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Pavement Roller with Perforated Operating Elements

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Abstract. The compaction of rod concrete mixes is a very complex process, envisaging a rapid increase of linear pressures, taking into account constant change in physical-mechanical properties of compacted material. Several hundred models of compacting equipment have been manufactured to date in the world; however, for a long period of time the models and types of rollers have been created and continue to be so, by the trial and error method, without accounting for the theoretical fundamentals of the process of compaction and specific features of mechanics of the force interaction of a operating element (drum, tire) with the material compacted. Contemporary directions of development of pavement equipment necessitate the creation of machines of the multipurpose use; designing the constructions, the working processes in which incorporate new technologies, ensuring the growing production yield and labor productivity; and careful treatment of economical and material resources. To improve the quality, reliability and competitiveness of the pavement equipment, it is important to create universal pavement roller, capable of compacting the different types of surfacing, automatically changing contact pressures, having wide range of regulation of compacting impacts and designed for work at all stages of the process of compaction of rod concrete mixes. Pavement roller with perforated drums meets these requirements.

Key words: Rod concrete mix · Pavement roller · Compaction · Perforated operating elements · Intensification of compacting process

INTRODUCTION

The questions of intensification of compaction process are of top importance for improving the productivity. The general aim is to increase the mass, sizes of operating elements of compacting machines, perfection of their structural features and application of automation means [1]. Until early 1980s, research works, aimed at improving the productivity, reduction of steel and energy consumption in the compaction processes, were performed just in this direction [2]. Traditional solutions should evolve into more efficient, although generally more complex, solutions, because almost no further optimization of traditional structural and kinematic parameters of operating elements is now possible. Principally new methods for impacting the rod concrete mix with quality control of performed works in real time [3] are required.

Principal Part: The history of development of the compacting technology is closely related to search for a construction, capable of efficiently working at all stages of the compaction process. This could make useless the existing technological schemes of compaction of pavement surfacings at all and asphaltic concrete surfacings in particular. Many research works showed that the compactness of pavement surfacing is directly related to the value of compacting load and, more specifically, to the value of contact pressures. Particles of mineral skeleton reorient and come closer under the influence of these pressures. At present, technical-economic indices of compacting works have been improved in two ways, namely:

- By intensifying the force action of operating elements of the set of compacting equipment; and
- By improving the efficiency of operating elements through employment of equipment with nontraditional compaction methods.

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No progress in the first direction is now possible, leading us at present to concentrate on the second direction, i.e., to improve the efficiency of the compaction process. However, roller with small mass can make many passages and fail to give the required compactness of the surfacing, however wasting machine resources. We cannot exclude a hybrid approach, combining efforts in the two directions, i.e., through simultaneous regulated compaction force and through creation of regimes, during which the asphaltic concrete mix is impacted by different types of compacting loads in diverse combinations.

The required compactness can only be reached through exact fulfillment of technologies of compaction works and through a proper selection of components of asphaltic concrete mix in their quantitative proportions [4].

The technology of compaction implies the use of a few (up to 3) different compacting rollers (with the total mass of up to 30 t), timely replacement of rollers and accounting for the temperature of the rod concrete mix [5]. Total number of roller passages through one and the same place may reach 22-25. It is very difficult to record somehow the number of passages through a single place and other factors, influencing the compaction process (the ambient air temperature, the presence of wind, the composition of asphaltic concrete mix, its initial temperature and so on). Therefore, the quality of rod concrete mix primarily depends on the qualification of drivers of compacting rollers and on the coordinated team work as a whole. In this regard, even minor distortions of compaction technologies may lead to the fact that portions of surfacing will have insufficient compaction degree. These places are the main centers where surfacing begins to break down after a while. This process is especially apparent in the period of rapid temperature changes during the day in autumn-spring season. The rollers with different masses should be used in compliance with the developed technology of compaction works, dictating permanent growth of contact pressures from one roller passage to another.

For rollers of static action, no acceptable solutions concerning regulation of compaction force are found yet. For vibratory rollers, the compaction ability can be regulated in a certain range by changing the vibration parameters (generally, by varying the disturbing force).

The work of a pavement roller with perforated operating elements is specific in character [6]. The interaction of perforated drums is similar to the work of a rubber-mounted roller in certain degree. The difference lies in the shape of a free surface [7].

The surface F is defined by width B and generating line S of the drum:

$$F = B \times S, \tag{1}$$

In the presence of holes on the surface of the drum, the total roller area is reduced by the amount

$$\Delta F = \frac{Z \times \pi \times d^2}{4}, \tag{2}$$

where Z is the number of holes with the diameter d. Obviously, the new contact area will be

$$F^* = F\,\Delta F, \tag{3}$$

In the case of invariable gravity force Q_D per the drum, the contact pressures, on the one hand, are defined as

$\sigma_k = \frac{Q_D}{F}$ for usual drum and $\sigma_K^* = \frac{Q_D}{F^*}$ for perforated drum.

On the other hand, $\sigma_к^*$ can be expressed through $\sigma_к$, taking into account formula (3):

$$\sigma_k{}^* = \left(\frac{F}{F-\Delta F}\right) \times \sigma_k \text{ or } \sigma_k{}^* = \left(\frac{F}{F-\Delta F}\right) \times \sqrt{\frac{qE}{R}}. \tag{4}$$

Assuming that F = 1 and adopting that ΔF value is given in fractions of F or in percent of F, we obtain the formula for determining $\sigma_к^*$

$$\sigma_k{}^* = \left(\frac{100}{100-\Delta F_{\%}}\right) \times \sqrt{\frac{qE}{R}},$$

where $\Delta F_{\%}$ is in percent of F.

The ratio in parentheses before square root sign in (4) will be called the coefficient of grow in the contact pressure κ_{grow}. Then, formula (4) can be rearranged as:

$$\sigma_k{}^* = k_{grow} \times \sqrt{\frac{qE}{R}} \text{ or } \sigma_k{}^* = \sqrt{k_{grow}^2 \times \frac{qE}{R}}.$$

Table 1 presents variations in the coefficient κ_{grow} as a function of ΔF.

It can be seen that the coefficient κ_{grow} increases as the area of perforation grows. Square of this coefficient exceeds 2 for a change as small as $\Delta F = 30\%$. In fact, this

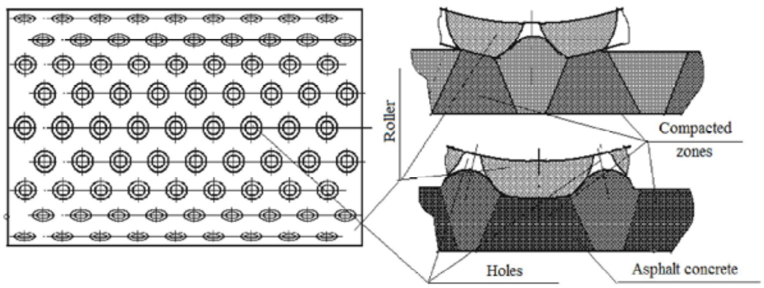

Fig. 1: Scheme of perforated drum and its work

Table 1: Variations in the coefficient κ_{grow}

ΔF,%	Coefficient of grow κ_{grow}	κ^2_{grow}
10	1.11	1.23
20	1.25	1.56
30	1.43	2.04
40	1.67	2.77

means that, for all other conditions kept the same, removal of 30% of roll surface is equivalent to compaction force of a roller, the mass of which is two times larger.

Figure1 presents the scheme of interaction of perforated drum with compacted layer. A part of the mix is actively pressed into holes already during first passage of roller. Obviously, the amount of this mix will depend on parameters of holes, their sizes and shapes.

When holes are cylindrical in shape, the volume of pressed mix depends almost linearly on the degree of the layer deformation. This increase in the compacting force will be the same at any stage of the process and its magnitude cannot be regulated. For curvilinear and conic generating line, as the layer is deformed and holes are filled with pressed volume of mix, there takes place an increase in the total area where drum surface contacts with compacted layer, which automatically entails a reduction in the contact pressures during first roller passages. This process takes place before equilibrium state is achieved. Holes cannot go exactly “trace in trace”; therefore, during every next passage of the roller, the mix volumes, pressed unto holes, become totally or partly under the surface of the drum and, conversely, certain part of previously compacted surface becomes under the hole. This process is analogous to that described above, the difference being that we deal with a denser layer of asphaltic concrete mix. Moreover, the volume of the mix, pressed into the holes and the total contact area will be smaller. As a result, the actual compacting load will be even larger. Thus, the presence of specially shaped holes leads to automatic increase of the contact pressure up to the level corresponding to the equilibrium state of the system: compacting element – compacted medium. Compaction load automatically increases to a certain degree also under the drum with continuous surface due to the growth of the deformation modulus.

We can envision that the use of the perforated rollers leads to the following effects.

- Loaded and unloaded zones are created in a regular order; as a result, compacted layer is faster relaxed and, hence, faster prepared for a subsequent compacting load.
- In unloaded zone, during the next passage of the roller, particles of mineral skeleton of the mix move relative to each other when the layer of the mix is pressed. Obviously, closed and open air cavities are both deformed in this case. As a result of local “damage” of the layer, closed cavities may readily evolve into open cavities. This creates more favorable conditions for escaping the air from the cavities. Even the presence of ordinary reach-through holes permits air to more easily escape from the compacted layer.
- With roller parameters properly specified, the compaction process can be such that the traces of “imprints” of the holes will disappear, signalizing that the compaction process may be complete in a given area.
- Road-building machines, with compaction force varying between wide limits, can be created, thus making certain roller types useless.
- Asphaltic concrete mixes can be pressed into the holes and equilibrium relationship between contact pressures and deformation properties of asphaltic concrete mix can be automatically established; thereby, threat of appearance and spread of capillaceous cracks can be reduced to the minimum level. These cracks usually appear at most early stages of the compaction process and are very difficult to eliminate.

Table 2: Types of compacting equipment

	Characteristics, taken into in compaction process						
Type of compacting equipment	Compactness assurance	Smoothness assurance	Need forextra compaction equipment	Range of regulation of compaction ability	Complexity of equipment vs. static rollers	Automatic increase of compaction force up to that required	Stability and controllability vs. static rollers
Asphalt paver	No	Yes	Yes	Not enough	Lower	No	–
Static pavement rollers	Yes*	Yes	Yes**	Not enough	–	No	–
Vibratory pavement rollers	Yes *	No, during reverse gear	–	Enough	Higher	No	Lower
Rubber-mounted pavement robbers	Yes *	No	Yes **	Not enough	Higher	No	Higher
Hybrid pavement rollers	Yes *	No, during reverse gear	No	Enough	Higher	No	Lower
Rollers with surface vibrocompressor	Yes *	Yes	No	Unknown	Higher	No	–
Rollers with oscillatory vibrator	Unkn.	Unkn.	Unkn.	Unknown	Higher	No	Unkn.
Rollers with perforated drums	Yes	Yes	No	Enough	Equal	Possible	Higher

NOTE: * when mass of equipment is sufficient;
** when mass of equipment is insufficient.

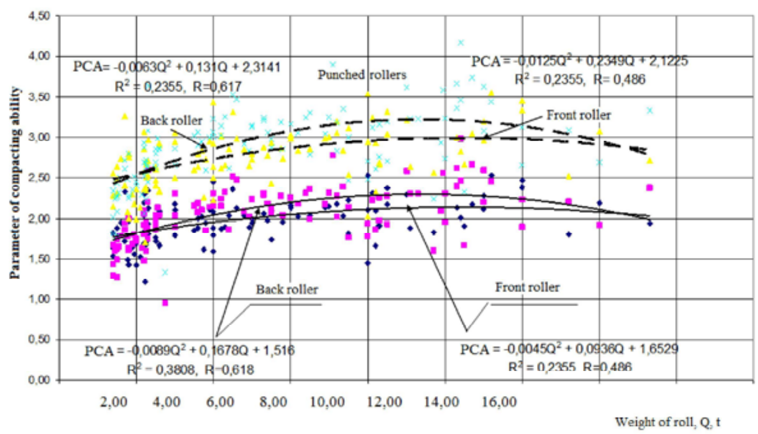

Fig. 2: The dependence of index of compacting ability on the mass of roller (biaxial dual-drum rollers)

Table 2 compares the characteristics of different types of compacting equipment.

The analysis of the table shows that perforated rollers have a number of advantages regarding the basic characteristics. This table gives no information about the cost of all types of rollers. Considering that perforated and static rollers have nearly identical costs, we can state that the former is more preferable.

Compacting ability of the roller can be estimated based on compacting ability index (CAI). As this index, N.Ya. Kharkhuta [8] suggested an equation, derived from the formula for determining the contact pressures, namely:

$$CAI = \sqrt{\frac{q}{R}}, \tag{5}$$

where q is the linear pressure exerted by the drum on the compacted surface (q = M/B, M is the mass of roller per drum, B is a width of drum); and R is the radius of the drum.

This index can be used to estimate the force impact of the drum of the roller, taking into account its basic parameters. Figure 2 shows the dependence of CAI on the mass of roller with smooth and perforated drums.

It can be seen that CAI of the last rollers is much larger than CAI of usual rollers. Based on this, we can calculate the parameters of the roller, ensuring the required change in CAI, corresponding to universal roller. Obviously, we can simultaneously increase the diameter and width of the drum.

CONCLUSION

Compaction of asphaltic concrete mixes is a very complex process, envisaging fast increase of linear pressures, taking into account permanent changes in physical-mechanical properties of the material compacted. Several hundred versions of compacting equipment have been manufactured to date in the world; however, for a long period of time the models and types of rollers were created and continue to be so, by trial and error method, without accounting for the theoretical basics of the process of compaction and specific features of mechanics of the force interaction of a operating element (drum, tire) with the material compacted [9].

Fig. 3: Perforated drums

An important question is the one about an active, unattended (automatic) change in the compaction force. None of the roller constructions, which can artificially increase or decrease the contact pressure, meets this criterion entirely. The modulus of deformation of compacted layer at a given time should be known to satisfy this main condition. These systems exist in practice, but there should be some time to process the obtained information and to take a decision. The modulus of deformation should be known in real time in order to change the compaction force rapidly [10].

According to different estimates, the total time of action of roller's drum on the compacted surface is within 6 seconds. Therefore, usual and traditional methods cannot be used to change the modulus of deformation and correct the compaction force. Moreover, it is necessary to know the time when compaction process should be decided to stop. How much passages across a given compaction area is required and how their number should be accounted for are an urgent problem for production workers.

The determined acceptable parameter values of perforated working elements, implemented in practice, are illustrated in Fig. 3.

Comparative tests were performed during compaction of reconstructed segment of one of the streets in Vladivostok. Tests were made according to standard scheme; we compared compactness of asphaltic concrete surfacing, obtained using drums with identical masses and geometrical parameters (DU-47 roller with mass of 7 t). The compactness of surfacing was determined in the laboratory of constructional materials a week after compaction; and index well corresponded to normative documentation.

Summary: Comparative tests showed that surfacing with required compactness can be obtained using one modernized roller with perforated drums. This is the main finding of the present work. The compaction process was performed from initial to final stage with a single roller type; this may principally change the technology of compaction of surfacings, i.e., substantially reduce the total mass of used compacting equipment. It is also noteworthy that the degree of compactness can now be rapidly and visually controlled according to the height of asphaltic concrete pressed into the holes. In practice, the compaction process can be considered complete if there are no traces of holes, which was just the case during our experimental works.

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