avoided by test-driving loaded truck intentionally before its normal operation. When a forklift is driven, there is a slight wear on the tires, which increases adhesion, whilst a slight wear on the brake lining, increases the braking power.

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