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LOADINGS OF LEGS IN SECTIONS OF MECHANISED SUPPORTS BY DYNAMIC MOVEMENTS OF ROOF AND FLOOR

OBCIĄŻENIA STOJAKÓW SEKCJI OBUDOWY ZMECHANIZOWANEJ SPOWODOWANE DYNAMICZNYM ODDZIAŁYWANIEM STROPU I SPĄGU WYROBISKA

Using results of measurements of the resultant force carried by hydraulic legs and of a vertical component of acceleration of a canopy, the sense of external loading of the section caused by the dynamic action of the rock mass and parameters characterising changes of the force in legs opposing the that external load was determined.

The sense of external loading of the section of the mechanised support was determined assuming that it causes a linear motion of the canopy. This results from the initial conditions of the equation of the canopy movement (the conditions corresponding to the initial static load) that initially senses that the vertical component of the acceleration of the canopy and of the resultant force of the external load are the same. It was assumed on the basis of the observations of changes of the force in the legs during setting that in the case of dynamic movement of the rock mass on the support the average speed of the force increase in legs — $w_{F,n}$ is at least 1.25 times bigger than the maximum value of $w_{F,n}$ registered during setting of the section.

As a result of the long-term measurements carried out in four longwalls, 37, recordings of dynamic processes at different times, of forces in legs, caused by dynamic movement of the rock mass were registered. In 9 cases of changes of forces in the legs were caused by external loads acting on the bases of the section.

Looking for a relationship between parameters characterising changes of the force in the legs and the natural and technical conditions in situ, a clear statistical dependence between maximum force — F_m and an initial static force — $F_{st,p}$ was demonstrated. The dependence is valid both for changes of force in the legs caused by an external load acting from the roof and for a load acting from the floor. The coefficient of load increase, K_d, which characterises changes of force in the legs caused by external load acting on bases is significantly greater than that imposed on the legs by changes in roof loadings. Also the average rate of increase of force in the legs is considerably greater in the case of an external load acting from the floor.

Key words: mechanised support, loadings of legs, dynamic movements of rock mass

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Przedmiotem pracy jest analiza zmian sił w stojakach sekcji obudowy zmechanizowanej spowodowanych dynamicznym oddziaływaniem górotworu. Podczas pomiarów obciążeń obudów zmechanizowanych, wykonywanych systemem ciągłym w wyrobiskach zagrożonych tąpaniami, rejestrowano równocześnie dwa przebiegi czasowe:

- wypadkowej siły przenoszonej przez stojaki hydrauliczne,
- pionowej składowej przyspieszenia stropnicy.

Sygnały pomiarowe rejestrowano na taśmie magnetofonu pomiarowego usytuowanego na powierzchni. Parametry charakteryzujące zmiany siły w stojakach, jak również zwrot wywołującego je zewnętrznego obciążenia sekcji, wyznaczono analizując zarejestrowane sygnały pomiarowe w paśmie częstotliwości 0–500 Hz.

Zwrot zewnętrznego obciążenia sekcji obudowy zmechanizowanej określano zakładając, że wywołuje ono ruch postępowy stropnicy. Z warunków początkowych równania ruchu stropnicy, odpowiadających początkowemu statycznemu obciążeniu sekcji wynika, że w chwili początkowej zwroty składowej pionowej przyspieszenia stropnicy i wypadkowej obciążenia zewnętrznego są zgodne. Wyróżniono dwa rodzaje obciążeń zewnętrznych sekcji:

- obciążenie działające od strony stropu — np. rysunki 3 i 4,
- obciążenie działające od strony spągu — np. rysunki 5 i 6.

W pracy analizowano tylko te fragmenty przebiegów czasowych sygnałów pomiarowych, które spełniają warunki:

1) poziom zakłóceń sygnału wynosi co najwyżej 20% maksymalnej wartości sygnału,

2) średnie tempo przyrostu siły w stojakach — $w_{F,n}$ jest co najmniej 1,25-krotnie większe od maksymalnej wartości $w_{F,n}$ zarejestrowanej podczas rozpierania sekcji.

Warunek 2 jest równoznaczny z założeniem, że dynamiczne oddziaływanie górotworu powoduje intensywniejsze zmiany wartości wypadkowej siły w stojakach niż rozpieranie sekcji, co w przypadku wyrobisk w których wykonywano pomiary oznacza, że:

$$w_{F,n} = \frac{0{,}8(F_m - F_{st,p})}{t_n} > 0{,}6\,[\mathrm{MN \cdot s^{-1}}]$$

W rezultacie długotrwałych pomiarów prowadzonych w czterech ścianach (informacje o warunkach przeprowadzania pomiarów zestawiono w tabl. 1 i 2) zarejestrowano 37 przebiegów czasowych siły w stojakach spowodowanych dynamicznym oddziaływaniem górotworu. Zestawienie zarejestrowanych przebiegów czasowych według zwrotu obciążenia zewnętrznego sekcji zawiera tablica 3. W 18 przypadkach zmiany siły w stojakach spowodowało obciążenie zewnętrzne działające na sekcję od stropu. Dane dotyczące tych zmian siły w stojakach zawiera tablica 4. W przypadku 10 przebiegów czasowych siły w stojakach (tabl. 6) wyznaczenie zwrotu zewnętrznego obciążenia sekcji na podstawie zwrotu początkowego przyspieszenia stropnicy nie było możliwe ze względu na silne zakłócenia sygnału przyspieszenia. Kierując się innymi przesłankami (lokalizacja ognisk wstrząsów górotworu towarzyszących zarejestrowanym zmianom siły w stojakach, porównanie przedziałów zmienności parametrów charakteryzujących zarejestrowane przebiegi czasowe — tabl. 7, itp.) przyjęto, że zmiany siły w stojakach przedstawione w tablicy 6 również spowodowało działanie obciążenia zewnętrznego od strony stropu. W 9 przypadkach zmiany siły w stojakach spowodowało obciążenie zewnętrzne działające na spągnice sekcji (dane zawiera tabl. 5).

Poszukując związków pomiędzy parametrami charakteryzującymi zmiany siły w stojakach a warunkami naturalnymi i technicznymi w miejscu wykonywania pomiarów, wykazano istnienie wyraźnej statystycznej zależności pomiędzy maksymalną siłą — F_m a początkową siłą statyczną — $F_{st,p}$. Występuje ona zarówno dla zmian siły w stojakach spowodowanych działaniem obciążenia zewnętrznego od strony stropu — rys. 9 i 10, równania (5) i (7) — jak też od strony spągu — rys. 11, równanie (9). W przypadku prostych regresji pokazanych na rysunkach 9, 10, 11 i porównanych na rysunku 12 współczynnik regresji można utożsamiać ze współczynnikiem przyrostu obciążenia K_d, definiowanym jako iloraz sił F_m i $F_{st,p}$. W przypadku zmiany siły w stojakach spowodowanej działaniem obciążenia zewnętrznego na spągnice współczynnik przyrostu obciążenia K_d jest istotnie większy od współczynnika K_d dla siły w stojakach wywołanej obciążeniem sekcji od stropu. Granice

przedziałów ufności współczynnika przyrostu obciążenia dla wyróżnionych rodzajów zmian siły w stojakach, zbudowane na poziomie ufności 90%, zestawiono w tablicy 8. Również średnie tempo przyrostu siły w stojakach jest znacznie większe w przypadku działania obciążenia zewnętrznego od spągu.

Precyzyjniejszy opis związków pomiędzy parametrami charakteryzującymi obserwowane zmiany siły w stojakach a wielkościami opisującymi warunki naturalne i techniczne w wyrobisku oraz dynamiczne oddziaływanie górotworu wymaga przeprowadzenia dalszych pomiarów. Dotyczy to w szczególności pomiarów obciążeń występujących w wyrobiskach zagrożonych tąpaniami, prowadzonych po spągu węglowym.

Słowa kluczowe: obudowa zmechanizowana, siły w stojakach, oddziaływanie dynamiczne górotworu

1. Introduction

One of the factors which enables rational designing of new types of powered roof supports is a determination of the parameters which characterize the loads acting on the powered roof support unit. This problem is particularly important in the case of constructing the roof supports designed for operation in the workings where hazards of sudden rock movements are presented. The purpose of the measurements, carried out by the KOMAG Center and the Mining Mechanization Institute at the Silesian Technical University, in the workings threatened by rockfalls (Szweda 1992, 1996), has been to determine the parameters which characterize the loads in powered roof support units, caused by the dynamic action of a rock mass. The selected parameters, which characterize the loads recorded during these measurements, are discussed.

Usually, when examining the dynamic action of rock mass on powered roof supports, the phenomena occurring in the roof (like: roof vibrations, tremors, immediate roof sliding etc.) are taken into consideration. The dynamic action can also act upwards on the unit from the floor of the working. Some information about damage to subassemblies of units caused by sudden movements, collected by Profaska (1998) testifies to this fact. Analyzing the results of sudden movements, causing damage to powered roof support units, it has been stated that in longwalls driven between the coal floor and the roof of the seam (i.e. extracting the seam in layers) damage to the support elements has been accompanied by floor heave in the face area and the coal falling from the face. In longwalls mined within their entire seam thickness, beside the effects of sudden movements, resulting in the damage of support elements, coal falling from the face has been observed relatively frequently. Floor heave has occurred much more infrequently. However, there are some circumstances, indicated by phenomena occurring in the floor, which can be a cause of dynamic loads in powered roof support units. Some of these phenomena have been described in the literature (e.g. Szuścik 1994, 1995), but to date there has been no information about the value and the character of the dynamic loadings which these phenomena create in acting on the unit from the floor. That is why one of the research tasks of the measurements, discussed in the paper, has been to check whether the location of the dynamic phenomenon which causes the change in the loading of the unit (whether in the working roof or floor) influences the parameters which characterize these loads.

The method of determining the sense of the external load of a powered roof support unit and the measurement processes in the workings where a shock-loading hazard is presented, as well as the recorded loads are discussed.

2. The method of determining the sense of the unit external load caused by the dynamic phenomena in the rock mass

Developing the testing method, the following simplifying assumptions have been made:

1. An external dynamic load is applied to the canopy or the base of the support unit.
2. Temporary canopy movement due to the dynamic load is linear motion, taking place in the plane perpendicular to the working roof and floor.

Generally, the measurement method consists in simultaneous recording of two time processes:

- a resultant force transmitted by legs,
- a vertical component of the acceleration of a selected point of the canopy.

An arrangement of sensors has been presented in Fig. 1.

The resultant force transmitted by legs has been determined by strain gauges placed on the mechanical extension rod of the leg. A piezoelectric sensor installed inside the canopy has determined the vertical component of the canopy's acceleration, as close as possible to the leg head. This location of the acceleration sensor allows the influence of temporary canopy rotation on the value of the vertical acceleration of the canopy to be minimised.

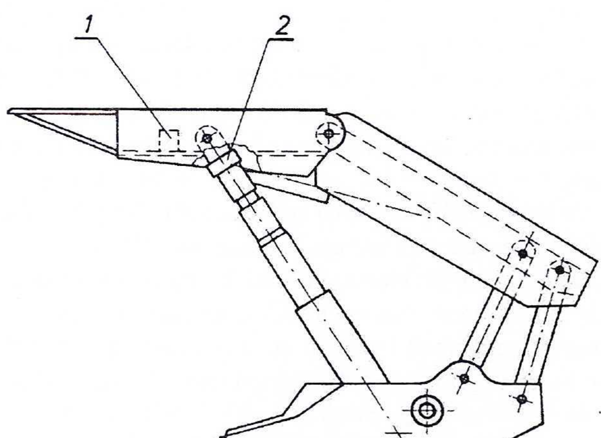

Fig. 1. Diagram of the sensors arrangement in the unit
1 — acceleration sensor, 2 — force sensor

Rys. 1. Schemat rozmieszczenia czujników w sekcji
1 — czujnik przyspieszenia, 2 — czujnik siły

Measurement signals are transmitted from the workings to the surface and they are recorded continuously. This method of recording the measurements enables loadings the unit caused both by static and dynamic action of the rock mass to be reproduced. Analyzing the recorded time processes, it is possible to determine the sense of the external load of the unit, caused by dynamic phenomena in the rock mass.

The method of determination the sense of this load is shown in Fig. 2

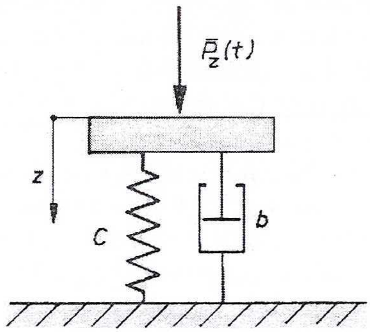

Fig. 2. Simplified model of the powered roof support unit

Rys. 2. Uproszczony model sekcji obudowy zmechanizowanej

A differential equation of the unit motion treated as a mechanism with one degree of freedom has the following form:

$$m\ddot{z} + b\dot{z} + cz = P_z(t)$$

where:

- m — weight of the unit reduced in relation to the canopy,
- b — coefficient of the viscous suppression,
- c — coefficient of rigidity,
- $P_z(t)$ — external load of the unit.

From the initial conditions, relating to the initial static load of the support unit:

$$z(t=0)=0$$

$$\dot{z}(t=0)=0$$

this results in:

$$m\ddot{z}(t=0)=P_z(t=0)$$

so at the initial moment, the senses of the vertical component of the canopy acceleration and of the external loads of the unit should be the same. According to the accepted system of coordinates, the external load

$$P_z(t=0)>0$$

relating to the positive acceleration $\ddot{z}(t=0)$ acts on the canopy from the roof side, and because of the unilateral character of the ties between the unit and rocks surrounding the load:

$$P_z(t=0)>0$$

should be interpreted as the external load acting on the base from the floor side.

The force in the leg is measured independently from the measurement of the canopy acceleration. Its value, irrespective of the sense of the unit's external load, always increases. In connection with this a determination of the sense of the support external load consists in a determination of the canopy acceleration sense when the value of the resultant force in the legs begins to increase.

The method of determining the initial acceleration of the canopy is given in Fig. 3 and 4, presenting the time processes of the force and acceleration, recorded during the measurements carried out at longwall IV, Seam 501, at the "Wujek" Colliery.

The following noise level of the measurement signal has been assumed:

- for a signal of the resultant force in legs

$$\delta F = 0.1(F_m - F_{st,p})$$

- for an acceleration signal

$$\delta a = 0.1|a_{\max}|$$

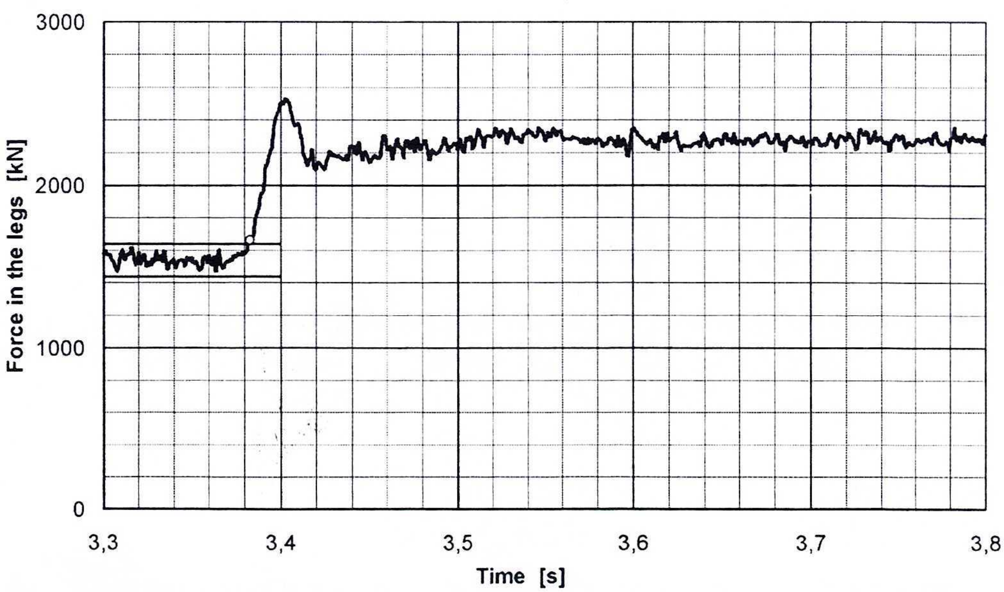

Fig. 3. Force time process in the legs caused by the external load acting on the unit from the floor

Rys. 3. Przebieg czasowy sił w stojakach spowodowany obciążeniem zewnętrznym działającym na sekcję od spągu

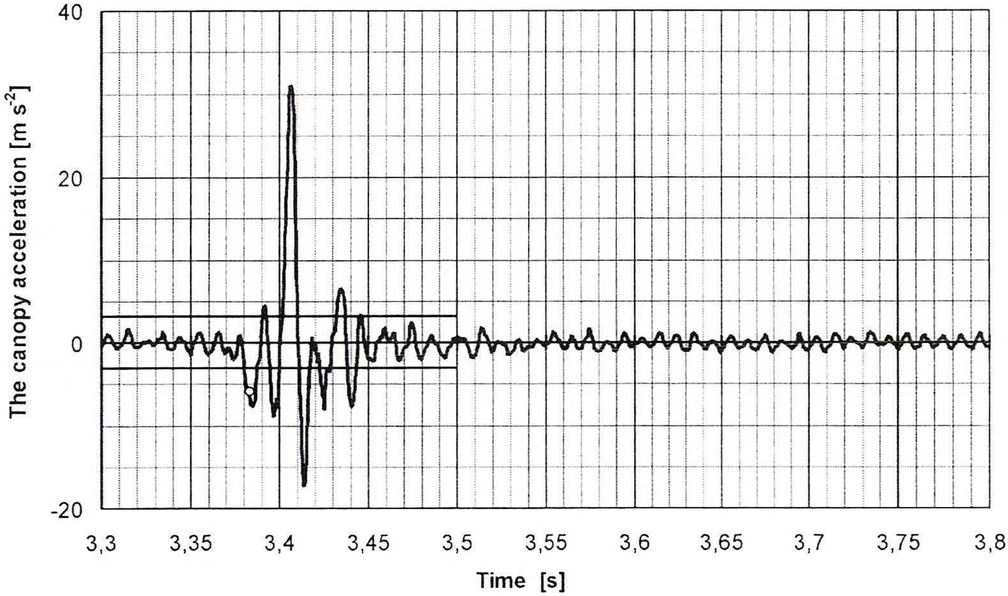

Fig. 4. Time process of the canopy acceleration caused by the external load acting on the unit from the floor

Rys. 4. Przebieg czasowy przyspieszenia stropnicy spowodowany obciążeniem zewnętrznym działającym na sekcję od spągu

It has been assumed that an initial acceleration of the canopy a_o will occur at the time t_o, when the following conditions are satisfied:

$$|a(t_o)| > \delta a \tag{1}$$

$$F(t_o) > F_{st,p} + \delta F \tag{2}$$

$$a_o = a(t_o)$$

The horizontal lines in Fig. 3 and 4 determine the limits of the signal noise levels, however the initial acceleration of the canopy a_o and $F(t_o)$ have been marked on the diagrams by the "o" mark. In the cases under consideration $a_o = -5.9$ m·s^{-2}, so the unit external load is applied to the base.

An example of the legs' loading, caused by an external force acting on the canopy of the unit is shown in Fig. 5. The simultaneously recorded time process of the acceleration is presented in Fig. 6.

In Fig 5. and 6 the initial resultant force in the legs — $F(t_o)$ and the initial acceleration of the canopy $a_o = a(t_o)$ have been marked by "o" (as in Fig. 3 and 4).

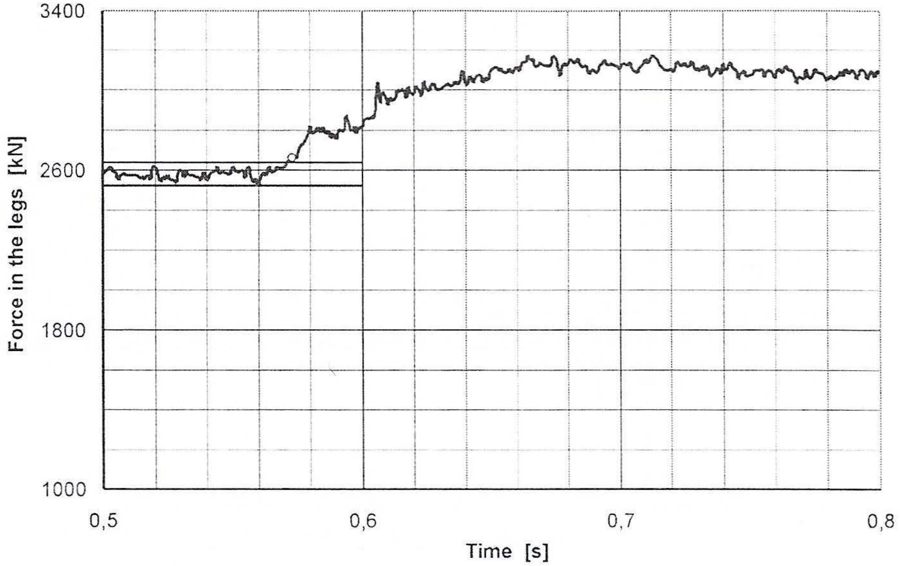

Fig. 5. Force time process in the legs caused by the external load acting on the unit from the roof

Rys. 5. Przebieg czasowy sił w stojakach spowodowany obciążeniem zewnętrznym działającym na sekcję od stropu

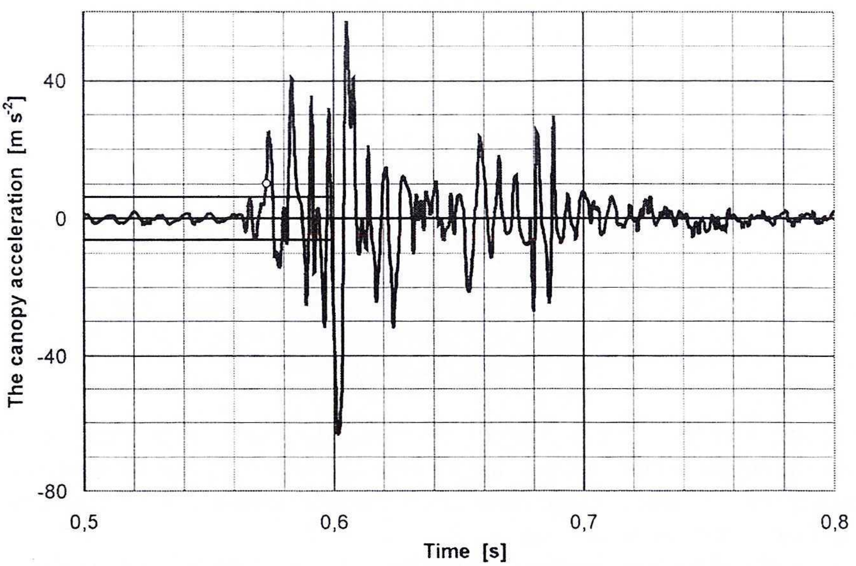

Fig. 6. Time process of the canopy acceleration caused by the external load acting on the unit from the roof

Rys. 6. Przebieg czasowy przyspieszenia stropnicy spowodowany obciążeniem zewnętrznym działającym na sekcję od stropu

The presented measurement method enables two groups of the unit external loads to be distinguished:

- loads applied to the canopy of the unit, which are characterized by the fact that at the initial moment the vector of canopy acceleration has a sense directed towadrs the floor,
- loads applied to the base of the unit, which are characterized by the fact that at the initial moment the vector of the canopy acceleration has a sense directed towards the roof.

3. Underground measurements

Measurements of loadings of powered roof support unit, caused by the dynamic action of rock mass, were carried out between 1992–1994 in four selected longwall workings, where the third degree of shock hazard was presented. Detailed information concerning the process of measurements, mining-and-geological conditions as well as the measurement results have been enclosed in the reports from the realization of the research project No. 9 9031 92 (Szweda 1994a). A general characteristic of the place and the object under testing is presented below. Due to the changeability of the mining-and-geological conditions along the longwall panel, six stages of measurements were decided upon. The basic data, concerning the time and the place of realizing the following stages of measurements are listed in Table 1, and the information concerning the mining-and-geological conditions at the place of measurements is given in Table 2.

TABLE 1

List of basic information characterising the time and the measurement site

TABLICA 1

Zestawienie podstawowych informacji charakteryzujących czas i miejsce wykonywania pomiarów

Item	Stage of measurements	Colliery	Longwall (seam)	Roof control	Mining technology	Remarks
1	I	"Zabrze--Bielszowice"	N791 (502)	gob	Shearer	
	II				Shearer	Influence of the extraction boundary in the seam 416
	III				Explosives	Influence of the extraction boundary in the seam 501
2	IV	"Wujek"	IV (501)	gob	Shearer	
3	V	"Śląsk"	8 (414/1)	gob	Explosives	
4	VI	"Porąbka--Klimontów"	758 (510)	Hydraulic backfilling	Shearer	

TABLE 2

Basic mining and geological conditions characterising the measurements site

TABLICA 2

Podstawowe warunki geologiczno-górnicze charakteryzujące miejsce wykonywania pomiarów

Item	Longwall (seam)	Immediate roof	Floor	Av. longwall height [m]	Roof support	Remarks
1	N791 (502)	Mudstone	Mudstone	2.4	FAZOS 15/31-Oz	Numerous zones of extraction boundaries effect
2	IV (501)	Sandstone	Coal (Seam 501)	2.2	FAZOS 12/28-Oz	Longwall driven in the near-the-roof layer
3	8 (414/4)	Mudstone	Mudstone	2.3	FAZOS 15/31-Oz	Support equipped with the relief valves
4	758 (510)	Sandstone	Coal (Seam 510)	2.6	FAZOS 12/28-Oz	Longwall driven in the near-the-roof layer

Projections of mining boundaries in the seams situated over the 502 Seam, located in the N791 Longwall Panel are shown in Fig. 7. The location of the No. 193 unit, where the measuring instruments were installed, has also been marked. The differentiation of three stages of tests in the N791 Longwall was dictated by different mining conditions (mining technology, shock prevention measures taken) and by extracting the upper section of the longwall under the area of influence of the mining boundaries in seams Nos. 416 and 501, respectively located 70 meters and 17 meters above the longwall face being mined.

Measurement signals were transmitted to the surface by two electrical connecting systems and were recorded on a magnetic tape. Total time of recording of measurement signals during all the measurement stages was 1237 hours.

The basic results of the underground measurements included the recorded changes of the vertical canopy acceleration and the resultant loads transmitted by the hydraulic legs. The intensity of the changes of the loading is differentiated — beginning from quasi-static force increase in the leg caused by a slow convergence in the working, through the changes caused by leg setting or lowering, including quick load changes occurring during rock-bursts, blasting or other dynamic phenomena in the rock mass.

It has been assumed that the measure of the unit load intensity is the average rate of force increase in the legs as determined from the following equation:

$$w_{F,n} = \frac{0.8(F_m - F_{st,p})}{t_n}$$

where:

F_m — maximum force transferred through the legs during the time process of unit loading under consideration,

$F_{st,p}$ — initial static force in the legs,

t_n — time of load increase, determined according to the PN-88/M-42000 Standard.

For a further analysis only these time processes, which are characterized by a higher than average rate of force increase in the legs than those recorded at the unit setting, have been selected from all the recorded changes in the leg loadings. To a large extent the setting rate depends on the pressure in the main pipeline, the cylinder diameter and the flow resistance in the hydraulic hoses. Analyzing the results of the force measurements in the legs, during the unit setting, it has been stated that the maximum value of the average rate of load increase in the legs during the unit setting — $(w_{F,n})_{st}$ — is:

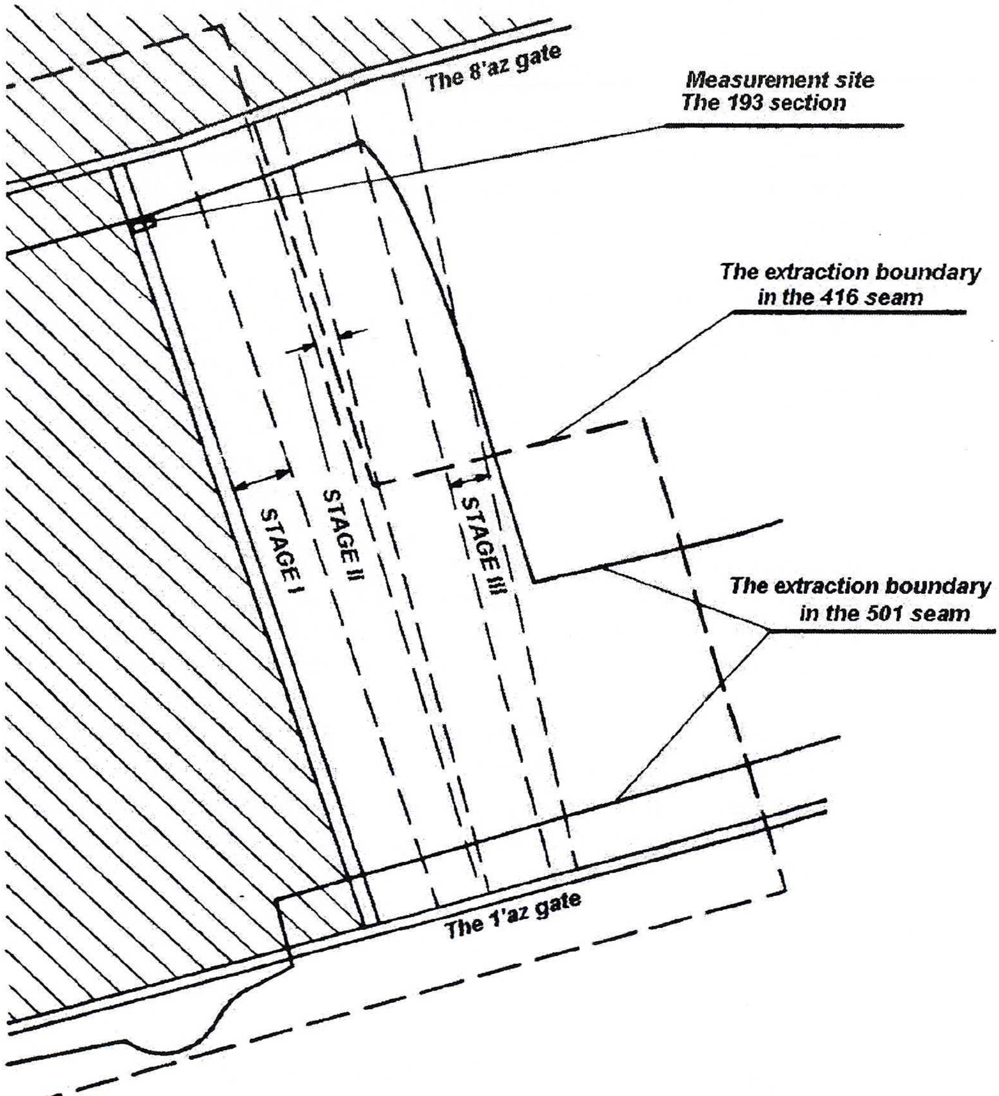

Fig. 7. Location of the measurement site in the N791 Longwall of the Seam 502

Rys. 7. Usytuowanie miejsca pomiarów w ścianie N791 pokładu 502

$$(w_{F,n})_{st} = 0.481 \text{ [MN·s}^{-1}]$$

In relation to the above statement it has been assumed that the unit loads, caused by a dynamic action of the rock mass, are characterized by an average rate of force increase in the legs, of a magnitude of at least 1.25 times higher than the maximum value of an average rate of the force increase in the legs caused by the unit setting.

$$w_{F,n} > 1.25 \cdot (w_{F,n})_{st}$$

$$w_{F,n} > 0.6 \text{ [MN·s}^{-1}] \tag{3}$$

Four cases of the rock mass dynamic action on the unit causing — instead of an increase — a rapid decrease of the force in the legs, were recordered (Szweda 1994). Such type of load has not been discussed in the paper, as from the support designer's and user's point of view the most important loads are those which are characterized by the increase of force in the legs.

An important factor, influencing the number of recorded dynamic loads of the supports, includes the noises of the measurement signal. Taking into consideration the underground conditions in which the measurements have been taken, it has been assumed, following Hagel (1975), that those time processes of measurement signals for which the coefficient signal/noise is greater than 5.0, can be subjected to a further analysis. This implies that the noises of a measurement signal cannot exceed 20 percent of the maximum recorded increase of the signal.

Finally, taking into consideration both factors mentioned above, 37 time processes of the force in the legs are eligible for a further analysis. A determination of the initial sense of the canopy acceleration — a_0 — has been possible in 27 cases of the time processes of the canopy acceleration signals recorded simultaneously with the time processes of the force in the legs. A number of recorded rates of acceleration are lower, as in the case of ten recorded acceleration signals the coefficient signal/noise of which did not exceeded 5.0. The reason for a bigger influence of noises on the acceleration process can be found in the much higher internal resistance of the acceleration sensor (order GΩ) in comparison to the internal resistance of the force sensor (about 100 Ω). A high internal resistance of the acceleration sensor facilitates an induction of noise in the acceleration measurement system.

The analysis of the selected parameters which characterize the indicated 37 loads of legs caused by a dynamic action of the rock mass on the powered roof support unit, is presented below.

4. Characteristic of the discussed loads of legs

The objective of the analyses, presented below is to establish a relationship between the parameters which characterize the discussed loads of the legs and the natural and technical conditions existing in the working. The following physical values are the subject of discussion:

- parameters which characterize the support static load:
  - $F_{st,p}$ — initial static force in the legs,
  - $F_{st,k}$ — final static force in the legs;
- parameters which characterize the change of legs loadings, caused by a dynamic movement of the rock mass:
  - F_m — maximum force transferred through the legs during the time process of unit load under discussion,
  - t_n — time of load increase, determined according to the PN-88/M-42000 Standard,
  - K_d — coefficient of load increase, defined as a quotient of the forces F_m and $F_{st,p}$,
  - $w_{F,n}$ — average rate of force increase in the legs.

Fig. 8 illustrates the relations between selected parameters which characterize the dynamic load.

The following parameters which characterize the risk of rock-bursts, as determined by the mine seismometric stations are also mentioned:

r — distance from the burst center to the area where the measurements have been taken,

E — energy of burst,

$\varepsilon_{r,s}$ — energy density of the seismic transverse wave at the area of measurements.

The seismic energy density has been determined from the relations given by Dubiński and Wierzchowska (1973):

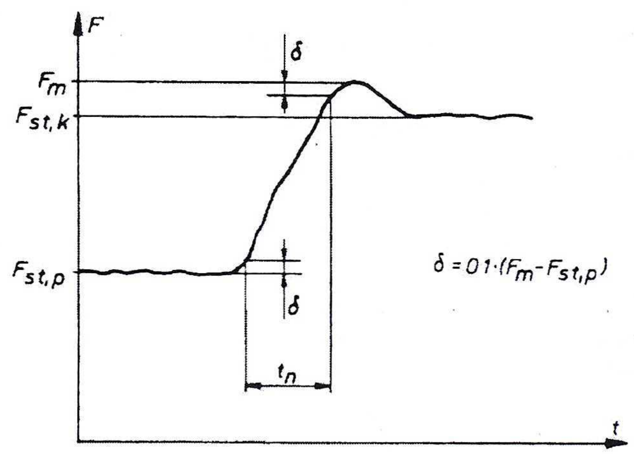

Fig. 8. Pictorial illustration of the selected parameters characterizing the discussed legs' loads of the powered roof support unit

Rys. 8. Poglądowa ilustracja wybranych parametrów charakteryzujących rozpatrywane obciążenia stojaków sekcji obudowy zmechanizowanej

$$\varepsilon_{r,s} = \frac{E}{4\pi R^2 \left(\frac{r}{R}\right)^{2n} e^{2\alpha(r-R)}} \tag{4}$$

where:

R — radius of the reference sphere; R = 500 m

n — exponent of the wave propagation function; n = 1.067

α — coefficient of the seismic wave amplitude absorption; $\alpha = 0.0165\ \text{km}^{-1}$

Beginning the analysis of the underground measurement results, the sense of the external load of powered roof supports has been taken into consideration primarily. The time processes of the forces in the legs, according to the external load sense acting on the unit and considering the information about the dynamic phenomena occurring in the rock mass during the recorded loads of powered roof support units, are listed in Table 3.

TABLE 3

Specification of the number of the recorded force time processes in the legs according to the sense of unit external load and the dynamic phenomena accompanying them

TABLICA 3

Zestawienie liczby zarejestrowanych przebiegów czasowych siły w stojakach według zwrotu obciążenia zewnętrznego sekcji i towarzyszących im zjawisk dynamicznych

Dynamic phenomena in the rock mass	Mark	Number of the force processes in the legs caused by the external load applied to the:		Sense of the unit external load has not been determined
		canopy	base	
Spontaneous tremor in the rock mass	1	10	7	4
Rock mass tremor excited by blasting	2	6	—	3
Rock mass tremor has not been detected	3	2	2	3
Tremor has not been detected when blasting	4	1	—	—
Total		18	9	10

Some information about the dynamic phenomena occurring in the rock mass, has been collected in the mine seismometric stations. The most frequent indication of these phenomena has been in rock-bursts, both spontaneous and initiated by blasting. During the measurements it was seen that not every rock-burst recorded in the longwall area, caused a change of loading in the legs. On the other hand, not all the changes of the load in the legs, as discussed in the paper, were accompanied by rock-bursts, recorded at the seismometric station. As seismometers, used in the mine geophysical network, generally record tremors of the energy exceeding 100 J, it has been assumed that in the case of the phenomena, marked by the numbers 3 and 4 (see Tables 3, 4, 5 and 6), the tremor energy accompanying the load of the unit, is lower than 100 J. Whilst making such an assumption, it can be said that whereas all the recorded changes of the load in the legs is associated with tremors, at the same time the energy of some of the latter is not within the range of the tremor energy determinable by the mine seismometric stations.

The parameters that characterize the time processes of the forces in the legs, caused by an external load action on to the canopy of the unit, have been listed in Table 4. The values of the parameters listed in Table 4 as well as in Tables 5 and 6, have been determined using the time processes of the force in the legs recorded in a form of a digital file and opened in the 0–500 Hz frequency band. In Tables 4, 5 and 6 some information on dynamic phenomena, occurring in the rock mass during recorded changes of the force in the legs, has been marked in the same way as in Table 3. The following marking of burst focus locations, accompanying each of the time processes of the force in the legs has been used:

w — burst focus along the panel length,
s — burst focus at the distance of 20 meters from the face,
z — burst focus in the gob.

Only 9 loads of the legs caused by external loadings, acting on the base, were recorded during underground measurements. Four of them were recorded in the Longwall IV mined on the coal floor in the roof layer of the Seam 501 at the "Wujek" Colliery. It should be emphasized that only in one of the measurement series, recorded at the "Wujek" Colliery $a_0 > 0$ was recorded, that is the external unit load, acting from the roof.

All the other cases of external load actions on the unit base were recorded in longwalls mined on shale floors. For the total number of 32 force processes in the legs, recorded in these longwalls, in five cases $a_0 < 0$ occurred. In the longwalls mined on shale, the cases of external load action on the unit base occur much more rarely than in longwalls mined on coal floor in the seam roof layer.

The parameters that characterize the force time processes in the legs, caused by an external load action on the unit base, have been listed in Table 5.

In the case of 10 measurement series a determination of the external load sense, using the method presented in Section 2, has not been possible due to excessive noises of the acceleration signal. The parameters that characterize the force time processes in the legs, recorded in these measurement series, are listed in Table 6.

All the force time processes, for which the sense of unit external load has not been determined, were recorded in the N791 Longwall of the 502 Seam at the "Zabrze-Bielszowice" Colliery. Comparing the parameters, listed in Table 6, with the parameters that characterize the force time processes in the legs, caused by the action of

TABLE 4

Specification of the parameters characterising the force time processes in the legs caused by the external load action on the canopy

TABLICA 4

Zestawienie parametrów charakteryzujących przebiegi czasowe sił w stojakach spowodowane działaniem obciążenia zewnętrznego na stropnicę sekcji

Id.	St.	Phenomenon	$F_{st,p}$ [kN]	F_m [kN]	$F_{st,k}$ [kN]	t_n [ms]	$w_{F,n}$ [MN·s^{-1}]	K_d	E [J]	r [m]	Location of focus	$\varepsilon_{r,s}$ [J·m^{-2}]
1	I	1	1 040	1 440	1 430	40	8	1.38	3.0E+4	36.4	z	2.599
2		1	700	800	760	73	1.1	1.14	8.0E+3			
3		1	2 580	3 180	3 090	90	5.33	1.23	3.0E+4	45.3	z	1.631
4		1	1 040	1 300	660	50	4.16	1.25	6.0E+4	38.1	z	4.721
5		1	1 420	1 560	1 490	74	1.51	1.1	4.0E+4	14.1	z	26.078
6		3	860	940	900	84	0.76	1.09				
7		1	680	780	730	74	1.08	1.15	8.0E+4	24.4	s	16.262
8		1	1 200	1 410	1 380	34	4.94	1.18	1.0E+4	18	z	3.883
9		2	800	880	840	33	1.94	1.1	2.0E+4	61.8	w	0.559
10	II	1	650	870	870	126	1.4	1.34	3.0E+4	65.2	s	0.749
11		2	650	740	710	35	2.06	1.14	4.0E+4	107	w	0.346
12	III	2	1 570	1 900	620	69	3.83	1.21	2.0E+4	96.6	w	0.216
13		2	1 290	1 390	1 340	69	1.16	1.08	2.0E+3			
14		2	2 350	2 540	2 510	14	10.86	1.08	7.0E+4	141.2	w	0.335
15		1	1 260	1 640	1 510	130	2.34	1.3	3.0E+4	50	z	1.32
16		1	740	840	810	36	2.22	1.14	3.0E+4	92.2	z	0.357
17	IV	2	1 820	1 970	1 970	15	8.0	1.08	1.0E+3	64.8	w	0.025
18	V	4	720	790	780	79	0.71	1.1				

an external load on the unit from the roof, it has been stated that their values are comparable. The limits of the variability intervals as well as the average values of the parameters that characterize the force time processes in the legs, caused by three determined types of the external loads, are compared in Table 7.

TABLE 5

Specification of the parameters characterising the force time processes in the legs caused by the external load action on the bases

TABLICA 5

Zestawienie parametrów charakteryzujących przebiegi czasowe sił w stojakach spowodowane działaniem obciążenia zewnętrznego na spągnicę sekcji

Id.	St.	Phenomenon	$F_{st,p}$ [kN]	F_m [kN]	$F_{st,k}$ [kN]	t_n [ms]	$w_{F,n}$ [MN·s^{-1}]	K_d	E [J]	r [m]	Location of focus	$\varepsilon_{r,s}$ [J·m^{-2}]
1	I	3	690	1 240	1 150	99	4.44	1.80				
2	II	1	1 350	1 670	1 120	20	12.80	1.24	4.0E+4	29	w	5.566
3	III	1	830	990	940	49	2.61	1.19	2.0E+4	25	s	3.864
4		1	1 070	1 460	1 070	45	6.93	1.36	5.0E+4	46	z	2.616
5		1	400	480	450	28	2.29	1.2	2.0E+4	89	z	0.254
6	IV	1	1 213	2 224	1 624	12	67.4	1.83	2.0E+4	104	w	0.182
7		3	2 261	3 112	2 478	23	29.6	1.38				
8		1	1 538	2 529	2 282	15	52.85	1.64	1.5E+4	239	w	0.023
9		1	1 010	1 240	1 070	12	15.33	1.23	5.0E+2			

TABLE 6

Specification of the parameters characterising the force time processes in the legs recorded when the sense of the unit external load was not determined

TABLICA 6

Zestawienie parametrów charakteryzujących przebiegi czasowe sił w stojakach zarejestrowane w przypadkach, kiedy nie wyznaczono zwrotu zewnętrznego obciążenia sekcji

Id.	St.	Phenomenon	$F_{st.p}$ [kN]	F_m [kN]	$F_{st,k}$ [kN]	t_n [ms]	$w_{F,n}$ [MN·s^{-1}]	K_d	E [J]	r [m]	Location of focus	$\varepsilon_{r,s}$ [J·m^{-2}]
1	I	1	1 630	1 770	1 720	158	0.71	1.09	1.0E+6	18.0	s	388.3
2	II	3	1 620	1 810	1 780	34	4.47	1.12				
3		1	630	720	680	93	0.77	1.14	1.0E+4	87.5	w	0.133
4		1	650	820	725	35	3.89	1.26	1.0E+4	45.3	w	0.544
5	III	2	1 430	1 660	1 590	145	1.27	1.16	4.0E+4	102.6	w	0.379
6		3	1 070	1 320	1 320	224	0.89	1.23				
7		2	1 140	1 210	1 200	79	0.71	1.06	1.0E+4	154	w	0.04
8		1	1 690	2 070	1 850	26	11.69	1.22	5.0E+4	44.7	z	2.791
9		2	740	860	780	56	1.71	1.16	1.0E+5	111.8	w	0.788
10		3	430	520	510	23	3.13	1.21				

TABLE 7

List of the values of the variability intervals and the values of the average parameters characterising the force time processes in the legs caused by three different types of external load

TABLICA 7

Zestawienie wartości granic przedziałów zmienności oraz wartości średnich parametrów charakteryzujących przebiegi czasowe sił w stojakach spowodowane trzema wyróżnionymi rodzajami obciążeń zewnętrznych

	From roof			Not determined			From floor		
	min.	average	max.	min.	average	max.	min.	average	max.
$F_{st,p}$ [kN]	650	1 177	2 580	430	1 125	1 690	400	1 151	2 261
F_m [kN]	740	1 388	3 180	520	1 259	2 070	480	1 661	3 112
$F_{st,k}$ [kN]	620	1 228	3 090	510	1 146	2 070	450	1 354	2 478
t_n [ms]	14	64	130	23	87	224	12	33	99
$w_{F,n}$ [MN·s^{-1}]	0.76	3.29	10.86	0.71	2.92	11.69	2.29	21.58	67.40
K_d	1.08	1.18	1.38	1.06	1.17	1.26	1.19	1.43	1.83

Analyzing the information, concerning the measurement series, for which (due to the acceleration signal noise) the sense of the unit external load has not been determined, it can be stated that:

- in the cases of three measurement series, recorded during advance destressing blasting, it can be assumed that the external load acts on the unit from the roof, because the blasting material is exploded in the roof,
- in the case of the remaining seven measurement series it can be assumed that the external load also acts on the unit from the roof because:
  - the bursts located in the area of the mining boundaries in Seams 501 and 416: that is in the roof of the Seam 502, have been indicated as the reason for the tremors recorded in the N791 Longwall,
  - the focuses of all the tremors, recorded in the area of the N791 Longwall, were detected by the mine seismometric station in the 502 Seam.

Finally, taking into consideration the parameters presented in Table 7 and the circumstances mentioned above, it has been assumed, that those force time processes in the legs for which the initial sense of the canopy acceleration has not been determined, were also caused by the action of external loads on the unit canopy.

Analyzing the relations among different parameters which characterize the force time processes in the legs as well as the natural and technical conditions in the working, it has been found that there is a strong correlated statistical linear relation between the initial static force $F_{st,p}$ and the maximum force F_m.

It has been proven, with the confidence of 90 percent, that in the case of changes of force, caused by the external load acting on the unit from the roof, the correlation coefficient between F_m and $F_{st,p}$ is, in the parent population, significantly higher than 0.965.

In Fig. 9 the points, related to the recorded forces F_m and $F_{st,p}$ (listed in Table 4), have been marked by a regression line according to the following equation:

$$F_m = 1.150 \cdot F_{st,p} + 22.3 \text{ [kN]} \tag{5}$$

as well as the confidence interval limits for the regression line built on the confidence level of 90 percent. Taking into consideration the small value of the free term in the equation of the regression line, it has been assumed that the slope of the line — m_{st} — is equal to the load increase coefficient K_d. Using the force measurement results, listed in Table 4, it has been stated that the interval:

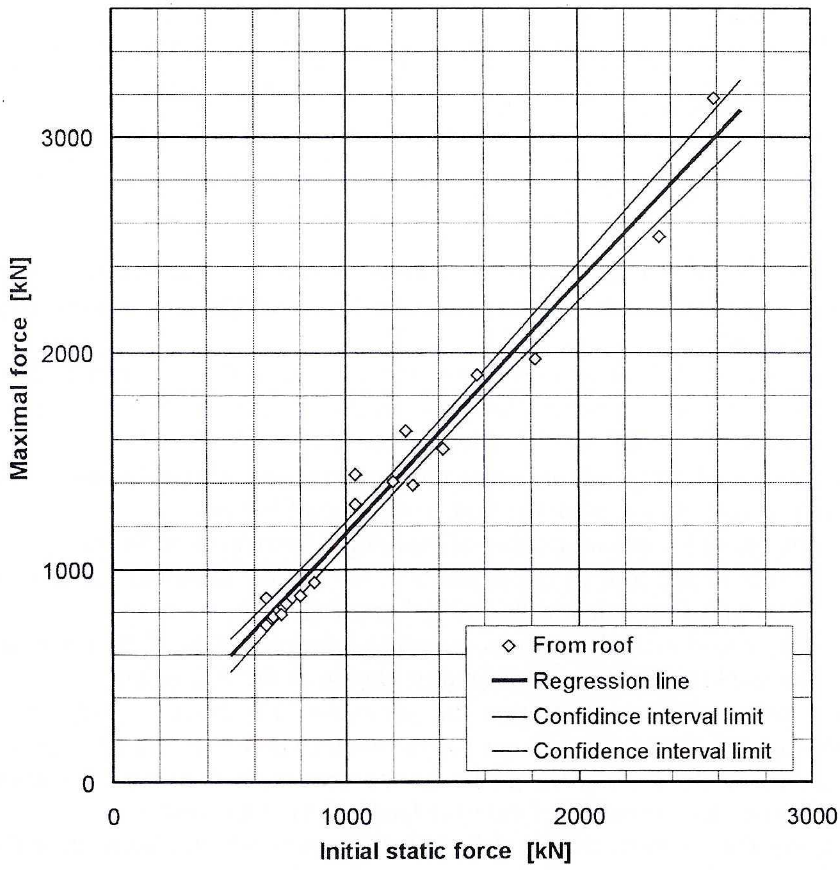

Fig. 9. Diagram of the relationship $F_m = f(F_{st,p})$ for the force processes in the legs caused by the external loadings from the roof side

Rys. 9. Wykres zależności $F_m = f(F_{st,p})$ dla przebiegów siły w stojakach spowodowanych działaniem obciążenia zewnętrznego od strony stropu

$$1.06 < m_{st} = K_d < 1.24 \tag{6}$$

with a confidence of 90 percent encloses the value of the load increase coefficient K_d in the parent population.

The calculations made for the forces in the legs, listed in Table 6, have also shown the existence of a strong correlation between F_m and $F_{st,p}$. In this case the correlation coefficient in the parent population is, with the confidence of 90 percent, significantly higher than 0.97.

In Fig. 10 the values of F_m and $F_{st,p}$, obtained from the underground measurements, have been presented as the regression line according to the following equation:

$$F_m = 1.120 \cdot F_{st,p} + 41.0 \text{ [kN]} \tag{7}$$

and the limits of the confidence interval for the regression line, built on the confidence level of 90 percent have also been shown.

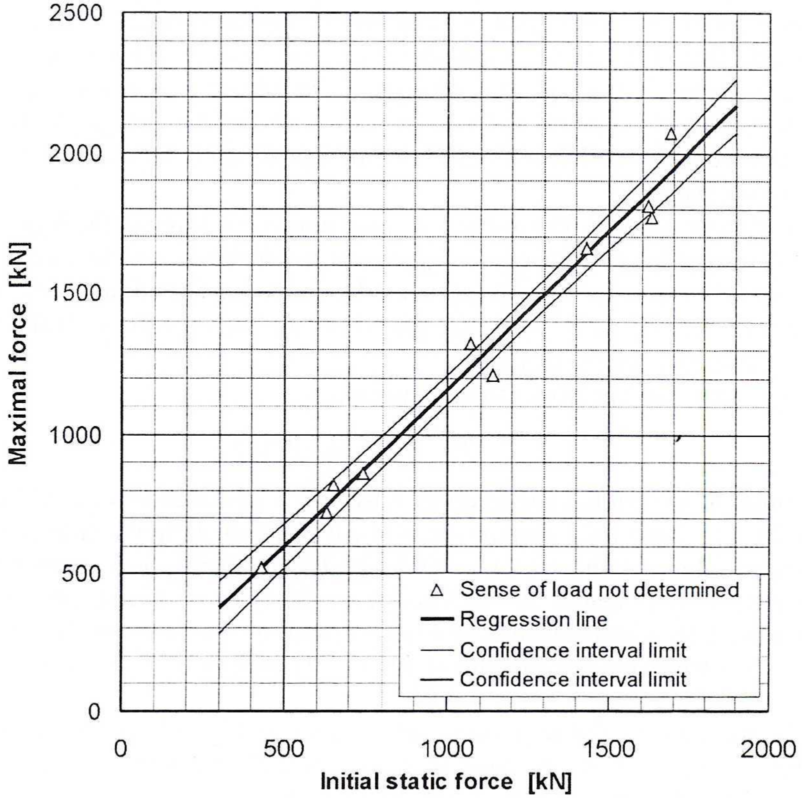

Fig. 10. Diagram of the relationship $F_m = f\,(F_{st,p})$ for the forces in the legs listed in Table 6

Rys. 10. Wykres zależności $F_m = f\,(F_{st,p})$ dla sił w stojakach zestawionych w tablicy 6

Also in the case of this regression line, taking into consideration the small value of the free term, the linear regression coefficient — m_n — can be identified with the load increase coefficient K_d. The calculations have shown that, within a probability of 90 percent, the following inequality is satisfied:

$$1.01 < m_n = K_d < 1.23 \tag{8}$$

The regression coefficients — m_{st} — determined for the forces in the legs, caused by the external loads, whose senses have been determined on the basis of the initial sense of the canopy acceleration — a_o — (Table 4) and for those cases, when on the basis of other circumstances, it was also assumed that the external load acts on the unit canopy (Table 6), differ slightly from each other. They equal respectively:

$m_{st} = 1.15$ for F_m and $F_{st,p}$ listed in Table 4,

$m_n = 1.12$ for F_m and $F_{st,p}$ listed in Table 6.

Verifying, with the regression line parallelism tests (Greń 1982), the statistical hypothesis H_0: $m_{st} = m_n$, in relation to the alternative hypothesis H_1: $m_{st} > m_n$, it has been found, with the confidence of 90 percent, that there are no reasons for a rejection of the H_0 hypothesis in the parent population. Therefore it can be assumed, with a confidence of 90 percent, that in the parent population the regression coefficients, characterizing both force processes in the legs, will be equal. A positive result of the regression line parallelism test renders it possible, in this case, to state that the changes of the forces in the legs, as listed both in Table 4 and Table 6, were caused by the external loadings applied to the canopy.

A clear statistical linear relation between the maximum force in the legs — F_m and the initial statistical force in the legs — $F_{st,p}$ exists also in the case of the force changes in the legs, caused by an external load action on the unit base. The value of the correlation coefficient between F_m and $F_{st,p}$ in the parent population is, with a confidence of 90 percent, significantly higher than 0.83.

The regression line according to the equation:

$$F_m = 1.439 \cdot F_{st,p} + 3.539 \text{ [kN]} \tag{9}$$

and the limits of the confidence interval, based on a confidence level of 90 percent, shown in Fig. 11, have been determined without distinguishing whether coal or shale constitutes the floor of the working. Only by taking many more measurements of the support loadings, created by the force from the floor will it be possible, among others factors, to take into consideration the parameters, characterizing the floor of the working, when the results of measurement are analysed and general conclusions are drawn.

Also in the case of the regression line shown in Fig. 11, the linear regression coefficient — m_{sp} — with the load increase coefficient K_d can be identified. The calculations have shown, that with a probability of 90 percent, the following inequality is satisfied:

$$1.08 < m_{sp} = K_d < 1.80 \tag{10}$$

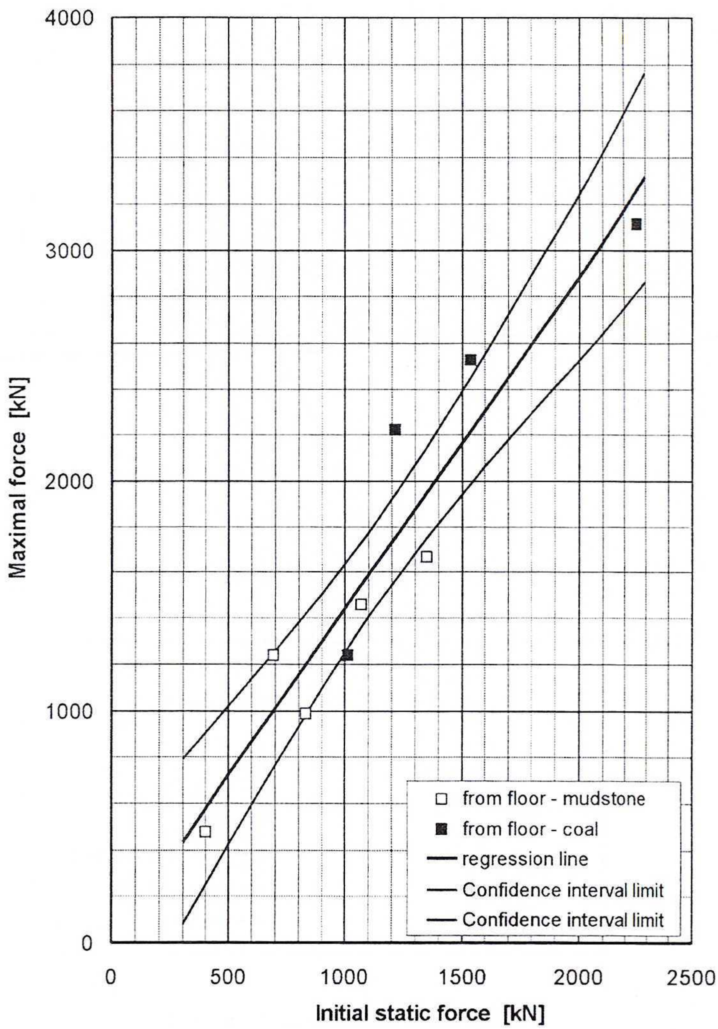

Fig. 11. Relationship $F_m = f(F_{st,p})$ for the force processes in the legs caused by the external loadings from the floor side

Rys. 11. Zależność $F_m = f(F_{st,p})$ dla przebiegów siły w stojakach spowodowanych działaniem obciążenia zewnętrznego od strony spągu

The diagrams of the regression lines for the force time processes in the legs, caused by the effect of three types of external loads applied the unit, are compared in Fig. 12.

The regression line for the forces in the legs, caused by the external load on the base, is steeper than the regression line for the forces in the legs caused by the external load on the canopy, in the case of the results listed in Table 4 as well as those listed in Table 6.

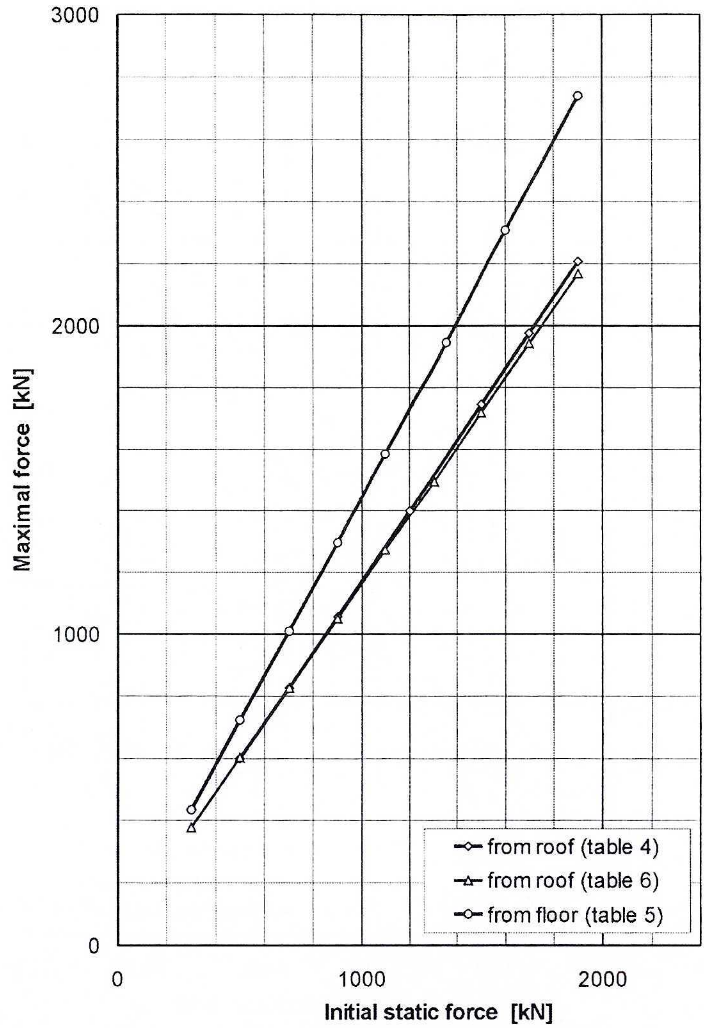

Fig. 12. Comparison of the regression lines for different senses of the powered support unit loadings

Rys.12. Porównanie prostych regresji dla różnych zwrotów obciążenia zewnętrznego sekcji obudowy zmechanizowanej

To check whether in the parent population the regression coefficient — m_{sp} — describing the relation $F_m = f(F_{st,p})$, in the case of external loads acting from the working floor, is also significantly greater than the regression coefficient — m_{st} in the case of external loads acting from the working roof, the appropriateness of the statistical hypothesis H_0: $m_{sp} = m_{st}$ as opposed to the alternative hypothesis H_1: $m_{sp} > m_{st}$, using the regression lines parallelism test, has been verified. With a confidence of 90 percent it has been found, that in the parent population the regression coefficient m_{sp}, determined for the force processes in the legs caused by an external load affecting the unit from the floor, is also significantly greater than the value m_{st}, determined when the external load acts from the roof.

On the basis of the above statement it can be assumed that the loadings received from the floor, are caused by phenomena at that location which are qualitatively different from those occurring in the roof. This conclusion accords with the research work of W. Szuścik (1994, 1995), concerning explosive floor movements.

The confidence intervals for the coefficients of the linear regression of the regression lines, shown in Fig. 12, have been listed in Table 8. In this case the confidence intervals for the linear regression coefficients are equal to the confidence intervals for the average values of the load increase coefficients.

TABLE 8

List of the confidence intervals, based on a confidence level of 90 percent, for the linear regression coefficient characterising the force changes in the legs caused by the external loads of different sense

TABLICA 8

Zestawienie przedziałów ufności zbudowanych na poziomie ufności 90% dla współczynników regresji liniowej charakteryzujących zmiany siły w stojakach spowodowane działaniem na sekcję obciążeń zewnętrznych o różnych zwrotach

Sense of the unit external load	Limits of the confidence interval for the regression coefficient	Forces in legs have been specified in Table No:
From floor	$1.08 \le m_{sp} \le 1.80$	5
From roof	$1.06 \le m_{st} \le 1.24$	4
	$1.01 \le m_n \le 1.23$	6

While designing powered roof supports for the workings threatened by the shock movement hazard, the maximum values of the load increase coefficient, resulting from the confidence intervals calculated and displayed in Table 8, should be taken into consideration.

Analyzing the influence of the natural and technical factors on the recorded force changes in the legs, it is difficult to find a correlation between them. For example in Fig. 13 the maximum values of the forces in the legs, occurring at different seismic energy densities of the transverse wave at the measurement site are shown.

The influence of the distance of the rock burst focus from the measurement site, based on the parameters, of the forces recorded in the legs, has also been analyzed. Due to the low accuracy of the burst focus coordinates in comparison to the distance of the focus from the measurement site and because of the lack of data with regard to the vertical coordinate, only two groups of the force time processes in the legs have been distinguished in relation to the location of the burst focus:

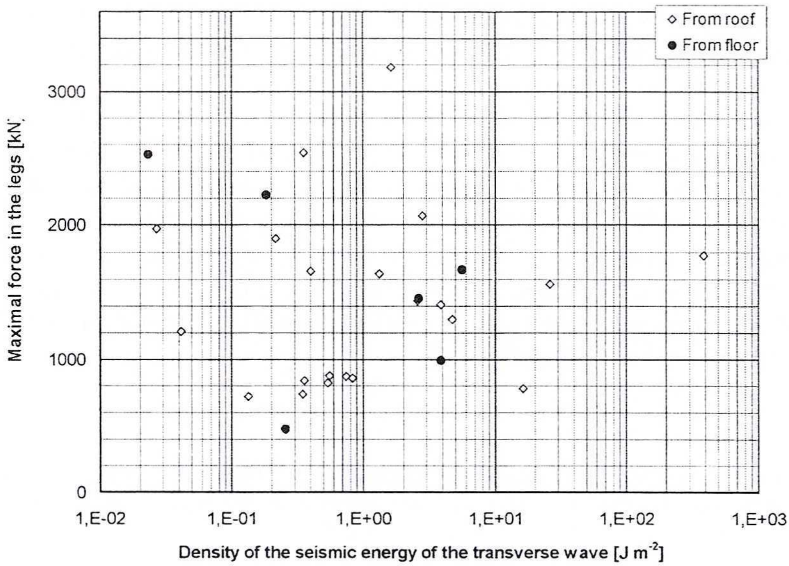

Fig. 13. Maximum force in the legs determined for different energy densities of the seismic transverse wave at the unit load measurement site

Rys. 13. Maksymalna siła w stojakach wyznaczona przy różnych gęstościach energii fali sejsmicznej w miejscu wykonywania pomiarów obciążenia sekcji

- the burst focus was situated in the gob or in the rock body within 25 meters of the face,
- the burst focus has been situated in the rock body at the distance greater than 25 meters from the face.

The relation between K_d and the density of the seismic energy of the transverse wave for different locations of the burst focuses is shown in Fig. 14.

When the focus of the burst was situated in the gob a small correlation between $\ln(K_d)$ and $\ln(\varepsilon_{r,s})$ could be discerned. The decrease in the K_d value, observed when the density of the seismic wave energy increased, could indicate a bigger dissipation and attenuation of the seismic wave energy in the disturbed rock environment, such as the gob.

The diagram, shown in Fig. 15, illustrates a greater intensity of change of force, caused by the external load acting from the floor.

The shortest time intervals of the force increase in the legs and at the same time the biggest coefficients of the load increase occurred when the external load acted on the unit from the floor. Finding a more strongly correlated relation among K_d, t_n and the parameters, characterizing the mining-and-geological conditions in the working, will be probably possible after recording the following force processes in the legs.

The intensity measurement of the force increase in the legs is an average force increase rate in the legs $w_{F,n}$. The values of this parameter obtained in the case of different initial static loads in the legs, are shown in Fig. 16. The points marked in

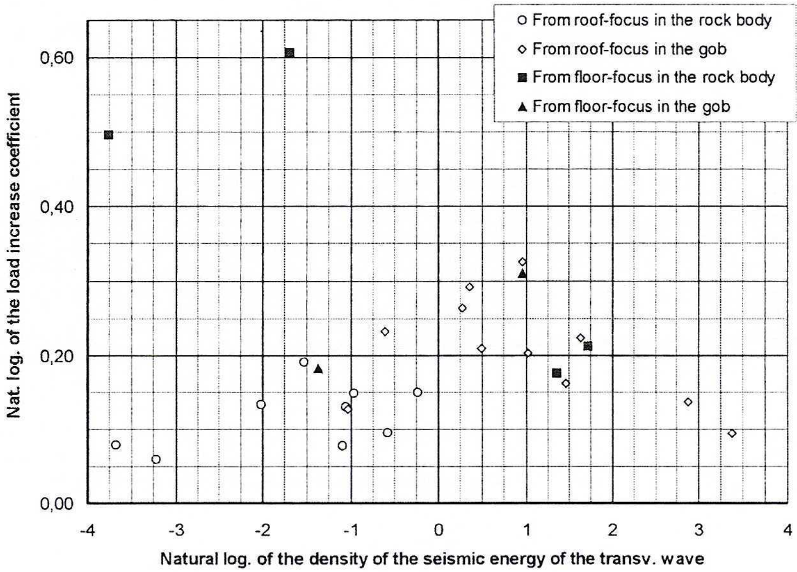

Fig. 14. K_d value for different energy densities of the seismic transverse wave and location of the burst center

Rys. 14. Wartości K_d dla różnych gęstości energii fali sejsmicznej i lokalizacji ogniska wstrząsu

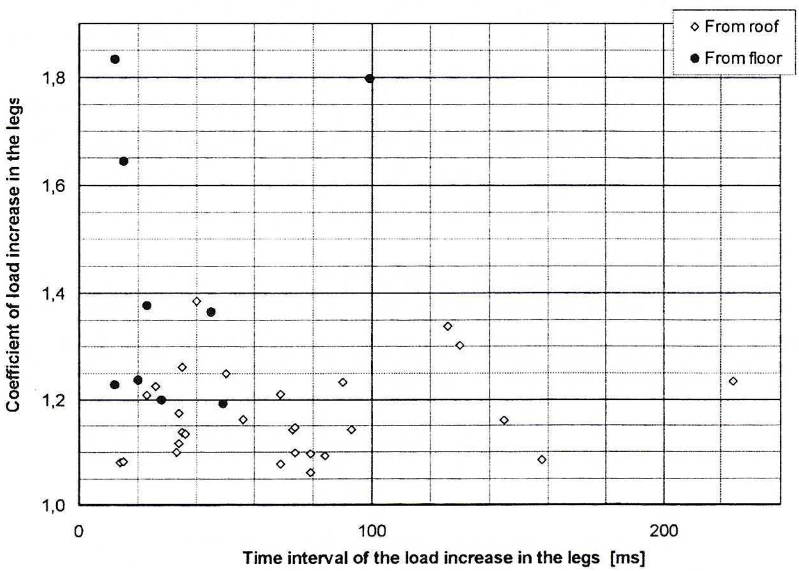

Fig. 15. Determined load increase coefficients and time of the load increase for different senses of the unit external loadings

Rys. 15. Wyznaczone współczynniki przyrostu obciążenia i czasy narastania obciążenia przy różnych zwrotach zewnętrznego obciążenia sekcji

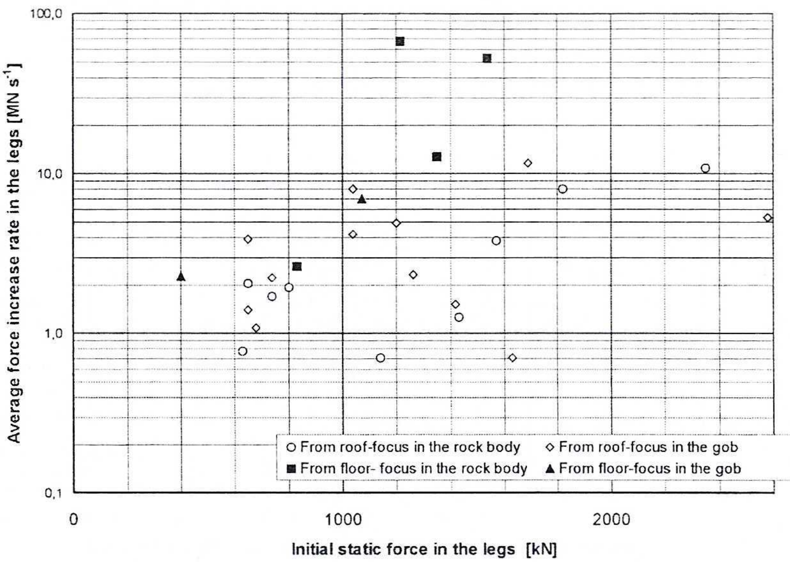

Fig. 16. Average force increase rate in the legs for different initial static loads

Rys. 16. Średnie tempa przyrostu siły w stojakach dla różnych początkowych obciążeń statycznych

Fig. 16, corresponding to the values $w_{F,n}$ and $F_{st,p}$ is dependent on the sense of the unit's external load and on the location of the burst focus, accompanying the recorded force/time process in the legs.

Using the data, included in Tables 4, 5 and 6 and graphically represented in Fig. 16, it can be stated that the average force increase rate in the legs, exceeding 12 $MN \cdot s^{-1}$ occurred only when the external load acted on the unit base and the burst focus, associated with this load, was situated in the longwall panel, relatively distant from the measurement site.

A more precise determination of the influence of individual factors on the average force increase rate in the legs requires the performance of further tests of the powered roof support loadings and a record of the force change in the legs, especially in those cases when the external load acts on the unit from the floor.

4. Summary

The measurements of the time processes of the resultant force, transferred through the legs, as well as the vertical component of the canopy acceleration have enabled two types external loads on the unit caused by the dynamic action of the rock mass to be distinguished; loads acting on the unit from the roof and loads acting on the unit from the floor. The method of determining the sense of the external load on the unit, based on the sense of the initial canopy acceleration — a_0, presented in Section 2, can be used when a level of the measurement noises does not exceed 20 percent. In ten cases, out of 37 recorded measurement series, the level of noises of the acceleration signal made the determination of the sense of the unit external load impossible by the method presented in the paper.

Based on the situations discussed in detail in Section 3, it was assumed that the changes of the forces in the legs, recorded during those ten measurement series, had been caused by the external load action on the unit from the roof.

Analyzing the measurement results, it has emerged that there is a very strongly correlated statistical linear relationship between the maximum force in the legs — F_m and the initial static force $F_{st,p}$. In the case of the changes of force in the legs, caused by the external load acting on the canopy, the strongly correlated relationship $F_m =$ $= f(F_{st,p})$ characterizes both the force time processes for which the sense of the external load on the unit has been determined by the method presented in the paper as well as those for which the determination of the sense of the external load on the unit on the basis of the sense of the canopy acceleration has not been possible. Using the test of the regression lines parallelism, it has been found that in the parent population there is no reason to reject the hypothesis of the equality of the regression coefficients, characterizing both groups of the force time processes in the legs, caused by the external load on the unit canopy.

Two different types of external loadings on the unit are characterized not only by a different sense of the external load but also by different values of the parameters which characterize the force changes in the legs which accompany them.

Using the test of the regression lines parallelism, it has been demonstrated that in the parent population the load increase coefficient — K_d — characterizing the force changes in the legs, caused by the external load action on the unit base, is significantly greater in magnitude than the coefficient K_d for the force in the legs, caused by the unit load from the roof. From the measurements taken on site to date, it can be concluded that the maximum value of the load increase coefficient, which equals the top limit of the confidence interval of the regression coefficient, based on a confidence level of 90 percent is:

$K_d = 1.80$ — for external loads acting on the unit from the floor,

$K_d = 1.23$ — for external loads acting on the unit from the roof

The force time processes in the legs, caused by the external load action on the unit bases, are also characterized by a much greater force increase rate in the legs in comparison with the values $w_{F,n}$, obtained for the external loads imposed on the unit from the roof.

A small number of the recorded measurement series has not made it possible to formulate general conclusions, referring to the relationships among the parameters characterizing the force changes in the legs and the mining-and-geological conditions in the working. In particular the statement given above concerns cases when the dynamic action of the rock mass causes an external load to act on the base of the powered roof support unit. The analysis of the results of the force measurements in the legs, caused by such external loads, indicates a need for a confirmation of the measurements of the powered roof support unit loads, caused by the dynamic action of the rock mass, especially in those workings where risk of shock movements exists and which are driven in the top layer of the seam.

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