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PNEUMATIC SHUTTERING SYSTEMS: RESEARCHES AND USE

Technological modes of use of pneumowireframe shutterings at construction of span and enclosing structures are proved. Results of a complex of experimentally-theoretical researches on studying of deformability of pneumatic shutterings perceiving total operational influence are described. Maximum changes of technological parameters which don't cause integrated moving above permitted standard of a working surface of a pneumowireframe shuttering at various stages of its use are established.

Keywords: pneumowireframe shuttering, operational influences, deformations, permissible changes of technological parameters.

Increase of efficiency of concrete works at erection of reinforced concrete constructions is one of the basic problems in economy of monolithic building. The important reserve of reduction of labour intensity can be the use of pneumowireframe shutterings. This kind of works owing to application of high-efficiency and essentially new designs of shuttering systems in a complex with modern means of mechanization and automation of concrete works allows to reduce construction time, to raise labour productivity and to lower labour input.

Pneumatic shutterings are one of these kinds of shuttering, which helps to solve assigned problems. The usage of pneumoshutterings raises quality of concreted surfaces, reduces expenses for the subsequent finishing of a construction, improves working conditions, allows to erect space and plate structures of the rational geometrical form.

They distinguish air-inflated and pneumowireframe shuttering systems. The first type from the very beginning of its development and up to now has occupied a leading position in building practice in comparison with the second. It was credited to relative simplicity of operation of air-inflated shutterings, at which the losses of air caused by breaches in rubber fabric, insufficient air tightness of connections of fabric widths and shuttering with the base, were compensated by continuous work of the basic and duplicate air supply systems that inevitably raised working costs and reduced technical and economic indicators of erection.

Pneumowireframe constructions as shutterings practically were not applied. Constructing long spans led to necessity of high air pressure and problems with air tightness. Frequently, complex of engineering arrangements for maintenance of stable air pressure after single strain of a pneumatic framework led to considerable rise in price and to loss of the competitive edge.

Application of pneumowireframe elements in the capacity of shutterings for erection of span and enclosing constructions of small overall dimensions opens an absolutely new, effective from economical point of view technological niche. Relatively low overpressure in pneumoframe elements for perception operational forces (due to small spans), and also small time use period, defined by time for concrete to gain stripping strength, solve an air tightness problem. Besides, the ease of manufacturing of pneumatic cylinder-shuttering, possibility of their shifting from pour to pour, instead of installation of a shuttering entirely on an all construction as in a case with air-inflated systems, lack of necessity in continuous work of air supplying devices. Universality of use at erection of span and enclosing structures makes pneumoframe shutterings investment-attractive.

Their wide introduction is interfered now by insufficient studying of questions in soft covers forming and in maintenance of a necessary geometrical invariance at different technological stages of application as the most important requirement shown to shutterings. The complex of operational influences on pneumoframe shuttering system is diverse and grouped depending on a concrete technological stage of its use. To each stage there corresponds its condition (form) of a shuttering. The analysis of conditions of a shuttering ([1], [2]) has allowed to develop their new classification.

Initial condition — the designed geometrical form of a pneumoshuttering at zero errors in the process of installation of a shuttering and zero operational influences. The analysis of this condition of a shuttering allows to develop requirements in pattern cutting accuracy and connections of widths when manufacturing in factory environment or building conditions.

Starting condition characterizes position of a shuttering after installation at zero operational influences. It allows to substantiate requirements to limiting permissible errors while installation of a shuttering (offsetting between supports in span, deviation in marks of supports etc.).

Adjustment condition — is characterized by the form caused by integrating influences of internal pressure of air, its temperature, and change of nonrigid properties of impregnated materials. This intermediate condition which can vary at the expense of change of a mode of internal air pressure and its temperature, nonrigid properties of a shuttering material for perception of loadings from laid concrete without deviations of the designed form of a monolithic construction above permitted standard.

The final condition is a form of a pneumatic shuttering after been affected by wind influence, and weight of concrete and armature. To a large extent this condition is defined by technological conditions of concrete casting (providing that correcting influences are applied).

The complex of the influences peculiar to each of listed conditions, is described in the table.

Table

Condition	Types of influences					
	Deviation on installation stage	Cutting accuracy and connections of widths	Nonrigid properties	Internal air pressure	Internal air temperature	External action
Initial	-	+	+	-	-	-
Starting	+	-	-	-	-	-
Adjustment	-	-	-	+	+	-
Final	-	-	-	-	-	+

The influence of this nonrigid disbalance on shuttering forming was investigated in experimental and theoretical directions (3). It is necessary to notice that in the researches, existing at present, concerning connections of widths in pneumoframe shuttering, them strength characteristics were mainly considered. The methodological base of an estimation of nonrigid properties of joints did not develop. Thereupon the researches technique of an extensibility of working deck connections of a shuttering has been conducted and experimental works were carried out. Two samples were used in these works. Resting on existing regulatory system in examination of rubber-fabric materials on biaxial stretching, there were used reference crosswise samples without seams with the sizes, established by GOST 30 303—95. Samples of the second type which were called joint samples have been applied to an estimation of influence of constructional connection. They were of the same geometrical sizes, as well as reference, but unlike them consisted of two *T*-shaped details, jointed with glue-seam connection (Fig. 1).

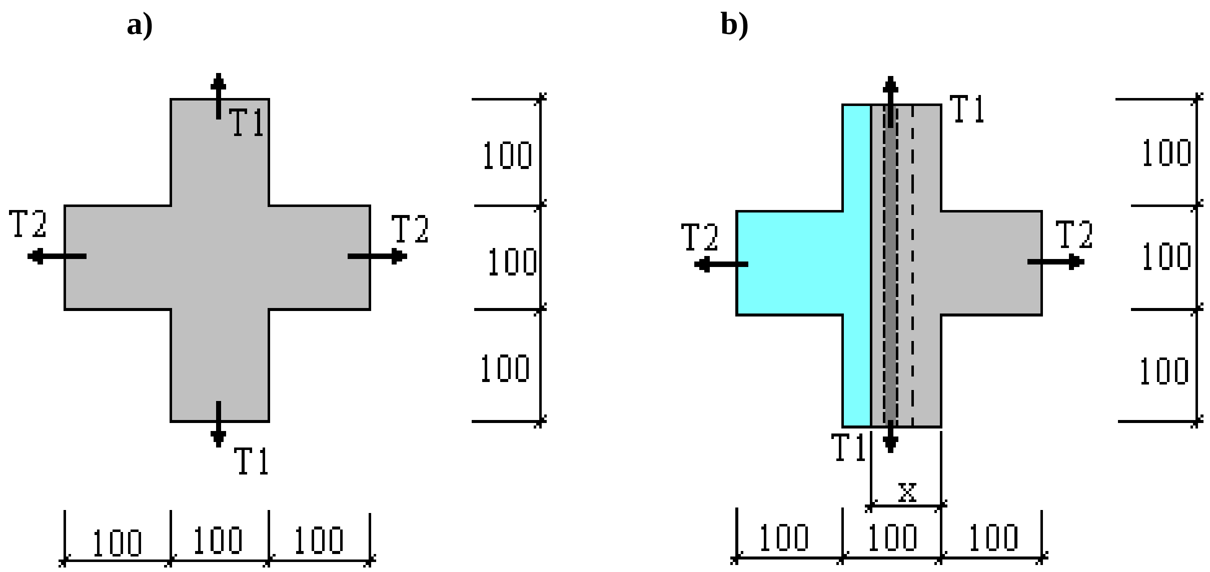

Fig. 1. Types of samples, tested on biaxial stretching:
a) reference; b) joint

As it has already been mentioned above, pattern cutting accuracy and connections of widths have an essential influence on the form of pneumoframe shuttering systems at its manufacturing. However constructional connections (joints) have nonrigid properties, which considerably different from nonrigid properties of shuttering material.

It is no wonder that for a substantiation of technological procedures of usage of pneumoframe shuttering while erection of span and enclosing constructions it s essential to conduct complex experimentally-theoretical researches covering estimation and analysis of form alteration in all above-stated conditions. Such researches were carried out, but within the limits of the given publication we will cover only some of them.

The main condition of comparability of relative deformations reference and joint samples consisted in equality of the efforts (operating in considered directions) distributed on width of the sample. Such approach helps to discover not only joint influence as more rigid element, but also scission of the sample on details with smaller width that increases sample deformability (Fig. 2).

The results of the experimental researches were used for developing a mathematical model, describing cylinder pneumowireframe element form, provided with constructional connection (Fig. 3).

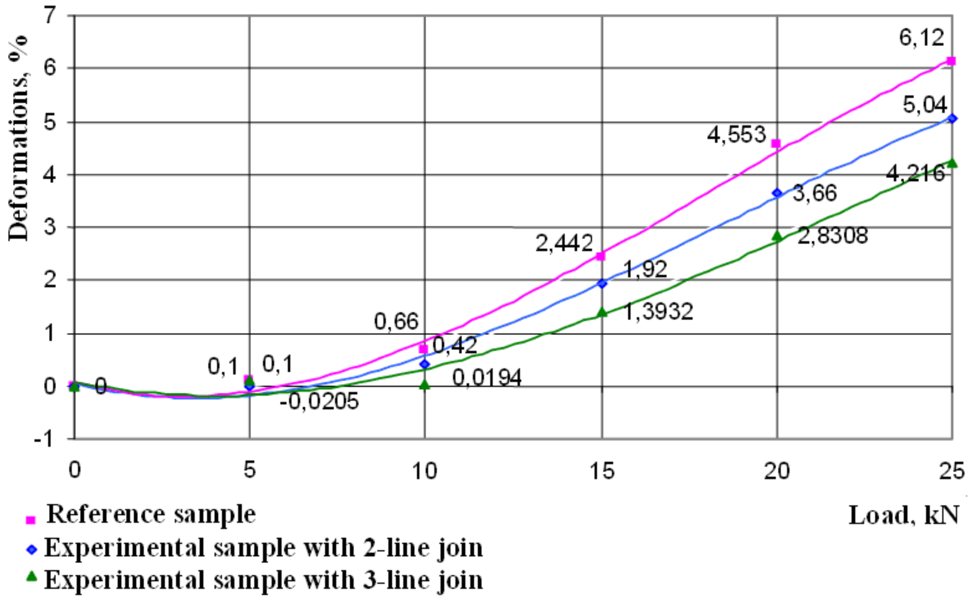

Fig. 2. Biaxial stretching diagram

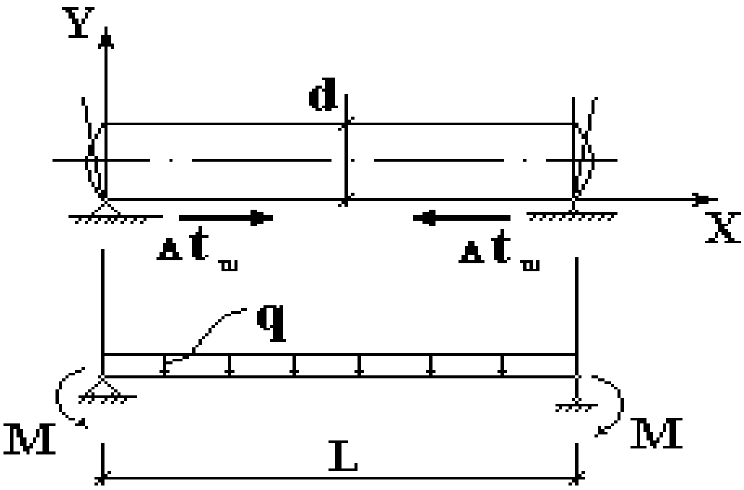

Fig. 3. The calculated scheme of a shuttering element supplied with a longitudinal joint

The whole deformation in the middle point of shuttering will be

$$f = f_{вд} + f_q + f_ш . \tag{1}$$

Here

$$f_{вд} = \frac{\Pr^2}{E_ш h}, \tag{2}$$

where $f_{вд}$ is the deformation caused by internal air pressure; *r* is the cylinder radius; *h* is the cover thickness; $E_ш$ is the module of cylinder resilience in latitudinal direction.

$$f_q = \left(\frac{5qL^4}{384E_ш J} \right) 1 + \lambda \ , \tag{3}$$

where f_q is the deformation caused by operational loading, q; λ is the factor considering nonlinearity nonrigid properties of a pneumoshuttering; *L* is the span; *J* is the moment of inertia of cross-section of a pneumoshuttering.

$$f_ш = \left(\frac{\Delta t_ш r L^2}{8E_{мерид} J} \right) 1 + \lambda \ , \tag{4}$$

where $\Delta t_ш$ is the additional effort connected with disproportion nonrigid characteristics of cover and connection materials; $E_{мерид}$ is the module of fabric resilience in meridian directions.

Usage of analytical model has allowed to prove ranges of admissible change of superfluous internal air pressure depending on size of operational loading, loading pattern, joint position and type of resting of pneumowireframe elements of the various geometrical sizes.

It is impossible to reduction of terms and cost of erection of monolithic constructions without modern means of mechanization of concrete works, for example, high-efficiency concrete pump, pneumatically operated placers, and also spray guns which allow to pour concrete without the subsequent ramming in place.

It is necessary to notice that usage of pneumatic shutterings of static type cannot be carried out without pneumoapplying of a hardening mix on their front surface. As technological modes of concrete placing on “pliable” pneumoshuttering are not quite proved, a number of researches were conducted in this direction (4).

In the course of analysis of existing physico-mathematical description of processes of mutual collision between shotcrete and shuttering it was found out that at least two parameters which take place at usage of pneumoshuttering were not counted. These two parameters are a rebound and relative flexibility of a shuttering surface. In this developed theoretical model interaction between shotcrete and elastic-pliable surface of a pneumoshuttering was considered as impact of the material point having some kinetic energy with a tense string (Fig. 4).

As a result of salvation of the differential equation of string fluctuation expression for calculation of speed of a return movement of a string $V_{двр}$ in initial position is received:

$$V_{двр} = \sqrt{\frac{T}{\rho}} \, , \tag{5}$$

where *T* is the linear tense string, ρ is the linear density string.

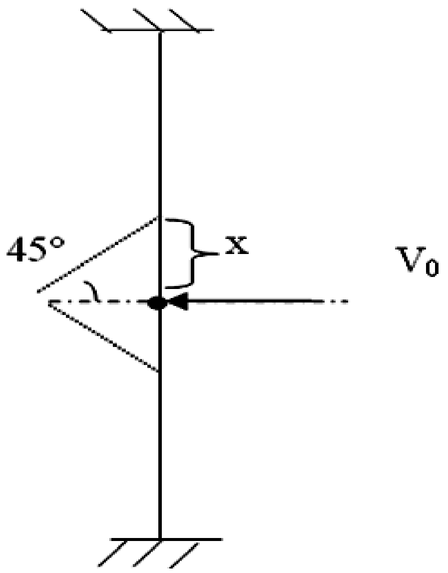

Fig. 4. Interaction of string with material point

Application condition of shotcrete to a shuttering and consequently, absence of a slope is possible to express in an equality

$$\sigma l \geq m_э V_{двр}, \quad (6)$$

where σ is the superficial tension of the sticked shotcrete element; l is active perimeter of a sticked shotcrete element; $m_э$ is the elementary mass of shotcrete element, depending on the conditions of applying (productivity of air concrete-placer, the size of concrete spot).

Realisation of the offered mathematical model in combination with results of experimental researches has allowed to build a nomograph for definition of rational technological parameters of application of a torkret-concrete mix on a pneumoshuttering (Fig. 5).

It is a well-known fact that time reduction of concrete curing on a shuttering surface is one of the ways of increasing of erection efficiency of monolithic constructions. This effect is reached through its warming up. The same method is used in winter concreting which is important for Russia because of its climatic peculiarity. For the decision of this problem a specially developed heating pneumoframe shuttering was introduced (work is executed under A. N. Tkachenko's academic advising). The layer of a torkret-concrete mix was put on cylindrical pneumoballons (the pneumoframe shuttering strained by warmed-up air) and it was kept under a layer of a warmth-keeping jacket.

In [5] offered the analytical description of nonrigid condition of a pneumoshuttering which is influenced of superfluous pressure, operational loading and raised temperature. From conditions of balance of an cover element the resolving equation concerning a cover bend f as radius increase registered.

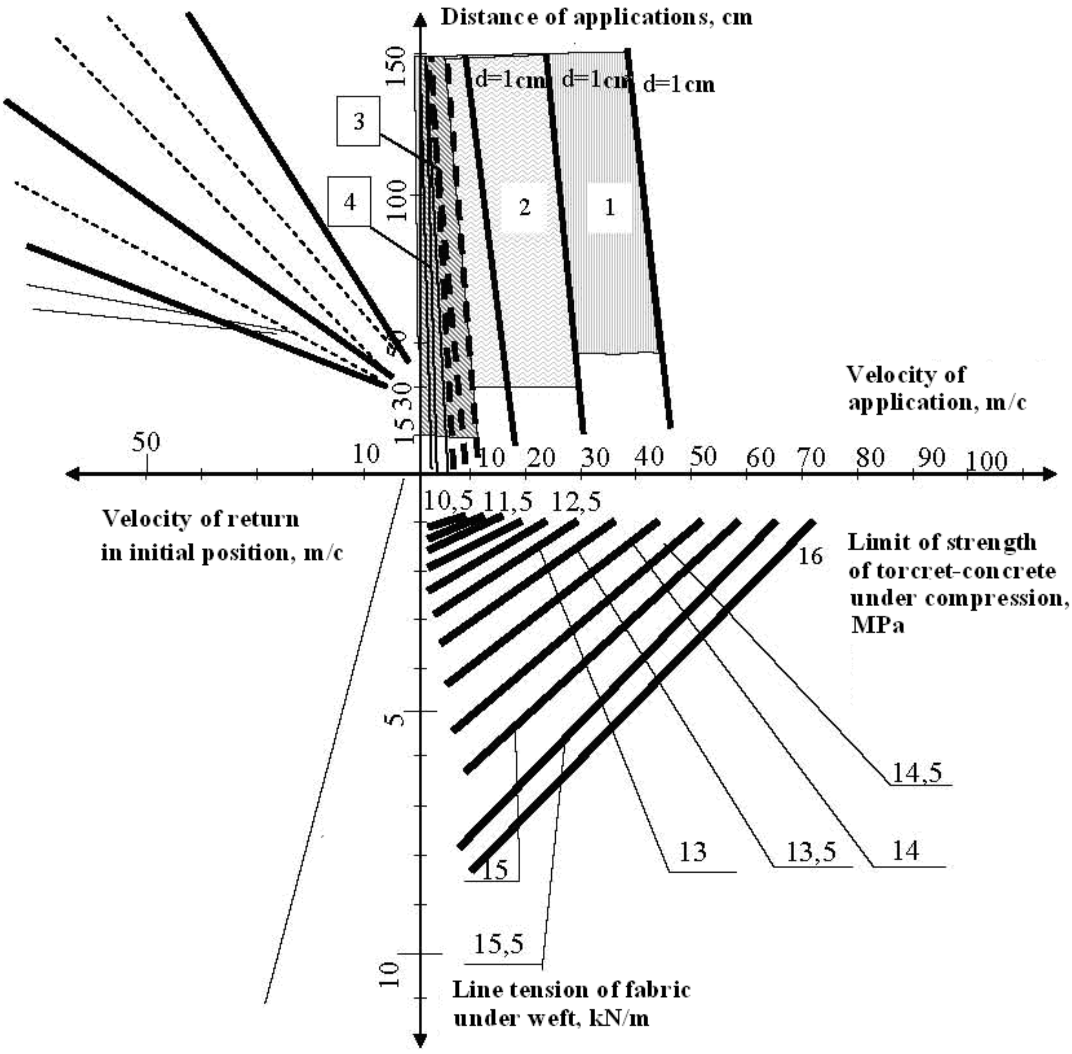

Fig. 5

Influence of technological temperatures was considered by special temperature effort.

$$f = \left[\frac{\Pr^2}{E_ш h} - \mu \frac{rN_{мт}}{E_ш h} + \frac{r}{E_ш h} \quad N_{шт} - \mu N_{мт} \quad \right] + C_1 e^{-\lambda x} + C_2 e^{+\lambda x}, \qquad (7)$$

where P is the internal superfluous air pressure; r is the radius of a median cove material surface; h is the thickness of cover material; $E_ш$ is the module of fabric resilience in latitudinal direction; μ is the Poisson ratio; $N_{шт}, N_{мт}$ are the additional temperature efforts in fabric in latitudinal and meridian directions.

Realisation of dependence (7) is impossible without applying the results of experimental researches, devoted to deformability of rubber-fabric materials under increasing temperatures (Fig. 6).

The obtained data became fundamental in principle regulation of parameters of working pressure of the heat-carrier. Admissible change intervals at various steps of working temperatures are shown on the Fig. 7; the area in which stable functioning of a heating shuttering from a position of stabile form maintenance is observed.

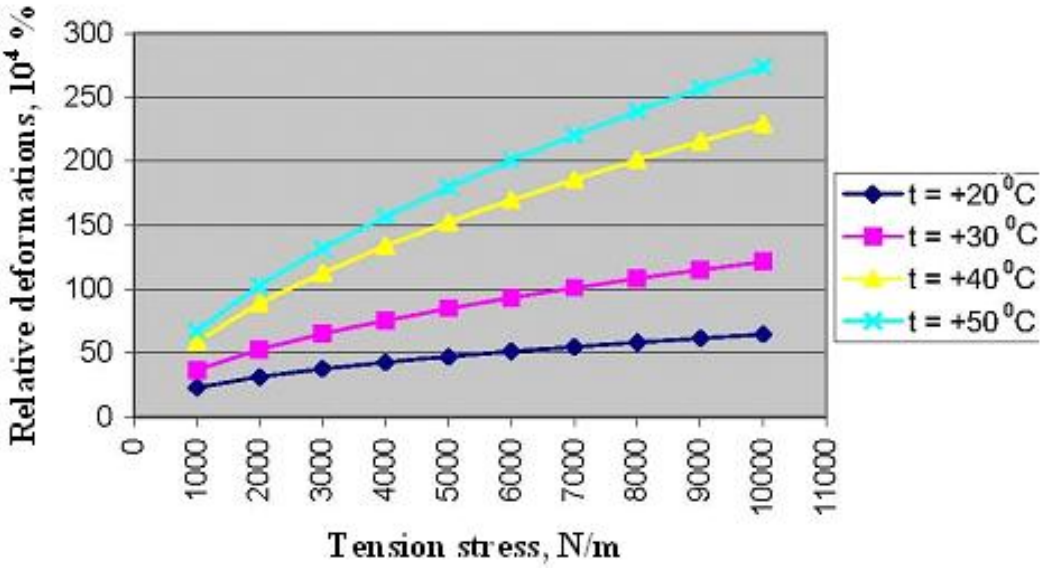

Fig. 6

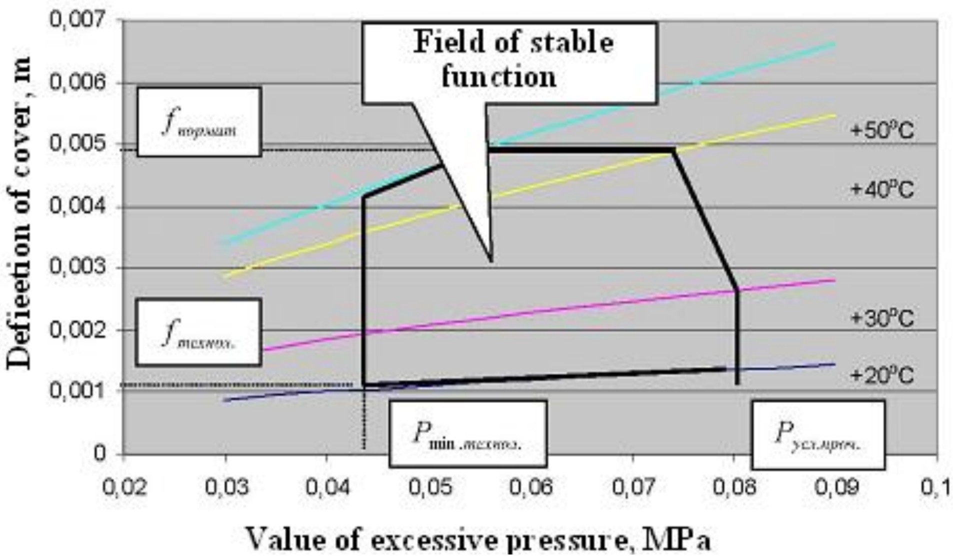

Fig. 7. Area of admissible change of pressure and temperature:
$f_{нормат.}$ — standard value of bottom bend, $f_{технол.}$ — bottom bend at minimum technological pressure; $P_{\min.технол.}$ — minimum technological pressure of heat-carrying agent, $P_{усл.прочн.}$ — maximum technological pressure of heat-carrying agent taking into consideration hardness of cover material

It is important that with increase in diameter of a cover the sizes of area decrease and at certain critical diameter the area turns to a point.

The analysis of correlation of operational influences on a shuttering and its nonrigid changes helps to establish the maximum permissible deviations of technological parameters which do not cause excessive integrated movements by its working area. Thus, one of the basic requirements imposed to shutterings, — permanents of their form, is provided. The results of researches have been used for working out a package of design-technological documents, which found application in operating engineering and building organizations.

In summary:

1. Experimentally-theoretical model of deformation pneumowireframe shuttering, different from previous ones by the account of influence of constructional connections and the analytical model of interaction shotcrete stream with the pneumoshuttering surface, allowing to prove conditions of non-rebound technologies of concreting, are developed.
2. Calculation procedure of constructive-technological parameters of heating pneumowireframe shutterings, research techniques of nonrigit shuttering characteristics taking into account joint connections, studying techniques of torkret-concrete applying on a pneumoshuttering are developed and realized.
3. Technological parametres of erection of monolithic constructions on pneumowireframe shuttering taking into account joint influence of superfluous air pressure, its temperature and other external loading are proved.

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