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WATER MAIN FAILURE RISK ASSESMENT

OCENA RYZYKA AWARII MAGISTRALI WODOCIĄGOWEJ

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***Abstract**: Town of Krosno is supplied with water by 3 intakes: Sieniawa, Iskrzynia and Szczepańcowa. After the treatment water flows in water mains to the water network in Krosno. The aim of his paper is qualitative risk analysis of the water main Sieniawa failures. The consequences of the failure: pressure value in the network and its duration, were described for different conditions of failures: time of failure, water demand and water storage tanks initial filling. For simulations of pipe failure water network model made in Epanet 2 program was used. The model was verified both during operation of water network and during the failure, where field data were used. The results of the simulations are corresponding to observations made during the real failures. Negative consequences appear only after emptying the water storage tanks, it results from two features of the storage tanks: they stabilize pressure in the network and for some time can provide water to the network. The time of emptying the storage tanks varies according to water demand their initial filling, it is at least 3 hours. During this time the are no sign of failure. When the storage tanks are empty reduction of pressure an shortage of water are observed on prevailing area of Krosno.*

***Keywords:** water main, failure, risk assessment*

***Streszczenie:** Krosno zaopatrywane jest w wodę z trzech ujęć: Sieniawy, Iskrzyni i Szczepańcowej. Po uzdatnianiu woda dostarczana jest do sieci wodociągowej Krosna.Celem niniejszej pracy jest jakościowa ocena ryzyka awarii magistrali wodociągowej "Sieniawa. Skutki awarii: rozkład ciśnienia w sieci wodociągowej i czas jego trwania zostały opisane dla różnych warunków eksploatacji: czasu awarii, wielkości zapotrzebowania wody i napełnienia w zbiornikach sieciowych. Symulacje awarii przewodów wykonano wykorzystując model hydrauliczny sieci wodociągowej sporządazony w programie Epanet 2. Został on zweryfikowany za pomocą danych eksploatacyjnych podczas pracy bezawaryjnej oraz w czasie trwania awarii. Wyniki symulacji pokrywają się z danymi eksploatacyjnymi. Wymierne, negatywne skutki awarii pojawiają się dopiero po opróżnieniu zbiorników sieciowych, co wynika z ich dwóch cech: stanowią źródło wody oraz stabilizują ciśnienie w sieci wodociągowej. Czas opróżniania zbiorników zależy od zapotrzebowania wody i początkowego napełnienia, i wynisi co najmniej 3 h. Jest to czas, w którym nie obserwuje się negatywnych skutków awarii. Wraz z oprócznieniem zbiorników przeważająca część miasta jest dotknięta niedoborem wody.*

***Słowa kluczowe:** magistrala wodociągowa, awaria, ocena ryzyka*

1. Introduction

Failures in water pipes are now seen as a significant nuisance for water consumers. Particularly important are these events which cause that the main pipelines are disconnected from operation [1, 7, 8, 9] because of the duration of the failure [3, 5, 6, 8], resulting from the relatively large diameters, as well as the impact on the distribution of flow and pressure in the water supply system [6, 9]. It is clearly shown in the measure of risk defined as the expected value of losses resulting from the failure of pipes [2, 8]. The qualitative risk analysis - responding to a question about the scenarios of undesirable events, and the quantitative risk analysis that evaluates risk, are distinguished [2].

This paper presents the qualitative risk analysis of the failure of one of the three mains supplying water to the town of Krosno. The town is supplied with water from three water treatment plants (WTP):

- WTP Sieniawa - water is supplied by an approximately 24 km long steel main ND 500 mm, of which the 4 km long initial section is duplicated by a pipe ND 400 mm,
- WTP Iskrzynia - water is pumped by an approximately 5 km long main ND 500 mm,
- WTP Szczepańcowa – it supplies the area of the city by an approximately 5 km long main ND 250 mm.

These mains create the ring system in the city, distributing water to the distribution pipelines and supplying the field tanks with a total volume of 2800 m^3.

The aim of the study is to determine the consequences of the failure of the water main supplying water from the WTP Sieniawa, the scope of the study includes the simulations of failures of the individual segments of the main, carried out by means of the water supply system hydraulic model. The risk was defined in a descriptive form indicating the potential impact of the disconnection of the individual segments of the main on the continuity of water supply to the city in the adopted operating conditions.

2. Research methodology

The analysis was performed using a hydraulic model of the water supply system created in EPANET 2, its verification was shown in [12]. The identical studies were conducted for the other two mains, i.e. "Szczepańcowa" and "Iskrzynia", presented in [10, 11]. The disconnection of the individual segments of the main "Sieniawa" was simulated, the term "segment" means the pipeline between the neighbouring gate valves that allow to shut down the pipeline if the repair of failure requires emptying the pipeline. It was assumed that no more than one segment will be disconnected at the same time. The pipeline diagram is shown in Figure 1, the data concerning the main were shown in Table 1, the numbering of the nodes corresponds to the numbering in the hydraulic model.

Table 1. Water main „Iskrzynia" pipelines.

Node nr	Nominal Diameter ND [mm]	Length [m]	Roughness [mm]
81-72	400	3840	k=2,6 mm
81-72	500	4750	k=2,6 mm
72-4	500	8704	k=2,6 mm
4-110	500	8128	k=2,6 mm
110-117	500	860	k=2,6 mm
119-120	500	1458	k=2,6 mm
120-281	500	15	k=2,6 mm
281-2	500	1309	k=2,6 mm

The different water demand values (average daily and maximum daily, based on the operational data), the duration of the disconnection (up to 24 h), the filling of the tanks at the close of the segment - from 1 to 4 m (full tanks), were assumed.
The verifications of water supply hydraulic models concern usually the extreme water demand - the maximum and minimum [4, 13]. Due to the specific flow distribution during the failure of the main - the flow rate in some segments is much higher than observed during the operation, it is necessary to check the accuracy of flow resistance mapping (absolute roughness) of these segments in an emergency. The model was verified by entering the operating data of the failure in the main "Sieniawa" which occurred on 19/07/2010. The data concerned:

- the number and types of pumps working in the pumping stations 2° in Sieniawa, Iskrzynia and Szczepańcowa,
- changes in the filling of tanks,
- pressure in 4 monitoring points.

The distribution of water demand in the areas where the failure lowered the pressure below the pressure which allows building water supply, remains unknown. The formula to calculate the reduction of water demand according to [4] was used. The pipeline water demand in a segment (or in EPANET in a node) during the pressure reduction resulting from the pipe failure, q_a is:

$$q_a = q \cdot \left(\frac{\min\{H_a, H_{gosp}\}}{H_{gosp}} \right)^{\xi} \tag{1}$$

where:
q - water demand in a node [dm^3/s];
H_a - pressure head during the failure, [m];
H_{gosp} – pressure head which allows building water supply, [m];
ξ - coefficient of relationship between the pressure deficit and water demand, [-].

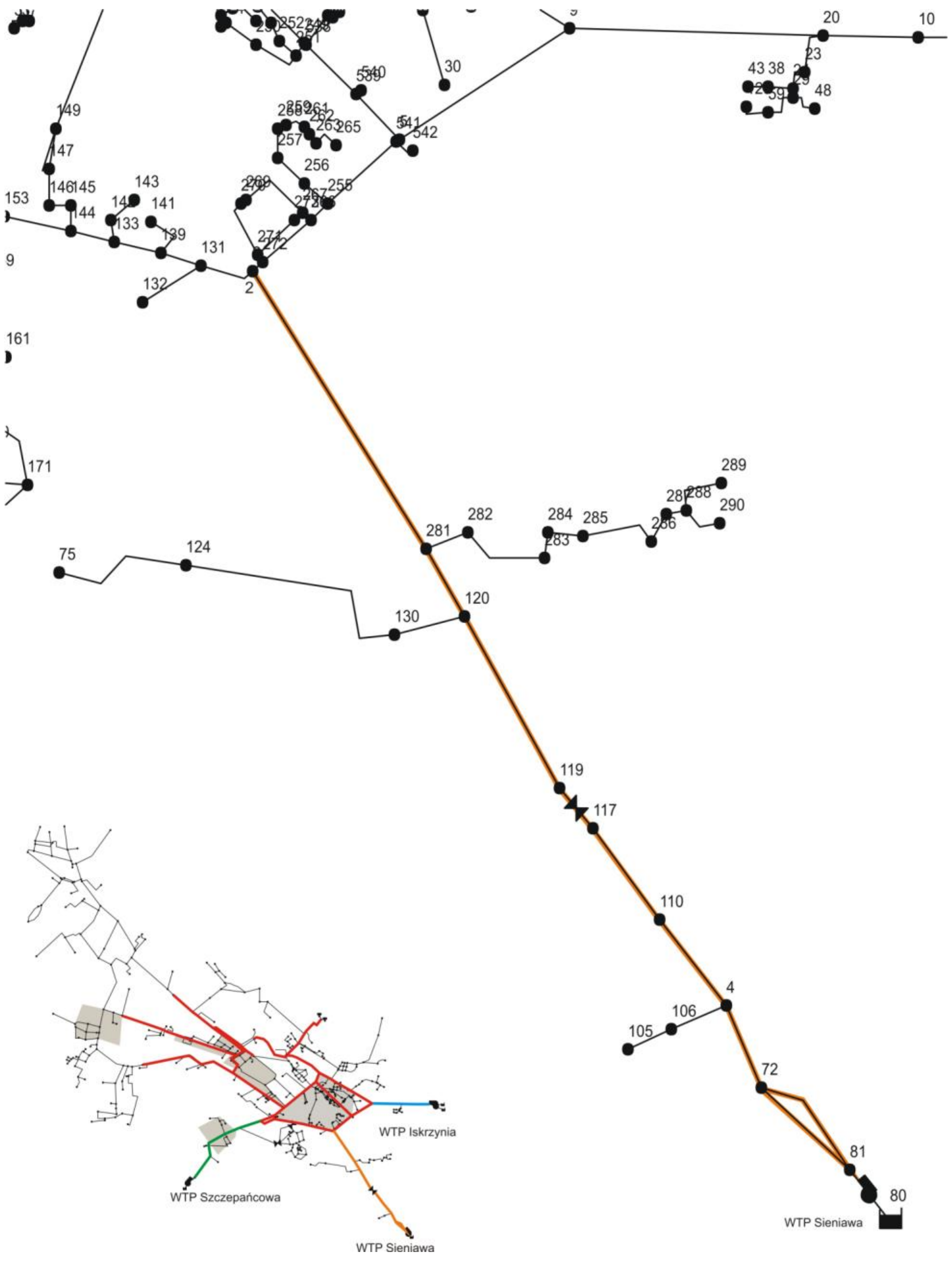

Fig. 1. Water main "Sieniawa"

The verification was made by comparing the simulation results and operating data, the area of lower pressure can be verified by estimating the area from which inefficiency was reported during the failure.

3. The simulations of main "Sieniawa" failure

As in the case of the main "Iskrzynia", the continuity of water supply with maintaining at least the pressure which allows building water supply is the result of three factors:

- the duration of the failure,
- the filling of the tanks at the time of the segment exclusion,
- the size of water demand.

The time of failure occurrence is less important, due to the insignificant hourly inequality, according to the measurements water consumption in the particular hours varies from 0.78 to 1.15 of average consumption. It results mainly from the high values of water losses.

The results of simulation for the segments 81-72 ND 400 and 81-72 ND 500 are equal, they lead to the conclusion that the exclusion of any of them does not cause any negative effects for the water supply in the city. The analysis of the exclusion of the remaining segments shows the effects observed also in the exclusion of the main "Iskrzynia" [10]. During the simulation we can observe the gradual emptying of the tanks, at this time there is not any significant decrease of pressure in the water network, which in turn means the continuity of water supply to all customers in the city. Figure 2 shows the water network simulation at full efficiency. A minimum pressure head of 30 m (except for the hills area) is noted, which allows to supply water to the whole area of the city. After emptying the tanks there is a sudden decrease of pressure in the water network, particularly severe in local hills area, where the pressure head can be lower than 5 m. The distribution of pressure in a pipeline depends only on the configuration of the terrain, the exemplary simulation is shown in Figure 3. This condition is observed until the inclusion of a closed pipe to operating. The pressure head in the water network allows for water uptake on the lowest floors of the buildings, with the exception of the areas where due to the low ground the pressure should be sufficient – it concerns the low land along the Wisłok river. Analysing the effects (losses) resulting from the failure of the main, a negative impact on fire safety in the city should be also mentioned. After emptying the tanks the water supply network does not meet the requirements of fire protection set by national regulations.

As in the case of the main "Iskrzynia" the determining factor is the duration of failure - when it exceeds the tank emptying time the pressure head will be lowered, but, in this case, much below the height of buildings, and not to a value of about 20 meters at the water demand Q_{dav}, that is above the height of buildings on the whole area, however with the limited discharge pressure on the last floors of the five-storey buildings. For the main "Iskrzynia" no reduction of water supply for two-storey buildings was observed.

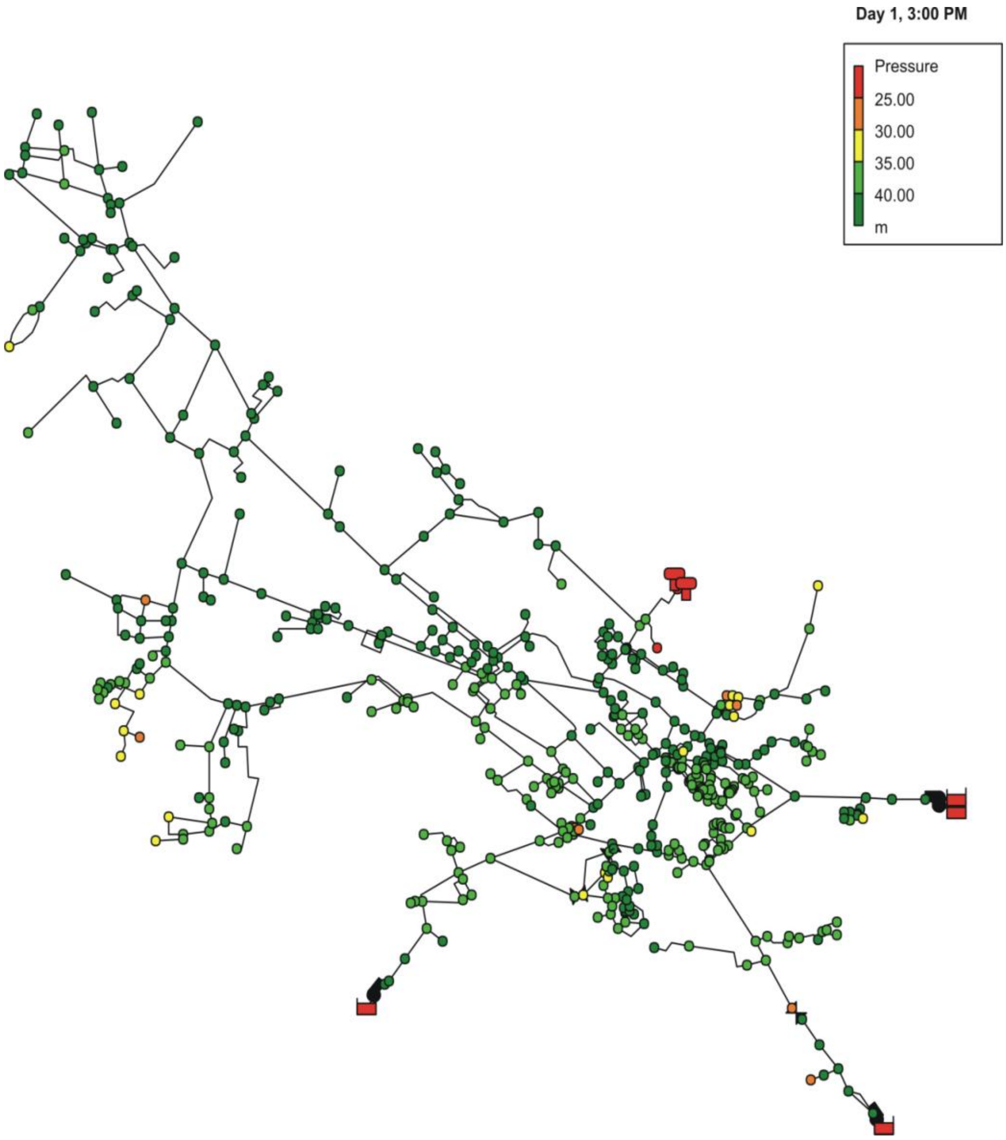

Fig. 2. Water network simulation at full efficiency

The third main - "Szczepańcowa" does not significantly affect the pressure distribution in the town [11], which is mainly due to the capacity of the pumping station in Szczepańcowa, small in comparison with two other pumping stations.

Table 2. Time of failure after water storage tanks emtying.

Initial tanks filling [m]	Time of failure, when water shortage begins [h]	
	Average daily demand	Maximum daily demand
0,0	0	0
1,0	2	2
2,0	6	4
3,0	8	6
4,0	11	8

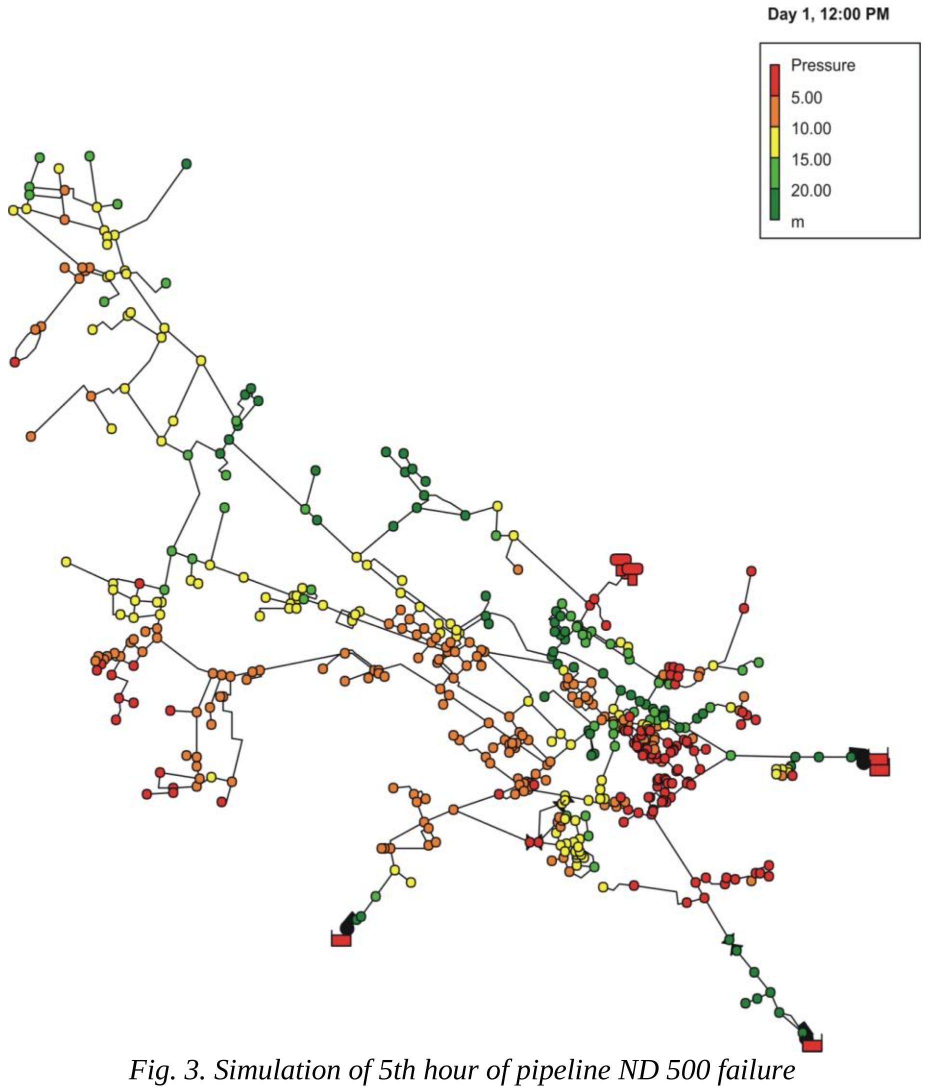

Fig. 3. Simulation of 5th hour of pipeline ND 500 failure

It has been shown that in terms of the potential losses the duration of the failure and the time of filling the tanks are critical, as presented in Table 2. For the tank completely filled it is 11 h at daily average water demand, at daily maximum water demand it is about 3 hours shorter. It was observed that the time of emptying the tanks was, on average, about 10 hours shorter than during the failure in the main "Iskrzynia".

When the main "Sieniawa" begins to operate, the filling of the tanks begins and, at the same time, the head pressure in the area of supply returns to the values observed during the fault-free operation.

The impact of the filling the tanks on the continuity of water delivery to the supplied area results from both, the volume of the tank, as well as the fact of pressure stabilization in the water network. In spite of the fact that the main "Sieniawa" has the same diameter and is 5 times longer than the main "Iskrzynia" the consequences of failure can be much more severe – both, for the area with water scarcity and the pressure in the water network. It is due only to the performance characteristics of the pumps installed in the pump stations.

4. Conclusions

1. The key for maintaining the continuity of water supply to the city in quantity sufficient to meet demand for water is the efficiency of the main "Sieniawa".
2. The potential losses expressed as water scarcity affect practically the whole area of the city. Because of the extent of the impact, as well as the size of pressure reduction, the potential consequences of the failure are much more severe than in the case of the failure of the main "Iskrzynia".
3. The duration of water supply restriction and the extent of this restriction result mainly from the filling of the tanks at the time of the failure, the size of water demand and the duration of the failure, less important is the time when the failure starts. The duration of water supply restriction is a maximum of 11 hours during the daily average water demand.
4. The simulations show the important role of the tanks. If the time when the main is closed is shorter than the time of tanks emptying, the deficit of pressure and efficiency in the supply area is not observed. Comparing it with the operational data on the average time of failure it can be concluded that maintaining a minimum filling level of 3 m (75% of the volume of the tanks) should allow for the repair of failure without adversely affecting the continuity of water supply to the water network.

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5. References

[1]. Ezell B., Farr J., Wiese I.: Infrastructure risk analysis of municipal water distribution system, Journal of Infrastructure Systems, 6(3), p. 118-122, 2000.

[2]. Haimes Y. Y.: Risk Modeling, Assessment and Management, Wiley, 1998.

[3]. Kleiner Y., Adams B. J., Rogers J. S.: Water distribution network renewal planning, ASCE Journal of Computing in Civil Engineering, 15(1), p. 15–26, 2001.

[4]. Knapik K.: Dynamiczne modele w badaniach sieci wodociągowych, Wydawnictwo Politechniki Krakowskiej, Kraków, 2000.

[5]. Kwietniewski M., Rak J.: Niezawodność infrastruktury wodociągowej i kanalizacyjnej w Polsce, Komitet Inżynierii Lądowej i Wodnej Polskiej Akademii Nauk, Warszawa, 2010.

[6]. Mays W. L.: Reliability Analysis of Water Distribution Systems. American Society of Civil Engineers, 1998.

[7]. Michaud D., ApostolakisG. E.: Methodology for ranking elements for water-supply networks, Journal of Infrastructure Systems, 12(4), p. 230-242, 2006.

[8]. Rak J., Tchórzewska-Cieślak B.: Czynniki ryzyka w eksploatacji systemów zaopatrzenia w wodę, Oficyna Wydawnicza Politechniki Rzeszowskiej, Rzeszów, 2007.

[9]. Studziński A.: Analiza hydrauliczna skutków awarii przewodów wodociągowych Rzeszowa, Instal nr 10, Wydawnictwo Ośrodka Informacji „Technika instalacyjna w budownictwie”, Warszawa, p. 109-112, 2008.

[10]. Studziński A.: Ryzyko awarii magistrali wodociągowej "ISKRZYNIA" w Krośnie. Polskie Towarzystwo Inżynierii Ekologicznej, Inżynieria Ekologiczna, v. 26, p. 247-256, 2011.

[11]. Studziński A.: Ryzyko awarii magistrali wodociągowej "Szczepańcowa" w Krośnie. Ośrodek Informacji "Technika Instalacyjna W Budownictwie", Instal. Teoria i Praktyka w Instalacjach, v. 11, p. 58-62, 2011.

[12]. Studziński A.: Ryzyko awarii przewodów rozdzielczych wodociągu Krosna, Czasopismo Techniczne, v.108, p.191-200, 2011.

[13]. Wieczysty A.: Metody oceny i podnoszenia niezawodności działania komunalnych systemów zaopatrzenia w wodę, Wydawnictwo Komitetu Inżynierii Środowiska PAN. Kraków, 2001.

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