Choosing the appropriate way of plastering works for transportation and construction facilities

Eliza Gumerova[1], Olga Gamayunova[1] and Roman Gorshkov[2]

[1]Peter the Great St.Petersburg Polytechnic University, Polytechnicheskaya, 29, St. Petersburg, 195251, Russia
[1]Moscow State University of Civil Engineering, Russia, 129337, Moscow, Yaroslavskoye shosse, 26

E-mail: eliza_gumerova@mail.ru

Abstract. The development of transport infrastructure causes the need of faster, and more improved method of construction technologies. Plastering works are a complicated technology using manual and mechanized methods. The article compares the ways of production of plaster works and defines cases of using each method of plaster works that improve the efficiency of finishing work in the construction of residential and public buildings and marine vessel.

1. Introduction

Current state of the construction is characterized by gradually increased requirements to the quality of works and their cost-effectiveness. Finishing work is the closing stage of construction. Protection of building structures from harmful environmental influence, increasing their lifespan, giving the surface a beautiful appearance and improving of sound insulation and fire protection are the purposes of its functions [1]. Plastering works, as the part of finishing works, are one of the most challenging type of works at the construction site. The total labor input takes up to 25% and the total cycle time is about 30% for the manufacture of plastering works during the construction of various facilities [2].

Modern construction requires automation of most processes on the construction site. Using the mechanized way of plastering works ensures the possibility of rise in the economic and quality rates of the process of production.

We will explore the technological features of the internal plastering works using the manual and mechanized methods, their advantages and disadvantages and define the economic efficiency (cost and time of production of the work) of carrying out plastering works using manual and mechanized ways in the selected building project.

2. Types of plastering works

Types of plastering work can be classified in several ways. Each of them has its own features which depend on conditions, place of finishing and necessary result [3]. Plastering works can be divided into two groups by leveling methods: wet and dry plaster.

Dry plaster is a facing of surfaces with gypsum boards which are prefabricated and have a various characteristics depending on its use. Finishing work with application of gypsum boards is a facing of walls and ceilings, an assembly of partitions. Dry plaster can be used only for finishing works indoors, because plasterboard consists of the cardboard which can not withstand long atmospheric effects. The dry plaster is also less reliable and does not have as good characteristics of maintenance as the wet

plaster has.

In wet plastering work, plastic mixtures and solutions are used. It is used everywhere for finishing works on facades of buildings and in internal premises [4-7].

A wet plaster is multilayer:

- "scratch coat" is a mandatory preparatory layer, the strength of subsequent layers depends on quality of the first plastering layer;
- brown coat is a basic layer. It is usually 10mm to 20mm thickness, due to the conditions of the site it can be thicker. The lining is required after its drying;
- the skim or finish coat is usually applied to a thickness of 1 mm to 2mm, its aim is the lining of preceding layers.

There are the following types of wet plaster:

1. Conventional plaster is the universal type, which is successfully used for finishing facades and premises of any purpose. Different requirements are applied for finishing surfaces, so a conventional plaster can be various:
   - simple plaster – double-layer, it is used in plastering works in the warehouses, basements, attics, subsidiary, temporary and industrial premises;
   - the improved plaster – three-layer, it is used for facades and internal premises of residential, public and industrial buildings;
   - high-quality plaster – four-layer, with the double "coat". It is used for finishing works on facades and interior spaces of residential and public buildings with high requirement in quality.
2. Decorative plaster [14]. The main difference from a conventional plaster is the color. It is convenient because it does not require further cladding and finishing work. Is mainly used for finishing the facades, but it also can be in public establishments. In recent years there is a tendency of its application in a residential buildings after the emergence of new types of this kind of plaster. Decorative textured plaster can be divided into several types:
   - coloured plaster. Various design solutions or a uniform background for intricate interior can be created due to wide range of shades.
   - stone plaster is the imitation of natural stone. It is used for finishing the facades of buildings and internal premises of café, restaurants, halls of hotels and other public buildings;
   - sgraffito plaster. There are several colored layers. The result of its hardening and the outcrop of each layer is a colorful embossed pattern;
3. Special plaster is applied for narrow specific fields of application where we need to improve the characteristics of the building, to protect the premise from harmful external influences, or conversely to isolate from the harmful sources, which are located indoors. The types of use of special plaster are:
   - waterproof plaster;
   - heat-insulating plaster;
   - X-ray protective plaster;
   - acoustic plaster;
   - acid-proof plaster.

3. Methods of plastering works

Nowadays a traditional wet plaster as widely used as a dry plaster in the performance of internal plastering works. But it is the most common the wet method of plastering works on large surfaces.

Wet way of plastering works includes an application of the mortar on prepared surface. After drying the solution is subjected to final alignment. Plastering works using wet technology depending on the method of applying the solution are sub-divided into two main types: plastering works using manual or mechanized way with an application of special technical equipment (see Figure 1).


Figure 1. (a) first picture; (b) second picture.

Plastering works using manual way is needed when there is a small total square of surfaces or if it is impossible to use the plastering units (for example, due to lack of space to house them). The process of plastering works using manual method consists of mixing dry materials (gypsum, cement, sand, lime, etc.) with an application of means of mechanization (manual mixers). Ready mortar is troweled on a plastered surface and is lined on the preinstalled beacons. Mechanized plastering is a technology that is due to the automation of manual processes allows to achieve high quality and low cost of production. Mechanization of plastering works consists of the following main operations:

- preparing of mortar or dry mixture;
- delivery of solution by the truck or dry mixture in the special delivery tanks;
- stirring the solution and supplying it to the floors;
- applying of "scratch coat";
- applying of one or more layers of the brown coat with following leveling;
- applying of the finish coat with a subsequent smoothing of the surface and the trowel using the float.

Main features of the mechanized method of applying the plaster:

- mechanized plastering works are 3-4 times faster than plastering works using the manual way;
- the quality of plastered surfaces is better if we use mechanized way. Applicator batches small portions of solution because its working life is 50 minutes. There is a nonsimultaneous drying-out on the walls if we use a manual way of plastering works. In time chops, spalls and uneven surfaces are formed on the joints of these sections. Plasterworks using mechanized way is applied quickly and the plastered surface is smooth.
- the quality of solution is improved, it also increases durability of the resulting surface. The ratio of ingredients in a mixture is clearly monitored by machine. As a result, a consistency of the applied mixture is constant;
- the coverage rate of solution is reduced if we use mechanized way. Moreover, mechanized plasterworks have a relatively low price.
- the main characteristics providing the operation capacity of the plastering coat are its maximum drawability (which provides cracking resistance of the coat) and gripping power [4]. There is a large percentage of gripping power to the structural material of wall, thereby durability and resistance to operational loads are increased;
- mechanized plasterwork is cheaper its manual performance as dry mixtures in the first case have a lower price;
- the price for mechanized plasterwork is lower because it does not require subsequent finishing work. It is ready for decorating immediately after applying [5,8-10].

Let us compare the time and cost of production of plastering works using manual and mechanized way.

4. The time and cost of production of plastering works using mechanized way

We will use the following data from Table 1 [6] to calculate the duration and the cost of production of plasterworks using mechanized way (on the example of low-rise buildings):

Table 1. Input data for determining the duration and the cost of production of plastering works (for low-rise buildings).

P, m	h, m	n_f	n_p	s, cm	l, cm	r, mm	$C_{in\ c.d}$	L_b, m
200	3.0	6	5	2.7	10	4	30	70

- P - the perimeter of the walls of one floor in one porch;
- h - the height of the walls of one floor;
- n_f - number of floors of the building;
- n_p - quantity of porches of the building;
- s - the thickness of the plaster;
- l – the flow ability of finishing mortar;
- r - fineness of aggregate;
- $C_{in\ c.d}$ - period of work execution in calendar days;
- L_b – length of the building.

Cubic capacity of plasterworks, m^3:

$$V_{pw} = \mathrm{P}\frac{s}{100}h \cdot n_f \cdot n_p = 486 \quad (1)$$

Technical production capacity of basic plastering machine, m^3/h:

$$C_{bm} = \frac{V_{pw}}{\mathrm{C}_{in\ l.d} \cdot t \cdot n \cdot k_1 \cdot k_2} \quad (2)$$

where t – the period of personnel shift, h (for calculations t =5);

n – quantity of personnel shifts per day (for calculations n =2);

k_1 – utilization efficiency factor taking in account time wasting due to repair and maintenance (k_1 = 0.85-0.9; for calculations k_1 = 0.87);

$C_{in\ l.d}$ - period of work execution in labor days;

k_2– coefficient taking in account equipment downtime due to rigging up and down of transit mortar tracks,

$$C_{bm} = \frac{V_{pw}}{\mathrm{C}_{in\ l.d} \cdot t \cdot n \cdot k_1 \cdot k_2} \quad (3)$$

where T – total time of rigging up of transit mortar tracks, h:

$$T = t_a \cdot n_f \cdot n_p = 7.5 \quad (4)$$

where t_a– average time of rigging up and down of transit mortar track to the height of one floor (t_a = 0.2-0.3 h; for calculations t_a=0.25).

Period of work execution in labor days is determined in this way:

$$\mathrm{C}_{in\ l.d} = \frac{n_{l.d}}{7}\mathrm{C}_{in\ c.d} = 25.7 \quad (5)$$

where $n_{l.d}$– quantity of labor days per week (for calculations $n_{l.d}$ =6).

Thus, technical production capacity of basic plastering machine, m^3/h:

$$C_{bm} = \frac{V_{pw}}{\mathrm{C}_{in\ l.d} \cdot t \cdot n \cdot k_1 \cdot k_2} = 2.24 \quad (6)$$

Technical characteristics of basic plastering machine should keep the given length of haul of mixture in horizontal and vertical direction.

Plastering machine is usually installed stationary at the building site. In this case, we should use length of the building and the length of haul of mixture in vertical direction.

The length of haul of mixture in vertical direction, m:

$$H_T = (h + h_1)n_f = 18.9 \quad (7)$$

where h_1 – thickness of interfloor overlapping, m (for calculations h_1 =0.15 m)

Plastering machine is chose according to technical production capacity of basic plastering machine:

$$C_{tm} \geq C_{bm} \quad (8)$$

where C_{tm}– technical production capacity of chosen plastering machine, which is given in technical characteristics.

While choosing an appropriate plastering machine length of haul and delivery pressure are taken in account. If one plastering machine is not enough for performing given tasks, we should choose several modular plastering machines. Nowadays German, Polish and Italian troweling machines (PFT, Putzmeister, Kaleta, Bunker, M-tec, Imer, etc.) are widely spread, their characteristics for comparison are placed in a table 2 [7, 8, 9].

Table 2. Comparison characteristics of troweling machines Knauf, Putzmeister, Kaleta.

Main characteristics			
Brand and model	Knauf PFT G4	Putzmeister MP25	Kaleta ATWG-3
Production capacty, m^3/h	0.36 - 3.3	1.5	0.72-2.4
Delivery pressure, bar	30	40	30
Range of solution, m	до 50	до 40	до 60
Cubic capacity of batch bin, l	145	115	116
Maximum size of fraction, mm	4	4	4
Dimensions, mm	1500 x 720 x 1580	1324 x 728 x 1443	1200 x 750 x 1550
Weight, kg	264	240	240

Plastering machines PFT of German company KNAUF, which manufactures several lines of plastering machines of various modifications occupy a separate niche on the market of equipment for repair and finishing works. Each plastering machine of this manufacturer is created with strict requirements to automation of the most labor-intensive work performing on medium and large areas. Plastering machines PFT have a modular construction that simplifies their transportation, and their small dimensions allow working in cramped conditions. Plastering machine PFT can be used for applying a mixture on any base with obtaining uniform high-strength surface. For the next calculations we will use the plastering machine PFT G4, which technical characteristics are shown in a Table 2. We will take a value of technical production capacity as the average value for this model C_{tm} = 1.47 m^3/h.

Operational production capacity of chosen plastering machine, m^3/h:

$$C_m = C_{tm} \cdot k_1 \cdot k_2 = 1.24 \quad (9)$$

We need two plastering machines Knauf PFT G4 with operational production capacity 1.24 m^3/h to provide production capacity not less than technical production of capacity of the basic plastering machine (C_{bm}= 2.24 m^3/h). Then total production of capacity of two machines is 2.48 m^3/h.

In the end, we should determine the actual period of work execution performed by chosen machines. The master machine is troweling machine (plastering machine), that is why the actual period of work execution in labor days can be defined in this way:

$$C_{in\ l.d} = \frac{V_{pw}}{C \cdot t \cdot n \cdot k_1 \cdot k_2} = 23.22 \quad (10)$$

If we use several plants, we should take in account the total production capacity of chosen plastering machines. The actual period of work execution in labor days should not be bigger than given period.

We will determine the cost of plastering works using the mechanized way. To do this we will make an estimate, using the input method (calculation in the current (forecast) prices of resources needed to implement the project, which are expressed in natural measures of the needs in materials, products, structures, machines and mechanisms, the cost of the building tradesmen). The input method is considered the most time-consuming, but it allows achieving maximum precision of the calculation.

Area of plasterworks, m^2:

$$S_{pw} = P \cdot h \cdot n_f \cdot n_p = 18{,}000 \quad (11)$$

We will take the high-quality plasterworks of walls and partitions using gypsum mixture Knauf MP 75 and mud pumps Knauf PFT G4 for the calculations.

If we make an estimate for the production of plasterworks using mechanized way (when the thickness of the plaster is 27 mm), we will obtain:

1) Labor inputs of the building tradesmen and machinists: 34.613 USD
2) Labor-inputs of the machines and mechanisms: 2.004 USD
3) Expenses on materials: 41.185 USD

The total cost of the plasterwork using mechanized way (including all additional charges and taxes) will be 147.691 USD.

5. The time and cost of production of plastering works using manual way

The high-qualified plasterer can plaster to 15 m^2 of wall per shift [11]. A team consists of 5 members, two of whom are preparing and carrying the solution. The team plasters to 40-45 m^2 per shift. Using a dry mixture in bags with a single mixing pump the team of four can plaster to 150 m^2, i.e. the gain in capacity by 4.5 times. Then the total capacity of a team of 5 workers, m^2/h:

$$C_T = 5 \cdot 0.28 = 1.4 \quad (12)$$

Period of plasterwork using mechanized way execution in labor days:

$$C_{in\ l.d} = \frac{486}{1.4 \cdot 5 \cdot 2} = 34.71 \quad (13)$$

We will make an estimate for the high-quality plasterworks of walls and partitions using gypsum mixture Rotband for the cost calculation. For the initial data from the table 1 and thickness of a layer 27 mm we will obtain:

1) Labor inputs of the building tradesmen and machinists: 38.813 USD
2) Labor-inputs of the machines and mechanisms: 218 USD
3) Expenses on materials: 53.365 USD

The total cost of the plasterwork using manual way (including all additional charges and taxes) will be 171.753 USD

6. Concluding remarks

The estimates suggested that using the mechanized method of plasterwork gives us not only cash savings but also a significant reduction of the period of work execution (see Table 3).

Table 3. Technical-economic indicators of plasterworks using manual and mechanized way

Indicator	Manual way	Mechanized way
Period of plasterwork execution in labor days	34.71 (team of 5 workers)	23.22 (2 plastering machines)
The total cost of the plasterwork, USD	171.753	147.691
The total capacity, m^3/h	1.4	2.48

Thus, if we use the mechanized method of plastering, we get savings in cash (14.01%) and lead-time (33%). It is not necessary to carry out the filling-up after mechanized plastering, which means there is no need to pay for additional works. Plasterwork using mechanized way does not require multi-stage alignment and it reduces the costs of treatment of the subsequent surface. The using of manual method can be advantageous in case of plasterwork indoors with a small area of the walls.

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