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METEOROLOGICAL AND HYDROLOGICAL CONDITIONS OF LANDSLIDES, POLISH FLYSCH CARPATHIANS

INTRODUCTION

Modelling of slopes due to mass movements is strongly influenced by meteorological and hydrological conditions. The latter belong to so called active factors, are very diversified in space and time, yet it is difficult to determine their probability. A role of meteorological and hydrological conditions consists in a supply and storage of water in substratum.

A relationship between mass movements and precipitation is discussed in papers by L. Sawicki (1917), M. Klimaszewski (1935), L. Starkel (1960), T. Ziętara (1968, 1974), K. Thiel and L. Zabuski (1979). Water circulation, that results in different substratum moisture, affects slope stability, and alternates hydrostatic and hydrodynamic conditions (Wiłun 1976, Thiel 1976, Gil and Kotarba 1977, Thiel 1989).

In the literature a lot of attention is paid to threshold values of precipitation causing formation of new landslides or rejuvenation of stabilized ones. M. Govi et al. (1980, 1982) who studied mass movements in Piedmont (mean annual precipitation 700–2,100 mm) concluded that shallow mass movements such as mudflows and debris flows were triggered by a 1–3 days precipitation, i.e. critical precipitation, that amounted to 13–40% of the annual total. An actual critical precipitation depends on a precipitation total of 30–35 days long preceding period, the latter called "dry period" if precipitation sums up to 70 mm or "wet period" if precipitation sums up to 140–300 mm. Moreover, during a moist winter-spring season landslides occurred if critical precipitation total was lower than in summer season.

Precipitation threshold values at which landslides are initiated differ depending on a substratum kind. In the case of marls, clays and sands initial movements are recorded at 90–110 mm precipitation and catastrophic movements are recorded at 200–220 mm. In the case of Mesozoic limestones and mudstones the appropriate values are 270–300 mm and 400–450 mm, respectively, while in the case of serpenitinites 350–400 mm and 600 mm, respectively. Common, catastrophic landslides are recorded when the critical precipitation makes up 28–30% of the annual total and its intensity in a final phase (3–6 hrs) is 30–40 mm·h^{-1}.

Similar relationships have been found for the Fiorentino valley (Silvano et al. 1985) where landslides occur if precipitation is of an order of 230 mm during 15–30 days with the maximum in the last 1–5 days.

F. Cappecchi and P. Focardi (1988), when analysing precipitation totals from 100 mm·day^{-1} to 400 mm·day^{-1} of 1970–1984, develop a coefficient of critical precipitation. The coefficient is expressed as a product of a length of a precipitation period (15 days) and an index of hydrological characteristics of terrain, divided by 15 consecutive day precipitation with a recurrence interval of 20 years. The so defined coefficient varies from 0 to 1.0, and landslides are observed if its value exceed 0.5.

W. Froehlich and L. Starkel (1987) based on the studies of slope processes in the Darjeeling Himalayas built mainly of gneisses and phylites, concluded that daily precipitation above 250 mm and a few days long precipitation above 350 mm cause local debris flows. Re-modelling of the slopes occurs commonly if daily precipitation exceeds 300 mm and if 3-day long precipitation exceeds 600 mm and precipitation intensity reaches to 50 mm·h^{-1}.

J.P. Meneroud (1983) analyses development of mass movements on the background of ground water table oscillations in the south-eastern France. For conditions existing there, he determines the precipitation threshold value as 300 mm if precipitation intensity is above 5 mm·day^{-1}, and occasionally above 20 mm·day^{-1}.

Studies performed on landslide “Zapadle” in Szymbark, Beskid Niski Mts (Gil and Kotarba 1977) allowed to define a role of precipitation and ground water level in transferring of wasted material within a landslide. Importance of these factors is found to vary in particular parts of the landslide and to be dependent on a local water storage capacity of colluvium. L. Starkel (1976) and E. Gil and L. Starkel (1979) point to the effects of precipitation totals and intensity on surface runoff and subsurface flow that are responsible for different slope modelling (washing out and sliding).

The role of precipitation and water circulation on a flysch slope and their influence on a slope stability are discussed in a work edited by K. Thiel (1989). Based on detailed measurements and observations (geological, geophysical, meteorological, hydrological, geotechnical and geodetic) carried out in 1981–1985 on landslide “Bystrzyca” in Szymbark the following precipitation threshold values for landslide movements were determined:

— annual precipitation total above 1,000 mm,
— monthly precipitation total above 200 mm,
— mean intensity of precipitation — not exceeding 0.025 mm·min^{-1}.

A full water saturation of the substratum is a necessary condition of a slope de-stability.

In the current paper hydrometeorological conditions of landslide formation are discussed within a framework of analyses of precipitation, water circulation on a slope (surface runoff, subsurface flow, evapotranspiration) and influence of these conditions on strength parameters of the ground in relation to records and observations from selected landslides.

Results of the studies on water circulation, carried out on an experimental, non-landslide slope at the Research Station of the Institute of Geography and Spatial Organisation, Polish Academy of Sciences in Szymbark (J. Słupik 1973, E. Gil and L. Starkel 1979, E. Gil 1986, K. Thiel 1989) have been used in the analyses. Geographical conditions of this experimental slope are similar or corresponding to those of the investigated landslides.

PRECIPITATION CONDITIONS AFFECTING SELECTED MASS MOVEMENTS IN THE CARPATHIANS

From the vast literature on mass movements it results that there are periods of a significant activity of landslides in years with higher precipitation (Sawicki 1917, Klimaszewski 1935, Jakubowski 1974, Starkel 1976, Ziętara 1974). T. Ziętara (1974), when analysing development of landslides in Pogórze Ciężkowickie, finds that activation of shallow landslides in the recent 40 years occurred every 2–10 years while of deep structural landslides every 12–14 years.

Not only is observed the development of landslides in the years when precipitation totals exceed mean values but also in the years when high precipitation is recorded in some months. Compilation of precipitation totals (Table 1) shows that formation of new landslides or activation of the stabilized ones in the flysch Carpathians takes place if precipitation during 20–40 days sums up to over 250 mm and if a preceding period was characterised by mean or higher than average precipitation totals and by a high moisture of substratum. During such a period, favouring landslide formation, there have been recorded over 70% of days with precipitation whose mean intensity was 7–25 $mm \cdot day^{-1}$.

Figure 1 presents a real time cumulative curves of precipitation when mass movements take place. Two different distributions of precipitation, characteristic of regions with different geology, as well as different threshold values necessary to initiate mass movements can be identified.

The first distribution represents precipitation of a moderate intensity, 7–11 $mm \cdot day^{-1}$, and with 1–3 days long episodes of rainfall with a higher intensity (15–20 $mm \cdot day^{-1}$). This type of precipitation is characteristic of mass movements recorded in Szymbark, i.e. it is characteristic of the areas where weakly resistant shales and clayey-shales, and medium permeable weaterhing covers predominate in the substratum. In a final phase of a precipitation period a slightly stronger precipitation impulse shows off which, as the substratum is fully

Table 1 — Tabela 1

Precipitation conditions during selected mass movements in the Polish Carpathiaus
Warunki opadowe podczas niektórych ruchów osuwiskowych w Karpatach

Site Miejscowość	Year Rok	Annual total Suma roczna opadów [mm]	Rainfall period Okres opadowy	Rainfall Wysokość opadów [mm]	Mean intensity Średnia intensywność [mm/24h]	Days with rainfall Dni z opadem [%]	Rainfall station Stacja opadowa
Szymbark	1913	920–1,123	16.05–30.06 24.06–15.08	217–219 371–391	7.4 10.8–9.0	63–65 68–77	Gorlice-Grybów Gorlice-Grybów
Beskid Żywiecki	1960	1,500	1–27.07 23–27.07	484 256	25.5 51.3	70 100	Pilsko Pilsko
Szymbark	1974	1,164	21.05–15.06	258	11.2	88	IG PAN Szymbark
Szymbark	1974	1,164	21.09– 3.11	285	7.7	84	IG PAN Szymbark
Szymbark	1980	1,140	3.05– 6.07	276	8.1	89	IG PAN Szymbark
Połoma	1980	1,427	15.06–26.07 21–26.07	553 289	17.8 57.7	74 100	Terka Terka
Szymbark	1985	1,052	29.05– 3.07	246	8.5	80	IG PAN Szymbark

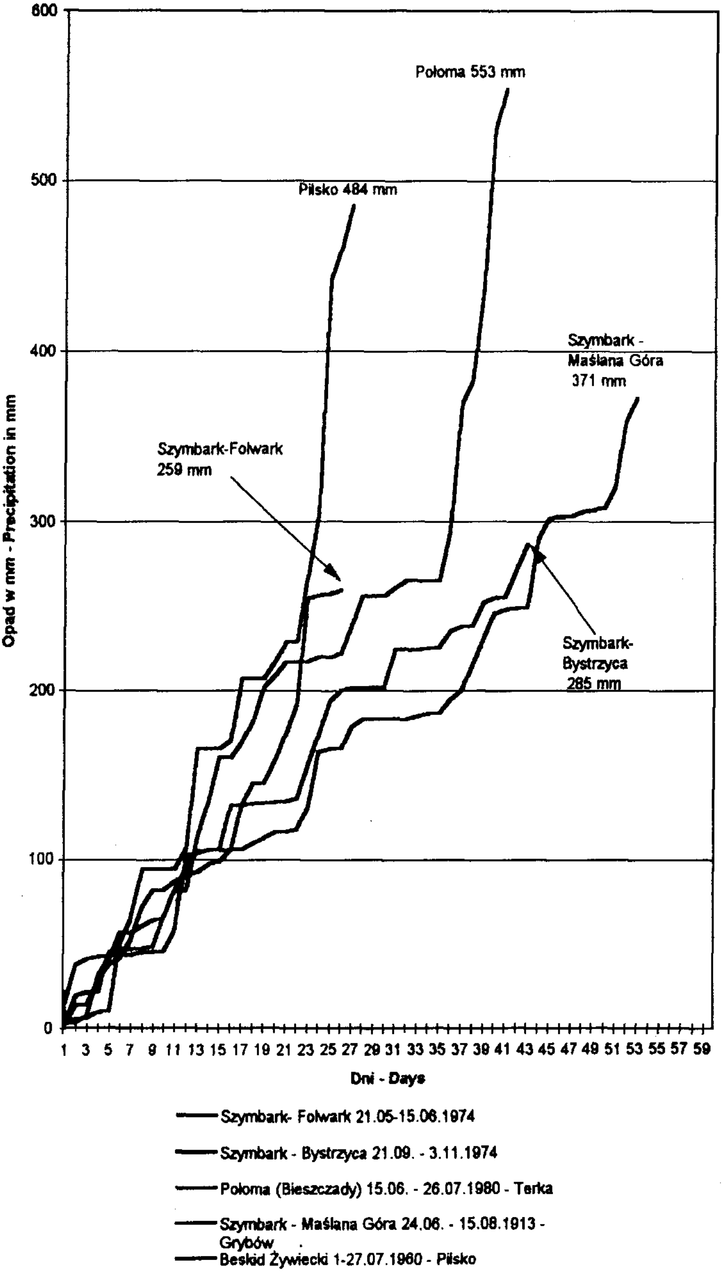

Fig. 1. Cumulative curves of precipitation on selected landslides: Szymbark — Maślana Góra 24.06–15.08.1913, Pilsko 1 — 27.07.1960 (Beskid Żywiecki Mts), Szymbark-Folwark 21.05–15.06.1974, Szymbark-Bystrzyca 21.09–3.11.1974, Połoma (Bieszczady Mts) 15.06–26.06.1980

Ryc. 1. Krzywe kumulatywne wysokości opadów wybranych osuwisk: Szymbark-Maślana Góra 24.06–15.08.1913, Pilsko 1 — 27.07.1960 (Beskid Żywiecki), Szymbark-Folwark 21.05–15.06.1974, Szymbark-Bystrzyca 21.09–3.11.1974, Połoma (Bieszczady) 15.06–26.061980 saturated with water, becomes a cause of sliding. The threshold value of precipitation triggering landslides is 250–300 mm during 30–50 days.

In the areas where lithology is similar precipitation impulse of an order of 250 mm may be reached in a much shorter time — 20 minutes. It happens when precipitation of a small intensity in an initial phase cause a full saturation of the substratum and change into precipitation of a much larger intensity during a few final days (Fig. 1 — Szymbark-Folwark).

The second type of precipitation is characterised by a much higher mean diurnal intensity, reaching 17–25 $mm \cdot day^{-1}$. The initial phase of precipitation is of a similar intensity as in the previous type, but the final phase of precipitation is characterised by intensity of an order of 50–57 $mm \cdot day^{-1}$. The described precipitation pattern is typical of mass movements in regions where sandstones predominate in the substratum: Bieszczady Mts, Beskid Żywiecki Mts, Beskid Śląski Mts (Ziętara 1968, Dziuban 1983). In the examples depicted in Fig. 1, precipitation lasting 5–6 days, with the total of 250–290 mm and extreme values of diurnal intensity of 93 mm (Terka-Połoma) and 138 mm (Pilsko) occurred after a 20–30 days long period of precipitation amounting to 250 mm. For these regions the threshold precipitation triggering mass movements were 400–550 mm during 25–40 days (Table 1).

It is still an open question what mass movements would be triggered by single episodes of precipitation of similar totals if not preceded by a moist period. Observations made by L. Starkel (1960) in Postołów on the San river, by T. Ziętara (1968) in Beskid Żywiecki and Beskid Śląski Mts, as well as in Szymbark in 1970 suggest that the weathering covers are mainly subjected to mass movements formed under the discussed conditions, and large areas of the slopes are affected by them that is related to water distribution on the slope and to substratum saturation (Słupik 1973).

CHARACTERISTICS OF PRECIPITATION TRIGGERING MASS MOVEMENTS IN SZYMBARK

A marginal zone of Beskid Niski Mts near Szymbark is particularly susceptible to mass movements (Kotarba 1986). Large height differences (300–450 m) between the Ropa valley floor and culminations of ridges as well as a complicated geology in the marginal zone of the Magura nappe are major causes of intensive mass movements. The Magura nappe, secondarily folded and cut into separate blocks (Świdziński 1953), is built of sandstones underlain by Eocene variegated shales and shale-sandstone inoceramus bed. A debris-clay layer of weathered material, covering the bedrock, is 2–4 m thick. Because of a high content of very fine particles, natural moisture of the weathering covers is high and rarely drops below 50% of water capacity of ground (Słupik 1973). Landslides mainly develop in shale zones and expand on the slopes built of

Table 2 — Tabela 2

Characteristics of precipitation during intensified landslide processes in Szymbark
Charakterystyka opadów w czasie wzmożonych procesów osuwiskowych w Szymbarku

Period Okres opadowy	Minutes Ogółem minut	Rainfall duration Czas trwania opadów [min]	Rainfall duration (% of the period) Czas trwania opadów w % okresu	Rainfall Wysokość opadów [mm]	Mean intensity Średnia intensywność [mm.min^{-1}]	Remarks Uwagi
21.05–15.06 1974	36,085	10,566	29.3	258.5	0.0245	Intensive movement intensywne ruchy
21.9–3.11 1974	63,360	17,635	27.8	285.3	0.0162	Intensive movement intensywne ruchy
30.05–6.07 1980	53,150	8,492	16.0	276.6	0.0325	slow movement within old landslide słabe ruchy odnawiające stare osuwiska
9.07–1.08 1980	32,260	5,440	16.7	211.8	0.0389	slow movement within old landslides słabe ruchy odnawiające stare osuwiska
29.05–3.07 1985	50,283	5,035	10.0	246.3	0.0489	slow movement within old landslides słabe ruchy odnawiające stare osuwiska

sandstones less susceptible to sliding (Kotarba 1986). Mountain ridges, built of water-bearing Magura sandstones, undercut by landslides, aliment with water the below laying shale deposits and increase their mobility. Not only is the weathering cover moving but the rocks in the substratum as well. The thickness of colluvium is 3–15 m (Gil and Kotarba 1977, Thiel 1989)

Observations of landslides in Szymbark (Gil and Kotarba 1977) indicate that the dynamics of moving landslide masses corresponds strongly to precipitation totals and their intensity. However, one has to distinguish dynamics of various landslides: those formed in one phase and then being stable, those rejuvenated several times and, finally, those always active. The latter react to larger precipitation, although with a certain time lag. That can be evidenced by traces of movement in landslide Zapadle recorded in 1972–1975 (Gil and Kotarba 1977) where, after periods of larger precipitation or spring thawing in 1973 and 1974, translocations in the most active zones increased from 0.5 to 3.0 m in a year. Landslides which are activated several times are rejuvenated during longlasting precipitation only, e.g. slopes of Wiatrówki, Bucza and others. On the other hand, formation of new landslides is associated with extreme precipitation events (Sawicki 1917, Starkel 1976, Gil and Starkel 1979, Dziuban 1983). Characteristics of the mass movements provides interesting data to explain impact of precipitation on the dynamics of these movements (Table 2).

Characteristics of precipitation is based on pluviograph records from Research Station, Institute of Geography and Spatial Organisation Polish Academy of Sciences in Szymbark and includes: totals, duration and intensity of precipitation. Based on the performed analyses it is concluded that the dynamics of the mass movements depends both on the total and intensity of precipitation. Initial mass movements are registered just after exceeding the precipitation total of 200 mm while intensive movements take place when the total exceeds 250 mm. Moreover, when the second value is reached, the movements are observed on the stabilized landslides as well as new landslides are formed. A critical sliding situation arises after c. 25 days of precipitation of a mean intensity smaller than $0.025\ \mathrm{mm \cdot min^{-1}}$, and a real duration of precipitation in relation to a whole precipitation period exceeds 27%. So small intensity of precipitation permits infiltration of a larger portion of rain water into the substratum and is a reason of intensive mass movements.

Precipitation that reach similar totals but their intensity does not exceeds $0.03–0.04\ \mathrm{mm \cdot min^{-1}}$ and the real duration constitutes 10–16% of precipitation period cause only weak sliding on temporary stabilized landslides. High proportion of water flows as surface runoff and infiltration is limited to the upper horizons of the substratum. Examples of changes in intensity of sliding due to precipitation of practically equal totals but differing in intensity were registered in 1974, 1980, 1985. Concluding, it can be said that the dynamics of mass movements is strongly dependent on the pattern of water circulation in the substratum.

TRANSFORMATION OF PRECIPITATION INTO WATER CIRCULATION ON A SLOPE

Water supplied by precipitation to a slope surface is then divided into two components: surface runoff and subsurface flow (Słupik 1973). Relation between the components depends on the substratum conditions controlled by lithology and land use, i.e. features that, among others, determine capacity of soil to store water from an infiltration process (Fig. 3). In landsliding the amount of infiltrating water that affects strength parameters of soil is very important. What is more, it is a factor which contributes to hydrostatic, hydrodynamic and gravitational forces acting in the substratum. At the same time, significant amount of water is carried away by evapotranspiration (Fig. 2A–D).

In figures 2A–D the following elements of water circulation pattern are presented for four selected periods:

— cumulative curve of surface runoff — SP,
— cumulative curve of throughflow to the depth of 100 cm — SŚ,
— cumulative curve being a sum of surface runoff and throughflow SP+SŚ — as an element of fast water outflow from a slope,
— cumulative curve of air humidity deficit — NW (in mbar) — presenting evapotranspiration in approximation (in mm),
— changes in ground water table in the upper and lower part of a slope (ZWG) that show the amount of water stored in the substratum to the depth of 150 cm.

The presented figures illustrate the amount of water supplied to the slope as well as the elements of water circulation pattern on the surface of the ground and underneath. Magnitudes of particular elements of water circulation vary in subsequent time intervals as well as the proportions between these elements.

In general, if precipitation increases so do the surface runoff and throughflow; ground water table rises. On the other hand, evapotranspiration is low, especially during precipitation. This general outline is often much more complicated. Percolation of water downward is limited by permeability of slope covers and the storage capacity depends not only on a volume of voids in the ground but also on its initial moisture (Fig. 3). The discussed conditions on the experimental slope are defined by the following parameters (Słupik, 1973):

— minimum permeability on grassland 0.03–0.7 mm·min^{-1} and on arable fields 0.6–1.1 mm·min^{-1},
— general porosity of the covers on shale-sandstone layers 40–51%, on sandstone 46–60%,
— infiltration capacity of the covers on arable fields 0.07–11.4 mm·min^{-1}, in forests 0.8–42 mm·min^{-1}.

If precipitation intensity is low, a soil profile saturates slowly and moisture interface moves downward from the surface to the substratum, increasing this way soil moisture. Later on, the ground water table rises and throughflow is initiated, and, when the whole soil profile is saturated, surface runoff occurs.

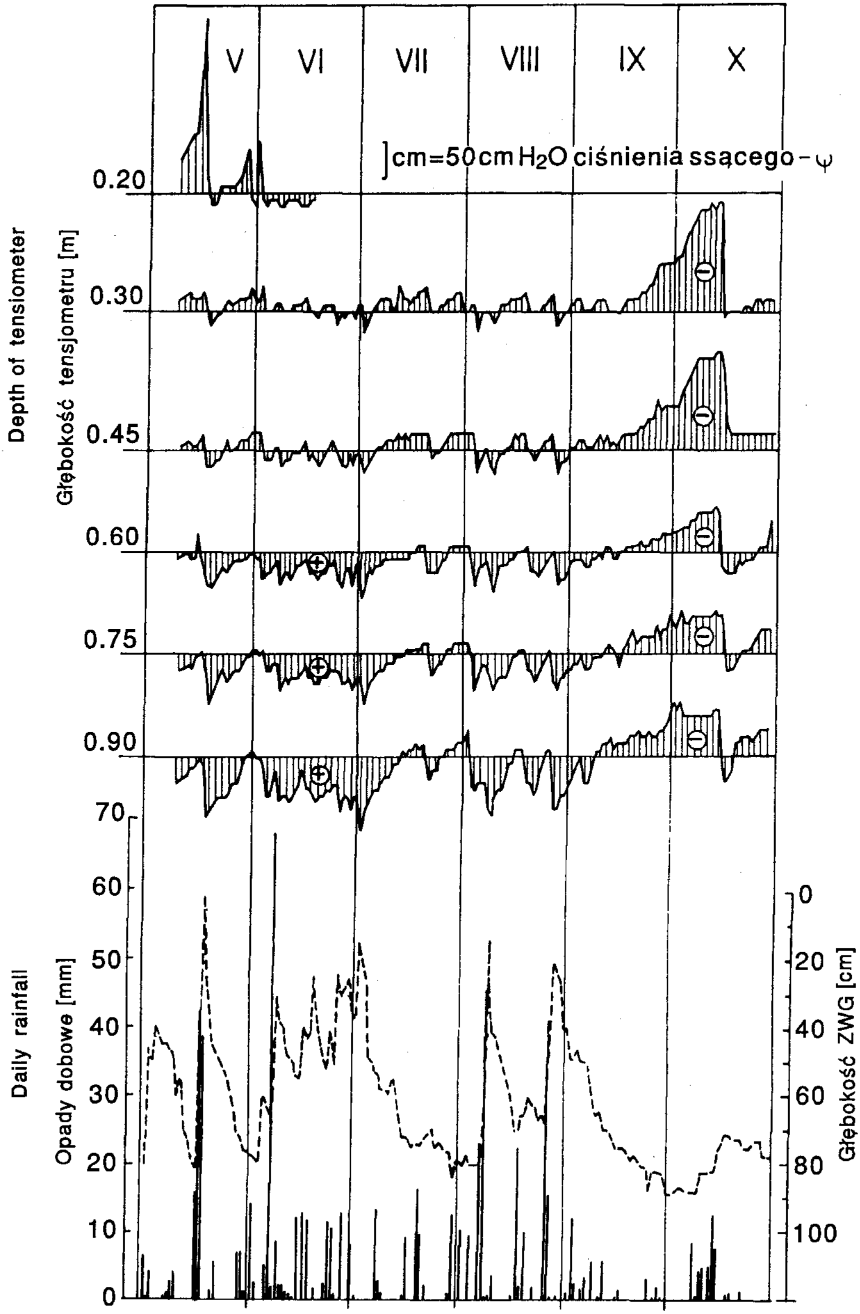

Fig. 3. Magnitude of suction forces in relation to precipitation and depth of ground water table in 1985 — the upper part of the slope at Szymbark (Thiel 1989); sign + denotes full saturation

Ryc. 3. Wielkość sił ssących w relacji do wysokości opadów i głębokości zwierciadła wód gruntowych w 1985 roku — górna część stoku IG i PZ PAN w Szymbarku (Thiel 1989). Znak + oznacza pełną saturację

Such conditions were satisfied in autumn 1974 (Fig. 2A–D). If the precipitation intensity significantly exceeds the infiltration index, provided the unsaturated substratum, the surface runoff occurs in most cases.

The results of calculations presented in Table 2 indicate that the largest amount of water could have infiltrated in both precipitation periods in 1974. In 1980 and 1985 precipitation of the intensities much larger than the average favoured the surface runoff although the substratum saturation was , for example, very high in 1985, yet the precipitation impulse sufficient to trigger mass movements did not occur.

The third element which is very important in carrying away water from a slope is evapotranspiration. As this element was not gauged, air moisture deficit (in milibars), which is approximately proportional to evapotranspiration, was only marked on the plots in Figures 2A–D. It is clear from the plots that the discussed element is very important, especially in a warm season, as it derives a large amount of water and limits ground storage and throughflow (Table 3).

The amount of water carried away from the slope is shown by the cumulative curves for surface runoff, throughflow and evapotranspiration (the latter curve is drawn on the plot starting form the value being a sum of SP+SŚ). The area hachured on the plot, between the cumulative curve for precipitation (P) — water supply, and the cumulative curve for evapotranspiration (NW) — sum of the amount of water carried away, points to a surplus of water temporarily present on the slope and determines a potential time interval when an equilibrium on the slope is in its critical state. The crossing point of the precipitation and evapotranspiration curves is the first threshold indicating possibility of the mass movements. An additional precipitation impulse in that time interval may be a cause of movement triggering.

The most intensive mass movements were recorded in 1974, when the water surplus on the slope reached the highest values (Table 3). Yet in 1980, despite high precipitation, the amount of water carried away by evapotranspiration was so high that the threshold values for the slope instability were not reached (Fig. 2A–D, Table 3).

According to J. Słupik (1973, 1978), a 100 cm thick layer of soil on the slopes built from shale-sandstones beds of the flysch, that is under farming practices, can store 160 mm of water, including 100 mm in capillaries. These data have been evidenced by the records presented here (Table 3, Fig. 2A–D) and show cases when the difference between precipitation and a total water outflow from the slope exceeds 100 mm. As there is a full saturation, the ground water table oscillates close to the surface of the ground. Similar conditions may also occur, if the sum of precipitation is lower, due to a high natural moisture of the weathering covers that rarely drops below 50% of the total water capacity.

The best conditions for the mass movements were in landslide Bystrzyca in Szymbark on 21.09.–4.11.1974 (Fig. 2D, 4). Because of the full water saturation of

Table 3 — Tabela 3

Elements of water circulation on the slope of the Research Station, lustitute of Geography and Spatial Organization during mass movements
Składowe obiegu wody na stoku IG i PZ PAN w Szymbarku w czasie występowania ruchów masowych

Period	Rainfall	Surface flow	Through flow	Air moisture deficit	Total outflow and evapotranspiration	Retention temporal	Remarks
Data	Opady P [mm]	Spływ powierzchniowy SP [mm]	Spływ śródglebowy SŚ [mm]	Niedosyt wilgotności NW [mb] = ewapotranspiracja [mm]	Suma odpływu i ewapotranspiracji SP +SŚ+NW [mm]	Chwilowa retencja P – (SP+SŚ+NW) [mm]	Uwagi
21.05–15.06 1974	258.5	117.3	23.8	100.6	241.7	+16.8	Intensive mass movement intensywne ruchy masowe
21.09–3.11 1974	285.3	85.3	32.2	82.9	200.4	+84.9	Intensive mass movement intensywne ruchy masowe
30.05–6.07 1980	276.6	91.3	12.4	188.9	292.6	-16.0	Slow mass movement słabe ruchy masowe
9.07–1.08 1980	211.8	118.2	25.4	104.4	248.0	-36.2	Slow mass movement słabe ruchy masowe
29.05–3.07 1985	246.3	78.4	24.3	136.2	238.9	+7.4	Slow mass movement słabe ruchy masowe

the ground due to the longlasting precipitation of the low intensity and due to the decrease in temperature to almost zero degrees by the end of precipitation period, a slow water circulation (increased water viscosity) occurred as well as the large surplus of water with respect to the potential outflow and evapotranspiration. As a result, the interplay of the parameters: cohesion (c), angle of internal friction (φ) and ground water table (ZWG) lead to the critical value of the slope stability coefficient (F_H = 1) what is presented as the hachured area in Fig. 4.

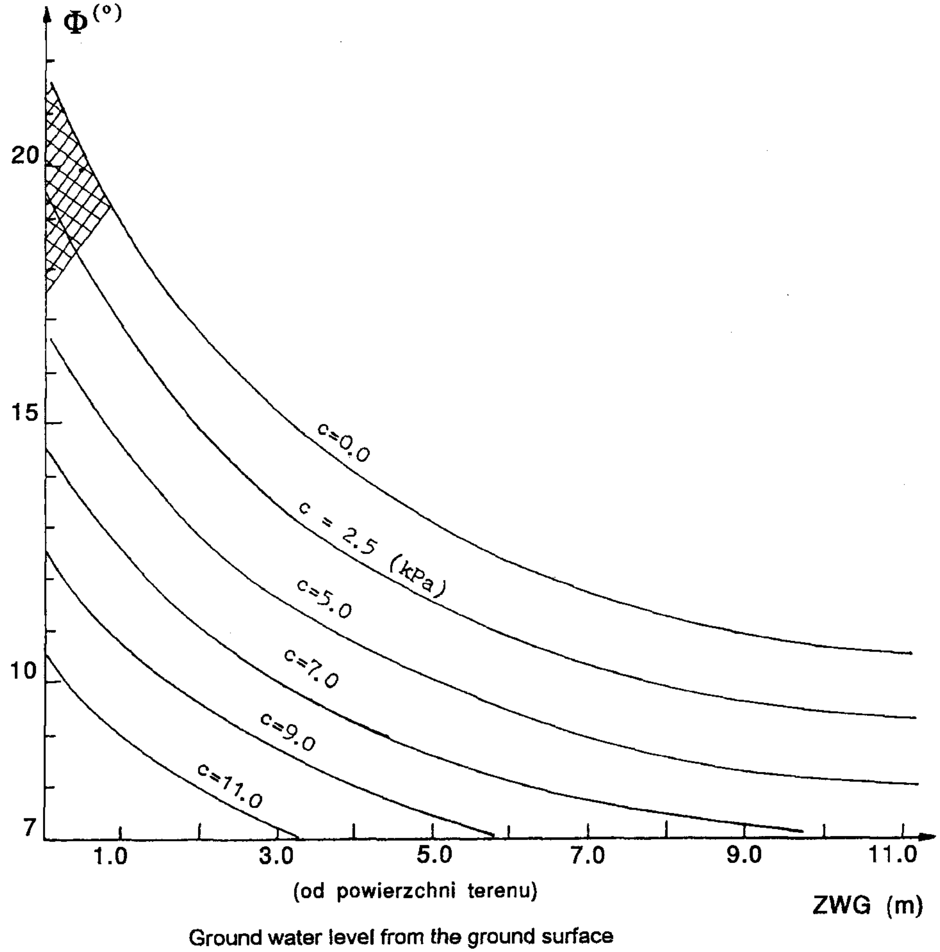

Fig. 4. Relation between parameters: cohesion (C), angle of internal friction (φ), ground water tables (ZWG) in critical state — slope stability F_H = 1.0 (Thiel 1989). Hachured area — critical conditions at which mass movements occurred on landslide Bystrzyca on 3.11.1974

Ryc. 4. Związek między parametrami: spójności (C), kąta tarcia wewnętrznego (φ), zwierciadła wód gruntowych (ZWG) w stanie granicznym — stateczność stoku F_H = 1,0 (Thiel 1989). Pole zaszrafowane — warunki graniczne, przy których wystąpiły ruchy masowe w dn. 3.11.1974 r. na osuwisku Bystrzyca

Landslide Bystrzyca, formed on 3 November 1974, occupied the area of 3.6 ha and the thickness of colluvia reached to 15 m. The rocky-weathered material was subjected to the movement. In the same period, landsliding was observed in the upper reach of the Bystrzanka valley, as well as in other parts of the Carpathians (Bober et al. 1977).

In 1989 and 1985, due to the larger precipitation intensity, and because of the larger surface runoff and evapotranspiration, the substratum was fully saturated with water for a short time span. So, there were observed only singular cases of activating some stabilized landslides and acceleration of the movements on the landslides being always active.

FINAL REMARKS

The simultaneous studies on the movements of landslides and on the water circulation pattern allowed to learn mechanism and conditions necessary for landslide formation.

Instability of the slope takes place if the substratum is fully saturated with water. The conditions depend on the water capacity of the substratum and on its permeability as well as on the totals and intensity of precipitation, modified by water circulation pattern on the slope, i.e. by the surface runoff, throughflow and evapotranspiration.

On the slopes built of the shale-sandstones and shales, the largest landslides are observed during precipitation exceeding 250–300 mm and lasting 20–45 days, and if the mean precipitation intensity is less than 0.025 $mm \cdot min^{-1}$ as well as it does not exceed the infiltration capacity of the substratum.

On the slopes where sandstones predominate, the mass movements occur if precipitation is 400–550 mm, lasts 20–40 days and if the sum of precipitation from the last 5–6 days of the precipitation period exceeds 250 mm.

During precipitation periods when the precipitation total is 200–300 mm and its duration is similar to that above but the intensity is higher, shallow slumps of ground and weathered materials as well as rejuvenation of the landslides being periodically active are observed.

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STRESZCZENIE

E. Gil

METEOROLOGICZNE I HYDROLOGICZNE WARUNKI RUCHÓW OSUWISKOWYCH

W artykule przedstawiono wpływ warunków meteorologicznych i hydrologicznych na ruchy masowe modelujące stoki fliszowe. Jednoczesne badania tych procesów pozwoliły na określenie relacji pomiędzy dostawą wody opadowej, sposobem jej krążenia na stoku, a przebiegiem ruchów osuwiskowych.

Głębokie, skalno-zwietrzelinowe osuwiska na utworach łupkowo-piaskowcowych i łupkowych powstają w warunkach pełnej saturacji, kiedy retencja chwilowa jest wyższa aniżeli odprowadzenie wody przez spływ powierzchniowy, śródglebowy i ewapotranspirację. Warunki takie występują podczas 20–45 dniowego okresu opadowego o sumie 250–300 mm i średnim natężeniu opadów nie przekraczającym 0,025 $\mathrm{mm \cdot min^{-1}}$.

Podczas opadów o podobnej wysokości i czasie trwania, lecz większej intensywności, woda odprowadzana jest przez spływ powierzchniowy, śródglebowy i ewapotranspirację. Przy niepełnej saturacji, występują płytkie ruchy osuwiskowe, obejmujące przeważnie pokrywę zwietrzelinową i odnawiane są osuwiska okresowo aktywne.

Na stokach z przewagą piaskowców, ruchy masowe notowane są przy opadach rzędu 400–550 mm występujących w okresie 20–40 dni, o sumie w ciągu ostatnich 5–6 dni przekraczającej 250 mm.

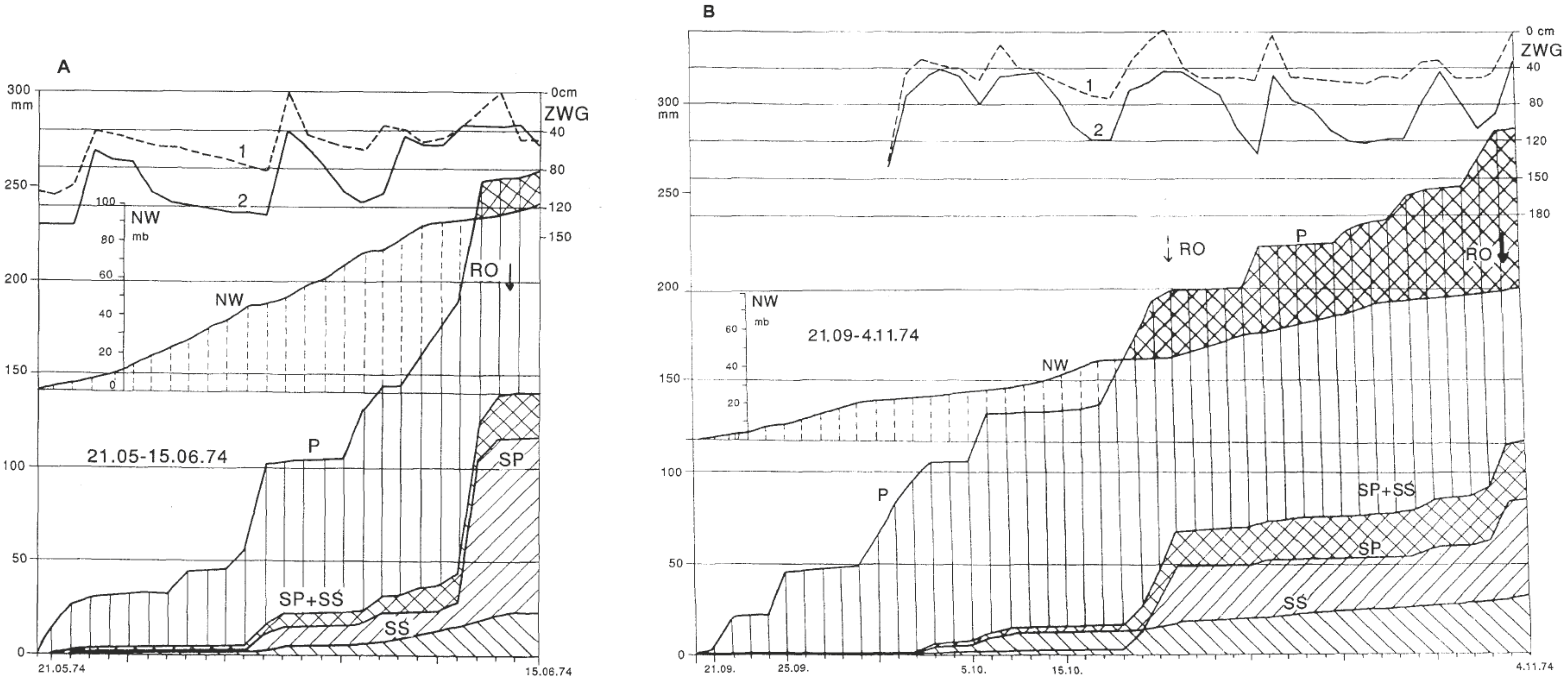

Fig. 2A–B. Elements of water circulation on the slope of the Research Station, Institute of Geography Polish Academy of Sciences during the mass movements in various hydrometeorological situations: P — cumulative curve of precipitation in mm, SP — cumulative curve of surface runoff in mm, SŚ — cumulative curves of throughflow, SP+SŚ — cumulative curve of the total water outflow, NW — cumulative curve of air moisture deficit in milllibars = evapotranspirtaion in mm, ZWG — ground water table to the depth of 150 cm: 1 — upper part of the slope, 2 — lower part of the slope, RO — timing of mass movements: solid arrow — strong movements, dashed arrow — weak movements. The densely hachured are between the cumulative curves P and NW denotes water surplus in the ground — a potential moment of landsliding

Ryc. 2A–B. Elementy obiegu wody na stoku IG i PZ PAN w Szymbarku w okresie występowania ruchów masowych, w różnych sytuacjach hydrometeorologicznych: P — krzywa kumulatywna opadów w mm, SP — krzywa kumulatywna spływu powierzchniowego w mm, SŚ — krzywa kumulatywna spływu śródglebowego w mm, SP + SŚ — krzywe kumulatywne sumy odpływu wody, NW — krzywa kumulatywna niedosytu wilgotności powietrza w mb = ewapotranspiracja w mm, ZWG — zwierciadła wód gruntowych do głębokości 150 cm: 1 — górna część stoku, 2 — dolna część stoku, RO — moment występowania ruchów osuwiskowych: strzałka ciągła — silnych, strzałka przerywana — słabych. Powierzchnia z gęstym szrafem między krzywymi kumulatywnymi P i NW oznacza nadmiar wody w gruncie — potencjalny moment ruchów osuwiskowych

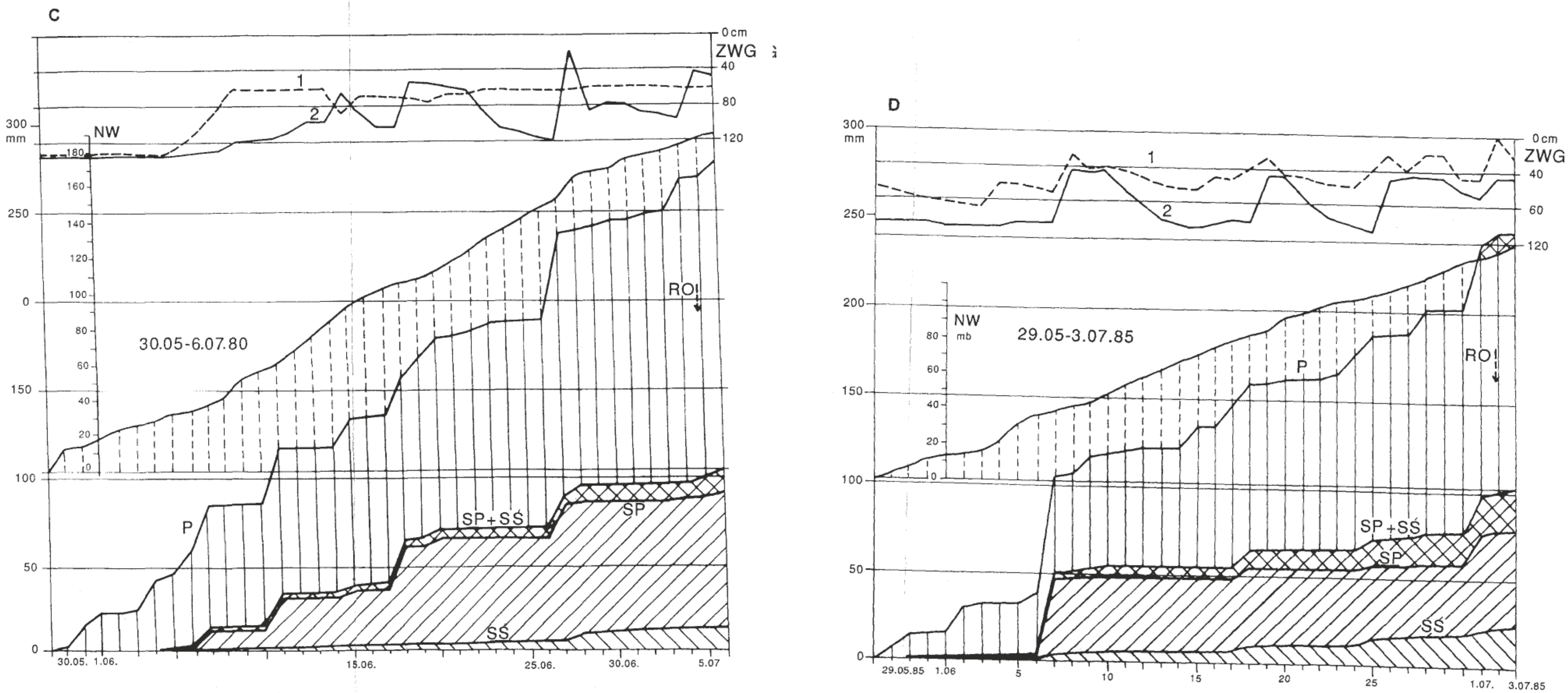

Fig. 2C–D. Elements of water circulation on the slope of the Research Station, Institute of Geography Polish Academy of Sciences during the mass movements in various hydrometeorological situations: P — cumulative curve of precipitation in mm, SP — cumulative curve of surface runoff in mm, SŚ — cumulative curves of throughflow, SP+SŚ — cumulative curve of the total water outflow, NW — cumulative curve of air moisture deficit in milllibars = evapotranspirtaion in mm, ZWG — ground water table to the depth of 150 cm: 1 — upper part of the slope, 2 — lower part of the slope, RO — timing of mass movements: solid arrow — strong movements, dashed arrow — weak movements. The densely hachured are between the cumulative curves P and NW denotes water surplus in the ground — a potential moment of landsliding

Ryc. 2C–D. Elementy obiegu wody na stoku IG i PZ PAN w Szymbarku w okresie występowania ruchów masowych, w różnych sytuacjach hydrometeorologicznych: P — krzywa kumulatywna opadów w mm, SP — krzywa kumulatywna spływu powierzchniowego w mm, SŚ — krzywa kumulatywna spływu śródglebowego w mm, SP + SŚ — krzywe kumulatywne sumy odpływu wody, NW — krzywa kumulatywna niedosytu wilgotności powietrza w mb = ewapotranspiracja w mm, ZWG — zwierciadła wód gruntowych do głębokości 150 cm: 1 — górna część stoku, 2 — dolna część stoku, RO — moment występowania ruchów osuwiskowych: strzałka ciągła — silnych, strzałka przerywana — słabych. Powierzchnia z gęstym szrafem między krzywymi kumulatywnymi P i NW oznacza nadmiar wody w grunce — potencjalny moment ruchów osuwiskowych