Influence of racking equipment parameters on the capacity of a covered warehouse

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Abstract. Warehouses located at cargo transfer points between different modes of transportation perform important functions in transforming cargo flows for further efficient transportation. When designing a warehouse for unit loads, the best method of cargo storage must be chosen, ensuring the fullest use of the warehouse area and minimal costs for moving cargo within the warehouse. Mathematical models have been proposed that establish relationships between individual parameters of a unit load warehouse. These models have been used to study the mutual influence of parameters on each other, as well as to determine the capacities of unit load warehouses.

1 Introduction

The need for their timely delivery imposes requirements both on the transportation process and on warehouse technologies. Warehouses located at cargo transfer points from one type of transport to another perform important functions in transforming cargo flows for further, more efficient transportation. The efficiency of delivery depends significantly on how well-equipped and organized these transport warehouses are.

When designing, reconstructing, or optimizing a warehouse for piece goods, it is necessary to choose the best method of storing goods, the type, and parameters of the shelving equipment. At the same time, the warehouse area should be filled with goods as much as possible, and the costs of moving goods inside the warehouse should be minimized. Currently, the storage area of the warehouse is the bottleneck in the warehouse system. This phenomenon is associated with the highest occupancy, low labor productivity, and in some cases the use of unskilled labor.

Usually, the shelving and aisles in warehouses for piece goods are arranged perpendicular to each other, as shown in Figure 1.

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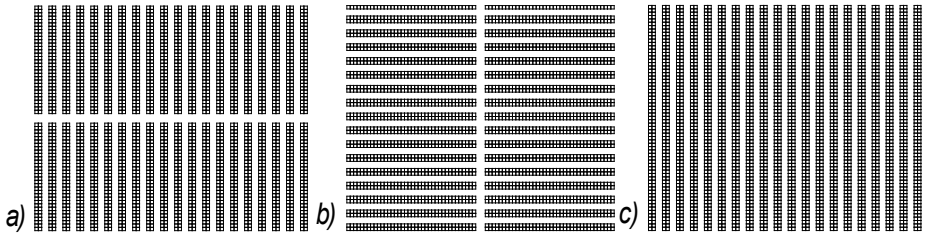

Fig. 1. Traditional warehouses equipped with frame racks.

The traditional arrangement of shelves has its advantages in terms of the number of storage spaces for goods, but also has disadvantages in terms of increasing operating costs associated with the distance that loading and unloading machines have to travel from loading and unloading points to storage spaces. Existing methods for calculating the capacity of warehouses for piece goods are not sufficiently perfect. There is a need to refine and supplement existing methods and develop a more accurate way of calculating the capacity of warehouses for piece goods. Various sources of literature discuss the rational arrangement of frame shelves, but many recommendations are not substantiated. In this work, there are questions about:

- the arrangement of shelves in the width of the warehouse;
- the stacking of pallets in the depth of the shelf;
- the capacity of the warehouse in height;
- the rational ratio of width and length.

2 Literature review

The problem of determining the area of a warehouse, primarily in the storage area, is explored in article [2]. The procedure for finding the optimal solution for warehouse design is discussed in article [3], which considers costs in three stages: initial investment costs (construction and maintenance of facilities), inventory costs, and costs associated with warehouse capacity. Additionally, article [3] presents a procedure for finding the optimal design for the storage area, including analytical optimization methods and modeling. Elements that influence the required capacity of a warehouse in a stochastic environment are examined in study [4]. The required capacity is measured in terms of its deviation from the nominal required capacity (NCR). A simulation model is also developed in the study to measure the relationship between warehouse capacity and various corresponding parameters. Study [5] is dedicated to minimizing the total cost of inventory by optimizing the storage area of the warehouse. In article [6], the problem at hand is determining the optimal size of a warehouse used for storing products for a limited time. Article [7] presents a detailed review of research on warehouse planning and its effective evaluation, discussing each area of the warehouse, including the storage area for goods. Authors of article [8] developed a deterministic inventory model that allows for determining rational warehouse operations for various storage times of goods. Article [9] presents an inventory model with a demand coefficient that depends on warehouse capacity. It is assumed that the demand level is a polynomial function of the current inventory level in the warehouse. Article [10] presents an approximate approach for determining container capacity. Study [11] aims to find rational values for container terminal parameters, specifically the capacity of the storage area. The goal of article [12-16] is to show that various factors, such as loading, unloading, and storage in the warehouse, affect cargo delivery, which are described in the article.

3 Determination of the main parameters of the warehouse storage area

The capacity of the warehouse for packaged goods is determined by the number of cargo storage units located in its storage area. When designing a storage area, it is necessary to choose the most rational way of storing packaged goods, the type of storage units, racking and handling equipment. At the same time, it is necessary to completely fill the storage area of the warehouse with cargo units and maximize the use of storage volumes. The capacity of the warehouse for packaged goods is determined by formula 1.

$$R = x \cdot y \cdot z \tag{1}$$

where x is the number of transport packages located along the width of the warehouse building;

y is the number of transport packages along the length of the warehouse building;

z is the number of tiers along the height of the warehouse building;

The number of transport packages located across the width of the warehouse building can be determined by the following formula:

$$x = 2 \cdot \varepsilon \left\{ \frac{B - B_e - B_0}{B_a + 2 \cdot (a + w)} \right\} \tag{2}$$

where 2 is the number of racks in a section consisting of two racks and a passage between them;

B is the width of the covered warehouse, mm;

B_0 – part of the width of the covered warehouse, which cannot be occupied by racks, mm;

B_a – width between racks for handling equipment, mm; Be is the width of the receiving-departure expedition, mm;

a – is the length of the transport package, mm; w is the gap between the pallet and the rack structure, mm;

The number of transport packages along the length of the racks is determined by the formula (3).

$$y = 3 \cdot \varepsilon \left\{ \frac{L - n_a \cdot L_a}{l_1} \right\} \tag{3}$$

where L is the length of the covered warehouse, mm;

L_a is the transverse width of the passage through the covered warehouse, mm;

l_1 is the length of the rack cell (for pallets with dimensions of 1200 × 800 mm, the length of the cell is exactly 2800 mm, and for pallets with dimensions of 1200 × 1000 mm, the length of the cell is 3300 mm);

n_a is the number of transverse passages along the length of the warehouse:

$$n_a = \varepsilon \left\{ \frac{L}{a} \right\}$$

3 - the number of pallets placed in a standard cell.

The number of tiers in height is determined by formula 4.

$$z = \varepsilon \left\{ \frac{H - h - C}{C} \right\} + 1 \tag{4}$$

where H is the height of the covered warehouse, mm;

C – height of the tier, m, is determined by the formula: $C = 150 + c + e$ (where 150 mm is the height of the pallet, c is the height of the load on the pallet, mm; e is the height dimension equal to the thickness of the longitudinal beam of the frame rack and the gap

between the load and the bottom of this beam of the next tier in height, take e = 200 - 300 mm);

1 – additional upper tier;

h – the gap between the upper load in the rack and the bottom of the floor trusses is equal to 500 mm. (used to install pipelines, lighting devices, etc.);

$\varepsilon\{...\}$ – designation of the integer part of the number resulting from the execution of actions in brackets (rounding down the whole number).

4 The question of the ratio of the width and length of the warehouse

When designing warehouse buildings, indicators such as column pitch, span and height of the warehouse are used. The column spacing is the distance between the main transverse supporting structures (usually the column spacing is 6 or 12 m). Span - the distance between the longitudinal supporting structures (12, 18 and 24 m). The height of the warehouse is the distance between the finished floor level and the bottom of the floor trusses. For a covered warehouse to meet the requirements of rational technology, it must have a certain ratio of length and width. Ratios 1:2 are considered the most rational; 1:2.5; 1:3; 1:5.

Indicators of the capacity of warehouses for packaged cargoes, considering the use of width and length in ratios of 1: 2; 1:2.5; 1:3; 1:5 and the height of the warehouse building are shown in Figure 2.

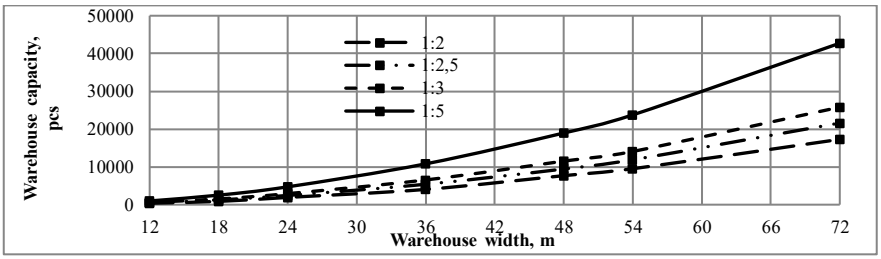

Fig. 2. The dependence of the capacity of cargo units on the width with different ratios to the length at a warehouse height of 7.2 m.

From Figure 1 it can be seen that the ratio of width and length of 1:5 provides the largest storage capacity, this is quite understandable and does not require further explanation.

5 Question about stacking the pallet in the depth of the rack

Pallets are recommended to be installed with the long side deep into the rack to obtain the largest storage capacity. The correctness of such a solution can be reliably confirmed (or refuted) by calculations using the above mathematical formulas.

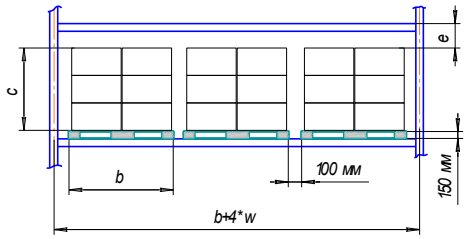

Fig. 3. Stacking the pallet with the short side b in the depth of the rack

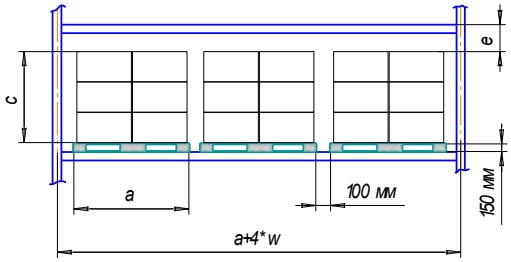

Fig. 4. Stacking the pallet with the long side a in the depth of the rack

The results of pallet stacking calculations for the considered options are shown in Figure 5.

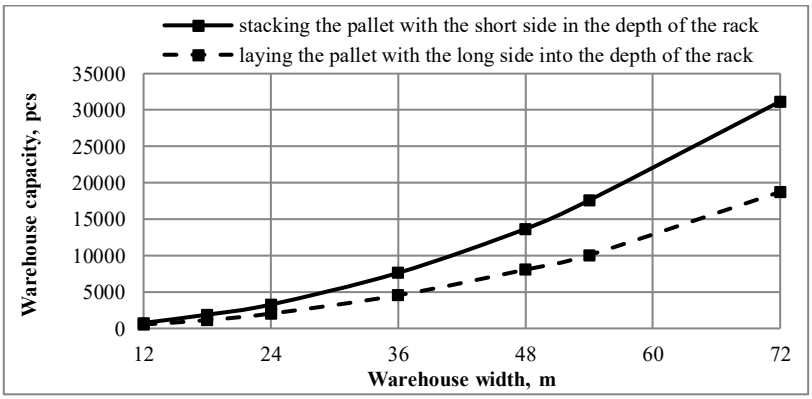

Fig. 5. Dependence of warehouse capacity at a ratio of length and width 1:3

The graphs in Figure 5 show that it is indeed recommended to install the pallet with the long side into the depth of the rack to obtain the highest capacity.

6 Question about the location of the racks according to the width of the warehouse

When calculating the capacity of a warehouse, piece-packed racks equipped with frame racks are installed along the long side of the warehouse, however, a reasonable decision is given extremely rarely (see Figures 6 and 7).

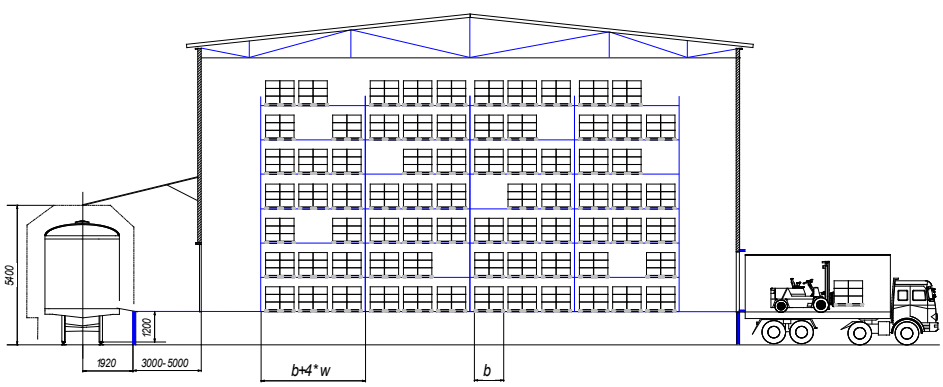

Fig. 6. Long side of shelving placed across the width of the warehouse

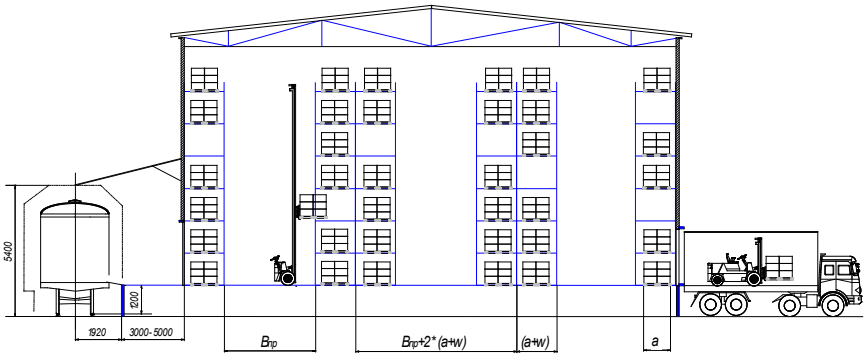

Fig. 7. Long side of shelving along the width of the warehouse

Figure 8 shows the result of a study of choosing a rational arrangement of frame racks.

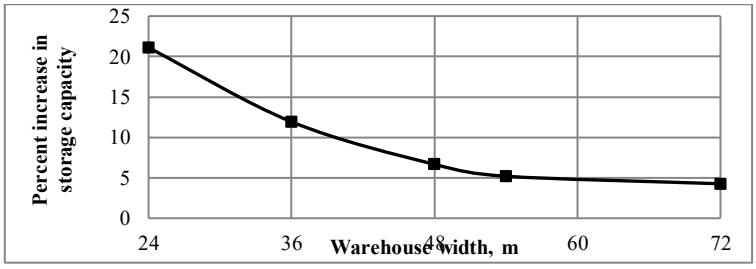

Fig. 8. Percentage increase in capacity when installing shelving along the long side of the warehouse

From Figure 8 the capacity of the warehouse increases when racks are installed along the long side of the warehouse.

7 Warehouse height question

The number of tiers along the height of the warehouse building is determined depending on the useful storage height and the height of the transport package (see Figure 9).

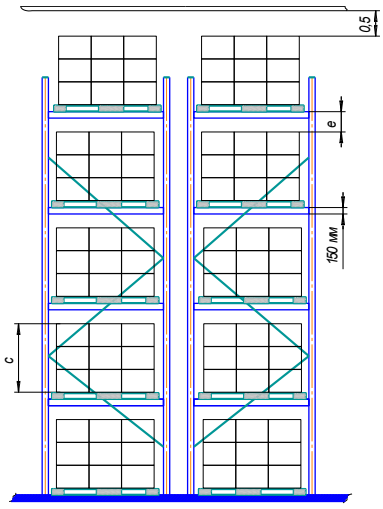

Fig. 9. Number of tiers in height