ZESZYTY NAUKOWE POLITECHNIKI ŚLĄSKIEJ 1989

Seria: GÓRNICTWO z. 175 Nr kol. 986

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A CASE STUDY ON FREZING PRESSURE IN DEEP SHAFT

Summary. Vibrating wire strain and temperature gauges and load cells were installed in two reinforced concrete sandwich shaft lining at different depths in Dongfeng Air Shaft and Nanfeng Air Shaft of Panji Collieries Anhui. In this paper the formation of the freezing pressure and the influential factors on the freezing pressure and the stress variation pattern of the ribs were discussed.

The alluvium of the Panji coal field is an unstable stratum containing water in relatively large quantity, the thackness of it through which the shafts pass averages more than 200 meters, its thickest part being 400 meters. It has been proved in practice that Shaft No. 1 (Dongfeng Shaft) and Shaft No. 2 (Nanfeng Shaft) in Panji have been greatly affected by the freezing pressure, which, on the worst occasion, has caused longitudinal crevices in the shaft wall made of reinforced concrete 500 mm in thickness. Subsequently remedy measures had to be taken by the excavation and replenishment method. It is seldom that the freezing pressure of these shafts increases at so high a speed. The calcareous clay stratum and the gravel sandy stratum with a depth of 120-170 and 265-292 meters respectively are found to be the most typical.

An expatiation on this is given in three aspects as follows:

1. The formation of the freezing pressure

During the construction of the shaft, the pressure exerted on the shaft wall by the frozen wall is referred to as freezing pressure both at home and abroad. As to the origination of its formation there still exists quite a number of different opinions. Professor Mohr of West Germany reckoned that water-bearing soil expands when freezing and freezing pressure will occur if this expansion is obstructed. The Russians objected to such a viewpoint, regarding creep deformation as the main factor of the shaft wall displacement. Some of our people held that it is the refreezing of the frozen soil that gives rise to the freezing pressure. Our point of

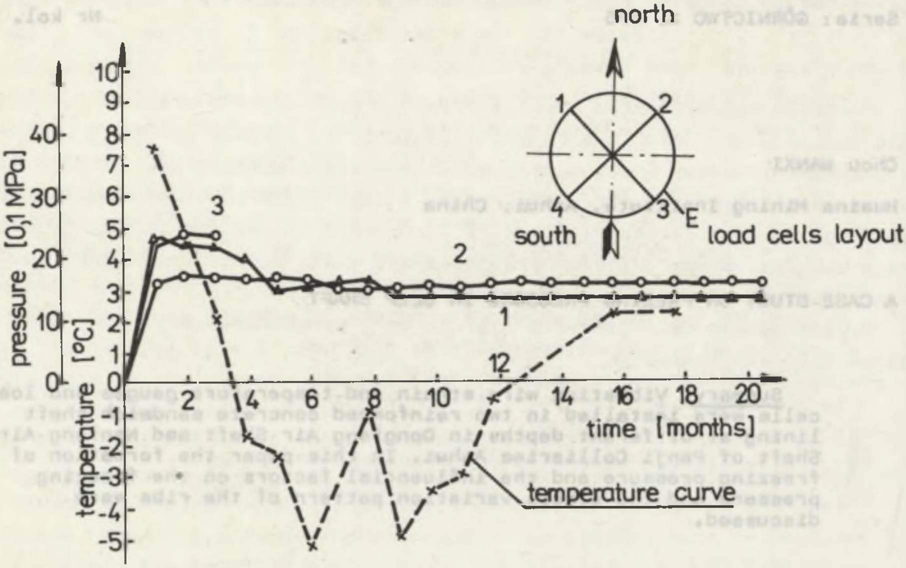

Fig. 1. The variation curve of the freezing pressure occurred in the calcareous clay stratum 137 meters in depth in Panji No. 1 Shaft

Rys. 1. Krzywa zmienności ciśnienia mrożenia występującego w warstwie margla na głębokości 137 metrów w szybie Panji Nr 1

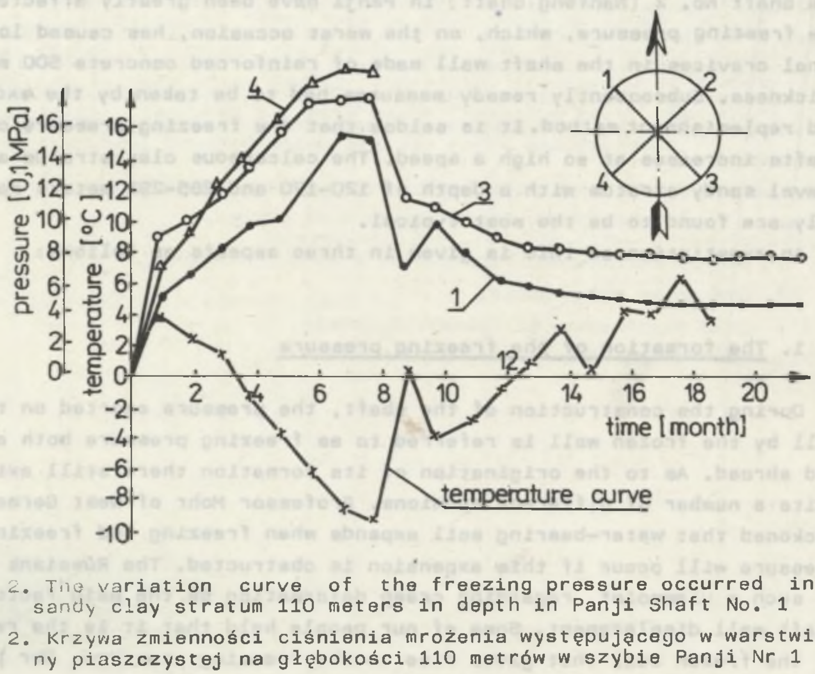

Fig. 2. The variation curve of the freezing pressure occurred in the sandy clay stratum 110 meters in depth in Panji Shaft No. 1

Rys. 2. Krzywa zmienności ciśnienia mrożenia występującego w warstwie gliny piaszczystej na głębokości 110 metrów w szybie Panji Nr 1 view is that it is not appropriate to attribute either the expansion or the refreezing of the frozen soil to be the only cause of the freezing pressure, because the phenomena we have encountered could not be interpreted thereby. For instance, the freezing pressure occurred in the calcareous clay strata 137 meters in depth at Panji No. 1. Shaft had already reached 2,4 MPa peak value before the freezing soil reached as far as the shaft side and thereafter, the freezing pressure did not noticeably change either to the high side or lower side as the temperature decreased (fig. 1). Of course, in certain type of solums, such as the above-metioned sandy clay stratum where the shaft passes through, there dose exist such a phenomenon that the freezing pressure increases with the decrease in temperature, and vice versa (fig. 2), the freezing pressure being subject to a variation as high as 0.5-0.6 MPa. Even so, neither the temperature change nor the voluminal expansion should be supposed to be the only cause of the formation of the freezing pressure; it can merely be one of the factors, not to say that the factor of temperature dose not necessarily apply to all strata. For example, it may be seen from the curves (fig. 3), showing the freezing pressure changes vs temperature in Panji Shaft No. 1 (Dongfen Shaft) in the gravel sandy solum 278 meters in depth, that no matter how the temperature varies, the freezing pressure, when arriving at its peak value, basically maintains constant, which accounts for the fact that the temperature factor in ruled out on this occasion.

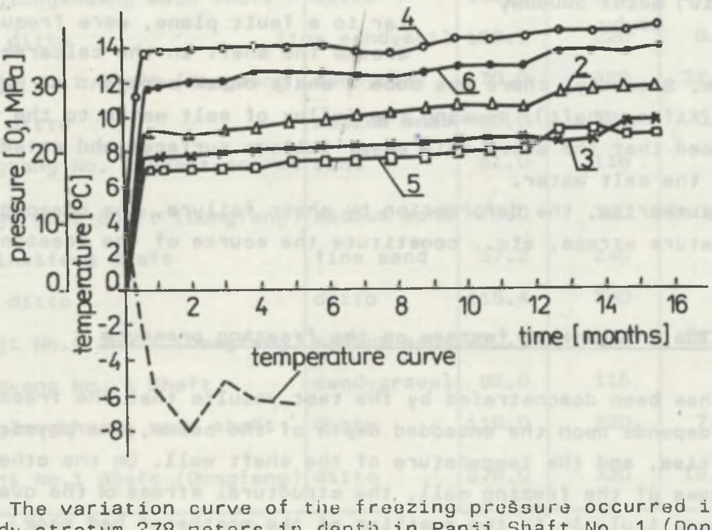

Fig. 3. The variation curve of the freezing pressure occurred in the gravel sandy stratum 278 meters in depth in Panji Shaft No. 1 (Dongfeng Shaft)

Rys. 3. Krzywa zmienności ciśnienia mrożenia występującego w żwirowo piaszczystej warstwie na głębokości 278 metrów w szybie Panji Nr 1 (Szyb Dongfeng)

Tsytovich, N.A. pointed put that the greater the effective load, the more rapidly will the frozen soil switch to flowing in a viscoplastic manner at a stable deformation rate, which in turn increases with the increase of the load. Undoubtedly creep is bound to occur along the shaft wall under complex stress. However, it remains to be discussed whether or not the creep can be regarded as the only facor that brings about the freezing pressure.

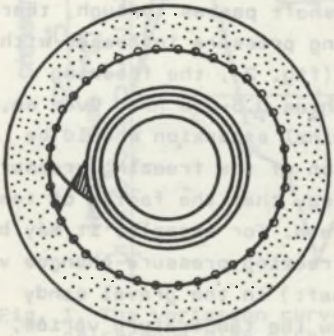

Fig. 4. The shear failure surface around the shaft lining.

Rys. 4. Powierzchnia pęknięcia poślizgowego (przy ścinaniu) wokół obudowy szybu

Above all, the frozen wall, in accordance with our consideration, is a nonhomogeneous elastic-plastic cylindrical body; if it is affected by the external forces (hydrolic pressure and soil pressure), its deadweight and the temperature stress, a number of shear failure surfaces may possibly occur in the inner edge of the freezing wall (the existance of such surfaces can be proved on the basis of the elastic-plastic theory); and many of the shear failure surfaces are intercrossed as to result in some wedge-shaped bodies; if these wedge-shaped bodies slip towards the shaft, the freezing pressure on the shaft wall will be produced. Moreover, the author has witnessed that quite number of smooth slip surfaces, similar to a fault plane, were frequently found around the shaft in the calcareous clay stratum. Secondly, there was once a shaft break accident at Panji shaft No. 2 (Xifeng Shaft), causing the influx of salt water to the shaft, which evidenced that the above-said shear failure surfaces ahd acted as passages of the salt water.

To summerize, the deformation by shear failure, the creepage, and the temperature stress, etc., constitute the source of the freezing pressure.

2. The influential factors on the freezing pressure

It has been demonstrated by the test results that the freezing pressure value depends upon the embedded depth of the solum, the physico-mechanic properties, and the temperature of the shaft wall. On the other hand, the thickness of the frezing wall, the structural stress of the over-burden rock (particularly in the position of the weathered bed rock) are also possibly supposed to be the factors that may influence the freezing pressure. But it is impossible to reach a conclusion at present because of the insufficiency of the available information. Of the above-metioned

Table 1

Test results of the frezing pressure of some shafts in China

No.	Shaft description	Solum	Burail depth (m)	Freezing depth (m)	Max. freezing pres (0.1 MPa)
1	Lulinxifeng Shaft	clay	35.7	240	11.2
2	Xinglongzhuang main shaft	ditto	59.0	220	12.0-13.9
3	ditto	ditto	88.5	220	12.3-13.4
4	Hongyang No.1 Shaft	ditto	90.0	116	16.3
5	Lulinxifeng Shaft	ditto	96.0	240	16.6
6	Panji No.1 Shaft (Dongfeng)	ditto	137.0	320	18.0-24.2
7	Xinglongzhong main shaft	ditto	151.0	220	14.5-17.1
8	Lulinxifeng Shaft	ditto	179.0	240	22.6
9	ditto	soil sand	24.5	240	6.2
10	ditto	ditto	45.0	240	10.6
11	Hongyang No. 1 Shaft		67.0	116	1.9
12	Lulinxifeng Shaft	soil sand	102.6	240	25.3
13	ditto	ditto	108.6	240	8.6
14	Panji No.1 Shaft (Dongfeng)	sandyclay	110.0	320	16.0-20.7
15	Xinglongxhuang main shaft	ditto	142.5	220	14.0-16.3
16	ditto	fine sandysoil	168.5	220	8.3-18.3
17	Panji No.1 Shaft (Dongfeng)	sandyclay	170.0	320	22.0-25.0
18	ditto	medium snad	40.0	320	0.4-2.3
19	Hongyang No. 1 Shaft	coarse sand	61.0	116	0.2
20	Panji No.1 Shaft (Dongfeng)	medium sand	70.0	320	0.4-10.9
21	Lulinxifeng Shaft	fine sand	67.2	240	4.6
22	ditto	ditto	115.4	240	8.5
23	Panji No.1 Shaft (Dongfeng)	medium sand	220.0	320	11.0-18.9
24	Hongyang No. 1 Shaft	sandygravel	82.0	116	1.2
25	Xinglongzhuang main shaft	ditto	118.0	220	7.5-14.2
26	Panji No.1 Shaft (Dongfeng)	ditto	278.0	320	18.9-30.7

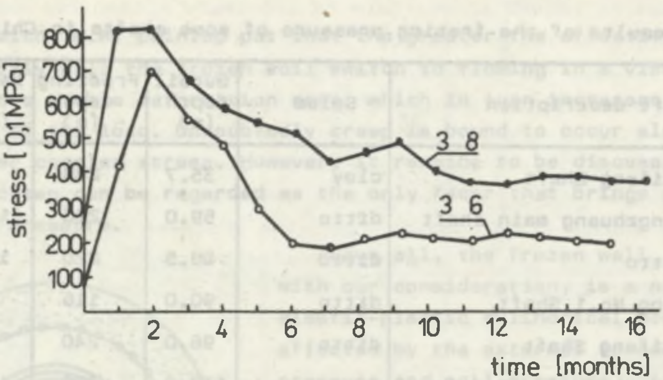

Fig. 5. The stress variation curve of the vertical steel bars in the outer lining at the depth of 121-125 meters in Panji Shaft No.1 (Dongfeng Shaft)

Rys. 5. Krzywa zmienności naprężeń w pionowych prętach stalowych w obudowie zewnętrznej na głębokości 121-125 metrów w szybie Panji Nr 1 (szyb Dongfeng)

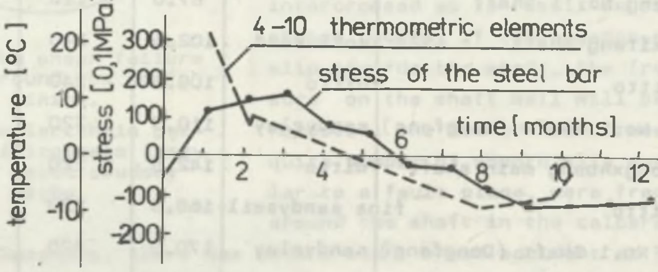

Fig. 6. The stress variation curve of the vertical steel bars in the outer lining at the depth of 137 meters in Panji Shaft No.1 (Dongfeng Shaft)

Rys. 6. Krzywa zmienności naprężeń w pionowych prętach stalowych w obudowie zewnętrznej na głębokości 137 metrów w szybie Panji Nr 1 (szyb Dongfeng)

factors, the depth of the solum bas the most remarkable influence upon the freezing pressure. It can be seen from table 1 that in the coal mine of our country, the freezing pressure in the same types of solums is always in close relation (through even not ideally linear) with its burial depth.

The influences of the properties of the solum on the freezing pressure are shown in the following aspects: 1) When the embedded depths of the solums are the same or approximately the same, the freezing pressure occurred in the clay strata is larger than that occurred in sandy strata or gravel sandy strata. 2) The nonuniformity coefficient of the freezing pressure varies with the differences in solum properties. For example, the

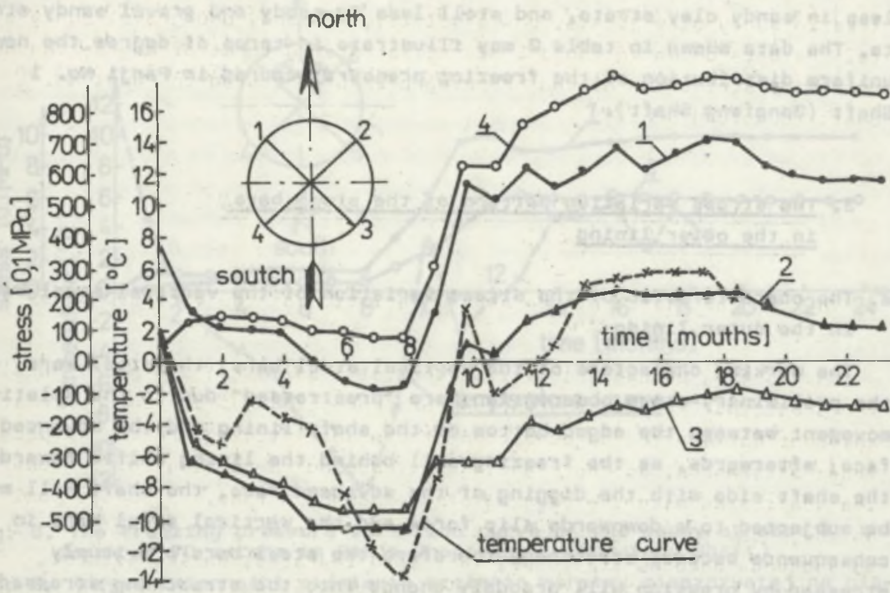

Fig. 7. The stress variation curve of the steel bars at the depth of 70 meters in Panji Shaft No. 1 (Dongfeng Shaft)

Rys. 7. Krzywa zmienności naprężeń w warstwie piaszczystej na głębokości 70 metrów w szybie Panji Nr 1 (Szyb Dongfeng)

Table 2

The nonuniformity coefficient of the freezing pressure in Panjo No. 1 Shaft (Dong feng Shaft)

No.	Solum description	Burial depth (m)	Max. P_f (0.1 MPa)	Min. P_f (0.1 MPa)	Non-uniform coefficient	Duration (months)
1	Medium sand	40	1.5	0.4	2.75	10
2	Ditto	70	9.8	6.2	0.5	17
3	Sandy clay	110	20.7	16.0	0.29	8
4	Clay	137	24.2	17.7	0.36	3
5	Snady clay	170	28.8	22.1	0.3	2
6	Medium sand	220				
7	Sandy gravel	278	32.4	19.7	0.6	5

Note: Max. P_f - maximum freezing pressure
Min. P_f - minimum freezing pressure
Non-uniformity coefficient $W = (P_{max} - P_{min})/P_{min}$

freezing pressure in clay strata is relatively evenly distributed, and less in sandy clay strata, and stell less in sandy and gravel sandy strata. The data shown in table 2 may illustrate in terms of degree the non-uniform distribution of the freezing pressure occured in Panji No. 1 Shaft (Dongfeng Shaft).

3. The stress variation pattern of the steel bars in the outer lining

a. The characteristic of the stress variation of the vertical steel bars in the outer lining:

The working characters of the vertical steel bars: the steel bars, on the preliminary-stage observation, are "prestressed" due to the relative movement between the edged-bottom of the shaft lining and the advanced face; afterwards, as the freezing soil behind the lining shifts towards the shaft side with the digging of the advanced face, the shaft wall may be subjected to a downwards slip force and the vertical steel bars in consequence becomes stretched; therefore the steel bars previously stressed by pression will gradualy change into the stretching stressed condition (fig. 5).

In spite of the fact that the temperature stress, in a certain degree, influences the stress of the vertical steel bars, yet from the variation curves (the stress of the steel bars versus the temperature) it can be seen that the stress variation of the steel bars is by no means restricted by temperature, the variation caused by the temperature change being negligibly small (fig. 6).

b. The characteristic of the stress variation of the circulatory steel bars in the outer lining:

The stress of the circulatory steel bars is composed of two components, i.e., that due to freezing pressure and that due to temperature change. In the case of a small external force (e.g., in shallow places where the freezing pressure is relatively small), the temperature stress is the primary; whereas the stress caused by the external forces the secondary. In fig. 7, it is shown that with the decrease of the temperature, the stress of the circulatory steel bars is gradually converted into a stretched condition from the previous pressed condition; in turn, with the increase of the temperature, the conversion is reversed. Neverther-less, the freezing pressure therein dose not noticeably change, and its value is relatively small (fig. 8).

Tn the deep position where the freezing pressure is relatively large, the influence of the temperature stress is not obvious, which is due to the fact that although the stress of the steel bars varies with the

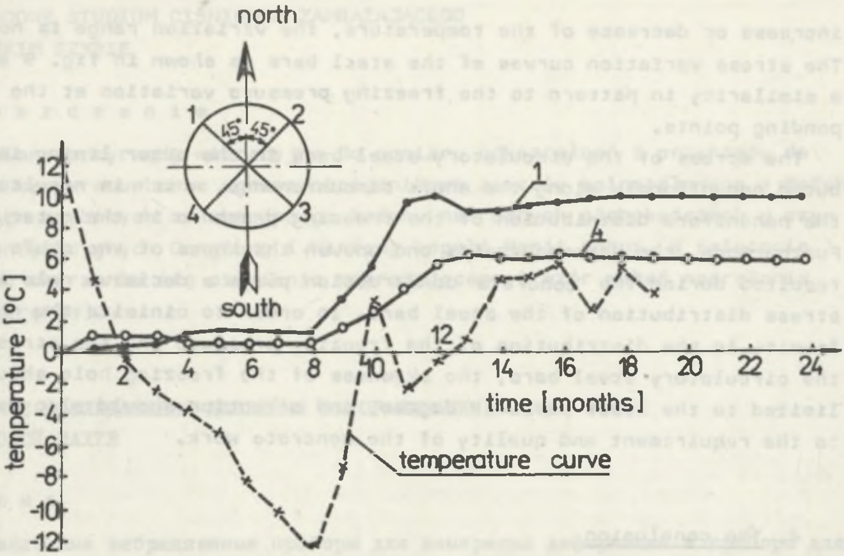

Fig. 6. The freezing pressure variation curve of the sandy stratum at the depth of 70 meters in Panji Shaft No. 1 (Dongfeng Shaft)

Rys. 8. Krzywa zmienności ciśnienia mrożenia warstwy piaszczystej na głębokości 70 metrów w szybie Panji Nr 1 (Szyb Dongfeng)

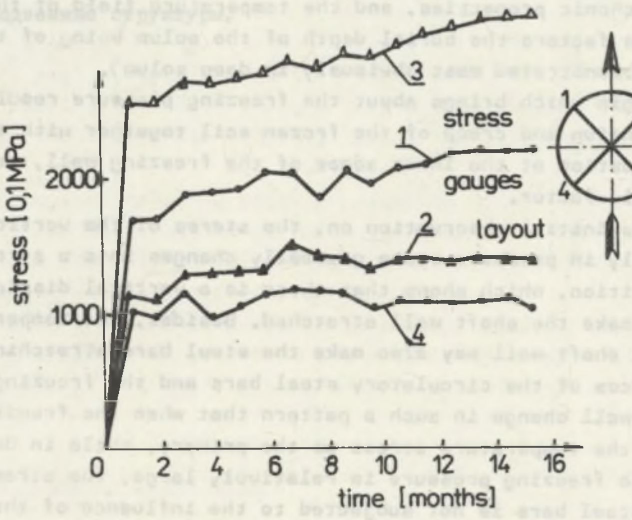

Fig. 9. The stress variation curve of the steel bar at the depth of 278 meters in Panji Shaft No. 1 (Dong feng Shaft)

Rys. 9. Krzywa zmienności naprężeń w prętach stalowych na głębokości 278 metrów w szybie Panji Nr 1 (Szyb Dongfeng) increase or decrease of the temperature, the variation range is not large. The stress variation curves of the steel bars as shown in fig. 9 exhibit a similarity in pattern to the freezing pressure variation at the corresponding points.

The stress of the circulatory steel bars in the outer lining is distributed nonuniformly along the shaft circumference, which is resulted from the nonuniform distribution of the freezing pressure in the outer parts. Furthermore, the nonhomogeneity and uneven thickness of the shaft wall resulted during the concrete construction plays a decisive role in the stress distribution of the steel bars. In order to minimize the nonuniformity in the distribution of the freezing pressure and the stress of the circulatory steel bars, the skewness of the freezing hole should be limited to the least possible degree, and attention should also be paid to the requirement and quality of the concrete work.

4. The conclusion

On the basis of the consecutive observation and researches on the freezing pressure of the shafts in Panji, the author deems that the freezing pressure of deep shafts is characterized by the following:

1. In accordance with the information accumulated on the spot, the magnitude of freezing pressure depends on the burial depth of the solum, the physicomechanic properties, and the temperature field of the freezing wall, of these factors the burial depth of the solum being of the most importance (demonstrated most obviously in deep solum).

2. The origin which brings about the freezing pressure results directly from the expansion and creep of the frozen soil together with the shear failure deformation at the inner edges of the freezing wall, rather than from one single factor.

3. From the initial observation on, the sterss of the vertical steel bars previously in pressure state gradually changes into a stretching-stressed condition, which shows that there is a vertical displacement of the solum to make the shaft wall stretched. Besides, the temperature change of the shaft wall may also make the steel bars stretching-stressed.

4. The stress of the circulatory steel bars and the freezing pressure in the shaft wall change in such a pattern that when the freezing pressure is small, the temperature stress is the primary, while in deep position where the freezing pressure is relatively large, the stress of the circulatory steel bars is not subjected to the influence of the temperature stress.

Recenzent: Prof. dr hab. inż. Mirosław Chudek

Wpłynęło do Redakcji w czerwcu 1988 r.

PRZYKŁADOWE STUDIUM CIŚNIENIA ZAMRAŻAJĄCEGO W GŁĘBOKIM SZYBIE

S t r e s z c z e n i e

Druciane przyrządy wibracyjne do pomiaru odkształceń i przyrządy do pomiaru temperatur oraz ogniwa obciążnikowe zostały zainstalowane w dwóch obudowach szybowych ze zbrojonego betonu na różnych głębokościach w szybach wentylacyjnych Dongfeng i Nanfeng kopalń Panji Anhui. W referacie omówiono tworzenie się ciśnienia zamrażającego i wzór wahań naprężenia żeber (prętów).

ПРИМЕРНЫЕ ИССЛЕДОВАНИЯ ДАВЛЕНИЯ ЗАМОРАЖИЗАНИЯ В ГЛУБОКОЙ ШАХТЕ

Р е з ю м е

Проволочные вибрационные приборы для мзмерения деформаций и приборы для измерения температур, а также нагрузочные элементы были помещены в двух железобетонных шахтных крепях на различных глубинах в вентиляционных стволах Донгфенг и Нанфенг шахт Панйи и Анхуи. В работе представлено образование давления замораживания и формула колебания напряжения ребер стержней .

Главные формулы: земное давление, эксперимент непосредственный, крепб, стволы, подземные структуры.