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Josef ALDORF
Arnošt GRMELA
Eva HRUBEŠOVÁ
VŠB – Technical University Ostrava, Czech Republik

THE LARGEST BREAKDOWN OF THE SHAFT IN THE HISTORY OF CZECH MINING INDUSTRY

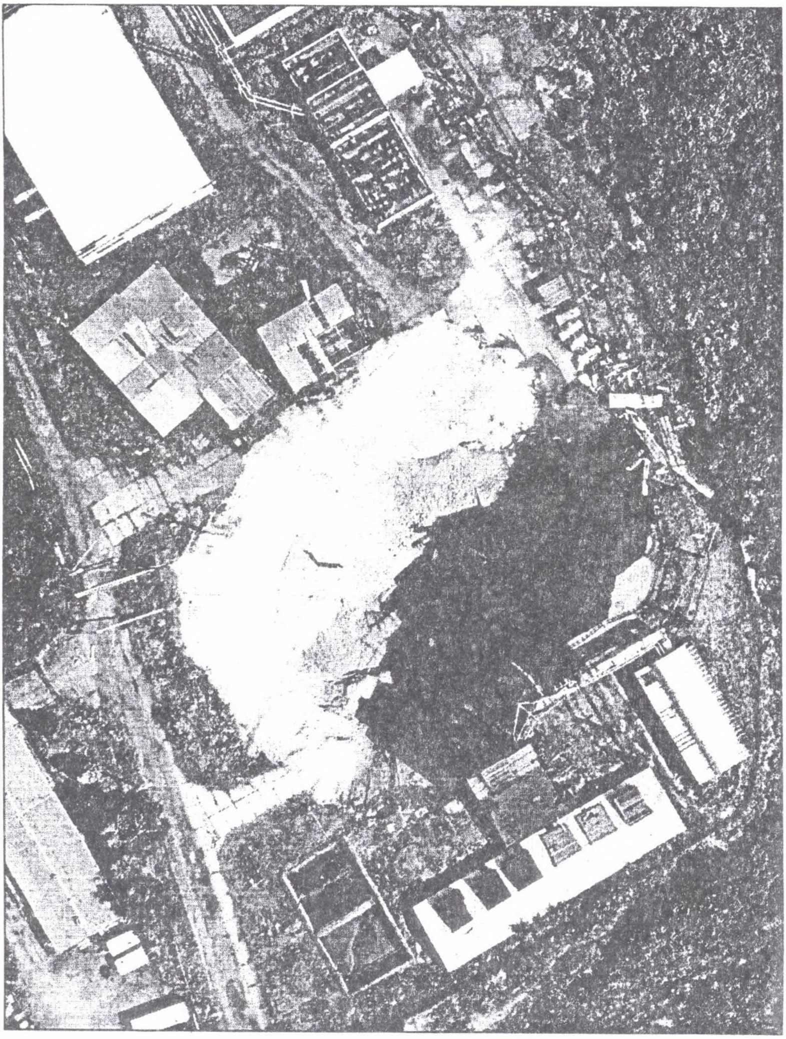
Summary. In July 1999 the largest breakdown of the shaft in the history of Czech mining industry occurred. Thousand and hundred meters deep shaft Do-IV, of 8,5 m of inner diameter, was buried in its whole length and the crater of volume 65.000 m^3 occurred on the surface during less than 24 hours. In the contribution the causes of breakdown will be analyzed and the conclusions for technical and technological recommendations will be formulated.

NAJWIĘKSZE ZNISZCZENIE SZYBU W HISTORII CZESKIEGO PRZEMYSŁU WĘGLOWEGO

Streszczenie. W lipcu 1999 roku nastąpiło największe zniszczenie szybu w historii czeskiego przemysłu węglowego. Szyb Do-IV o głębokości 1100 m i średnicy wewnętrznej 8,5 m uległ zniszczeniu na całej swej długości. Na powierzchni terenu wytworzył się krater o objętości 65.000 m^3 w czasie mniejszym niż 24 godziny. W artykule poddane zostaną analizie przyczyny tego zdarzenia. Na tej podstawie przedstawione zostaną wnioski i odpowiednie zalecenia techniczne i technologiczne.

1. Introduction

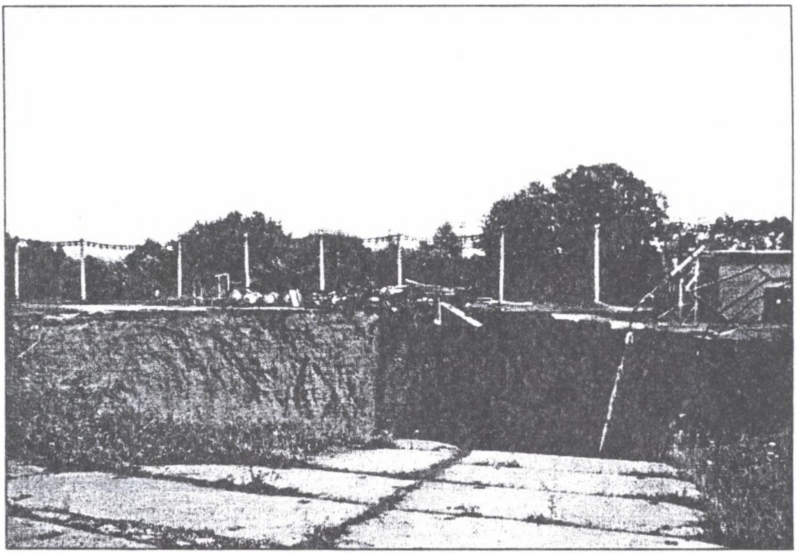
28th July 1998 at 4.08 o'clock the breakdown of the intake shaft Do-IV of the Doubrava plant of the Mine ČSA o.z. took place. The breach of a part of the mine's masonry on the south-west side of the shaft originated in the depth of about 86 – 90 m under the shaft head (opening approximately 3 x 3 m). As following the total destruction of the shaft's reinforcement over and directly under the place of dispense took place because of the local failure of the shaft reinforcement. The upper part of the shaft, shaft building and the mining tower subsequently crashed into the created crater with dimensions approx. 63 x 53 m and with the depth approx. 36 m from the surface (see Fig. 1, 2). The volume of the created crater was approx. 65.000 m^3. The lower part of the shaft was fully filled by surrounding damaged rocks and warped constructions of the overground and underground structures in the range of created crater.



Rys. 1. Lej powstały po zniszczeniu szybu Doubrava IV- lipiec 1998
Fig.1. Crater after breakdown of the shaft Doubrava IV- July 1998

1.1. The shaft Do-IV excavating characteristics

The shaft excavating of the Mine Doubrava started in September 1985 and 61.7 m was excavated until 20th January 1986 when the first breakdown took place in the shaft. The shaft was excavated with the inside diameter 8,5 m, the reinforcement thickness 0,6 m (in the lap of failure) and it was made of concrete B III (B 20). The excavation theory was based on the usual method of reinforcing by the poured concrete in approx. 2 m long meshes. The stability problems, which were determined by this technology in given natural conditions, already occurred in the higher situated gaps of the shaft (from approx. 30 m depth and also during an individual venting).



Rys. 2. Lej powstały po zniszczeniu szybu Doubrava IV- lipiec 1998
Fig.2. Crater after breakdown of the shaft Doubrava-IV - July 1998

In the depth of 61,7 m the failure of the last concrete rings and the displacement of the watery rocks into the shaft space took place. The shaft was filled up to the depth of 47 m and the construction works were interrupted until May 1988. In the period since January 1986 until May 1988 the bores (except another constructional works not pertinent to the breakdown) were realized. They were used for investigation (bore Do-IV) and dewatering (bores HV1-7) up to the depth 100 m and they were used until the shaft was excavated up to approx. 100 m (March 1989). During the excavation process 65–75 l per minute were pumped from the bores. The breakdown gap was loaded and more excavated due to the special technology usage (micropiles, injections, special suspended reinforcement, dewatering) and without any waterresistant peformance and hydrostatic water pressure dimensioning.

The following excavation in Miocene and Carboniferous waged already without any problem and the shaft excavation was finished in 1992 in the 12th level of the total depth

1176,5 m. The shaft served as a pull in shaft. In 1994 the shaft equipping was interrupted and the further controls of the shaft's stage were maintained only by help of wrecking winch ZH1500.

In that time the shaft was constantly without problems. The first indications of failure and the distinctly increased water inflow in the gap up to the depth 100 m was found out during the revisal in November 1996. During the further revisal (June 1997) the clay lodgment in the depth of 160-187 were found out and it was said that there is no delay danger. The repair and the maintenance of the shaft were involved into the 1998 plan.

During the revisal in December 1997 the reinforcement failure was found out in such a range that the revisal had to be finished in the depth 99 m from the shaft head (due to the workers' security).

The last revisal was realized in March 1998 and the distinct shaft's reinforcement failure in the depth of 89 m (up to approx. 142 m) together with distinct water percolation from the depth 40 m were found out.

3rd April 1998 the fall with the volume approx. 6-8 m^3 (1x1x6-8 m) was created near the shaft Do-IV and it was increasing until 5th May 1998. Immediately after creation of the fall the workers of VOKD made (due to plant's requirement) its revisal to find out the purposes of its origin. Withal the created crater was enlarged and extended to approx. 166 m^3 (range of influence prospecting). The Doubrava plant than took the exact monitoring of the fall's volume, depth and the water level. Another enlargement of the fall took place just before the shaft's breakdown. (22nd July 1998).

Due to the importance of the breakdown range and due to the fact, that it is not an occasional or an individual anomalous effect on this mine work, it was necessary to evaluate the effect purposes of this breakdown. **Very important facts e.g.** indicated older breakdowns on this work or another work situated near to this one, hydrogeological problems during the excavation works, geomechanical and stability problems of the watery rock surrounding environment or the problems with the quality or the poor condition of the shaft's reinforcement in the last few years, were **very unfavorable hydrogeological circumstances** and sequent to **this very unfavorable stability conditions of watery gaps of the overlaying rocks** in the locality.

2. Geological and geotechnical situation in the locality of the shaft Do-IV

Geological situation in the locality of the shaft Do-IV was checked due to the detailed geological revise already during excavation project elaboration. It is possible to divide the basic profile into the following characteristic gaps:

Quarternary: hydrogeological characteristics:

0 – 0,6 m	soil profile	dry
0,6 – 15,3 m	sandy and loamy clay	dry
15,3 – 20,8 m	loamy soil – glaciofluvial	dry

Miocene:

20,8 – 50,2 m non consolidated loam – gray, strong or hard with often sand positions

watery sand positions

sand coeff. = 0,10 coeff. of sand occurrence = 0,51 m^{-1}

50,2 – 67,7 m non consolidated loam – gray, strong or hard with very often sand positions

watery sand positions

sand coeff. = 0,22 coeff. of sand occurrence = 1,09 m^{-1}

67,7 – 84,6 m lime loam with often sand positions

watery sand positions

sand coeff. = 0,13 coeff. of sand occurrence = 0,65 m^{-1}

84,6 – 130,0 m lime loam with often sand positions

watery sand positions

sand coeff. = 0,004 coeff. of sand occurrence = 0,02 m^{-1}

After the breakdown 20th January 1986, when concrete reinforcement failure and "... *the withdrawal of muddy rocks from the south-east side of the shaft* ..." (citation of the time record) took place in the level of 61,7 m under the surface, the bore Do-IV was realized in the south or south-east direction from the shaft Do-IV. This bore was situated between later realized dewatering bores HV-5 and HV-6 (in the area of a former concrete manufacture and near the created fall) - see Fig. 3.

The bore was realized until the depth of 100 m in the profile 137 mm with the addition to Ø 216 mm. The bore was braced by bracing Ø 171 mm and treated by a concrete mixture according to the project. The important information from this bore was a fact that in the depth of 75,5 m a rinse got lost and it was never renovated. It was **a gap of the rock massive with a high permeability and so the breakdown took place there.**

After the breakdown in the excavation (20^{th} January 1986) the shaft was filled up to the level approx. 47 m and as first, three dewatering bores (HV-1, HV-2, HV-3) on the periphery and as following four more bores (HV-4 till HV-7) were realized. The bores with the diameter 273 mm were accomplished up to the depth 100 m. The geological profiles of the bores are not available and their **liquidation protocol was not retained.**

So probably no liquidation took place or it was not realized by the vocational way. This fact is the important factor of the shaft breakdown.

From the geological point of view the quarternary coat in the locality of the shaft approx. 17-20 m thick and it was stored on the mild morphological elevation. The coat was created by sandy and loamy clays based on lenses of glaciolacustrine sedimentary rocks of the Salland's glaciation.

Miocene coat of the upper Carboniferous of the Bohemian massive is composed of rocks of the lower baden lutaceous facies which fill the fore-deep of West-Carpathian system. It is placed in subhorizontal till very mild declined position. Up to the depth of approx. 130 m under the surface it is composed of very low stiffened till non stiffened green-gray lime loam (only sporadically with diagenesis reaching the mudstone parameters) with the insertions of lens sand positions (in the depth 75 – 76 m sandstone).

Rys. 3. Położenie studni badawczej Do-IV i studni odwadniających HV-1 - HV-7 w okolicy szybu Doubrava IV

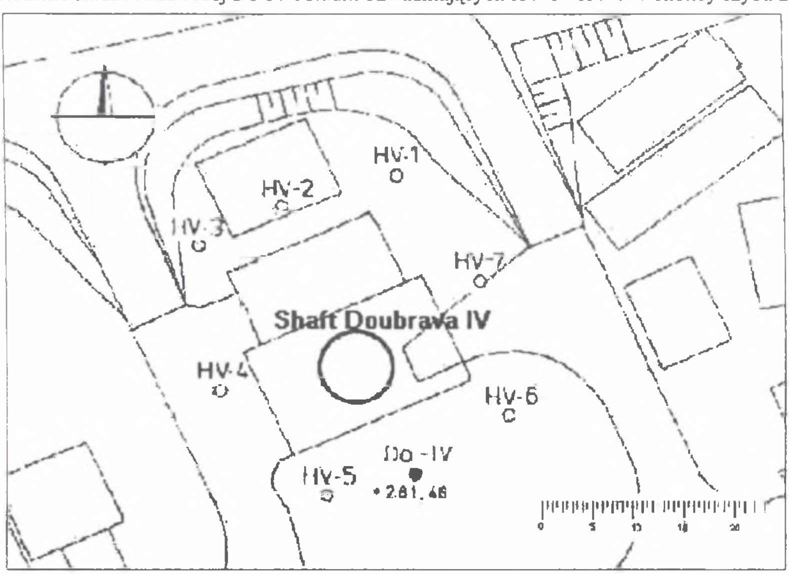


Fig.3. Situation of exploration well Do-IV and dewatering wells HV-1 to HV-7 in the area of shaft Doubrava IV

It is possible to divide the whole Miocene sequence in this gap into four characteristic gaps:

- upper gap 17 – 50 m with non distinct and low extensive sand positions (by some bores and the shaft it was proved their watering),
- strongly sandy gap 50 – 85 m with distinct and extensive sand positions (mostly by bores and the shaft it was proved their watering),
- softly sandy gap 85 – 100 m with non distinct and low extensive sand positions (by some bores and the shaft it was proved their watering),
- lower gap 100 – 130 m without important sand positions

3. Hydrogeological situation in the locality of the shaft Do-IV

The hydrogeological proportion as well as the geological situation of the place of the shaft Do-IV excavation were inspected. The pilot pre-bore Iv-206 indicated watering in the sand positions of the lutaceous facies of Miocene. These suggestions of watering were subsequently confirmed during the shaft excavation where in the upper and in very sandy gaps there were the following watery positions:

The depth	46 m	inflow	86 l/min
	48 m	inflow	110 l/min
	49 m	inflow	110 l/min
	50 m	inflow	90 l/min
	52 m	inflow	60 l/min
	58 m	inflow	130 l/min

(note: according to another documentation the inflow in the depth 53,2 m was 80 l/min)

After the dewatering of the breakdown shaft Do-IV surrounding there were constructed the dewatering bores HV-1 till HV-7. They were bored up to the depth 100 m in the distance 10 – 12 m from the shaft axis. The production of the wells system was 65 – 75 l/min and the water level stabilized in the level of 75 m under the surface. The bores were not inclinometrically angled and they were supposed to be liquidated by the cementing process.

The pilot bore Do-IV also proved the existence of very permeable rock in the depth 75,5 m. The rinse got totally lost and this technical problem was not possible to solve even by several cementing processes. The water probably percolated from the bore Do-IV through the collector into the pumped dewatering bores, it means through the collector into the shaft of breakdown. Here it could disappear in the shaft fill (47 till 61,7 m). The bore was liquidated by concrete treatment according to the protocol (without the quality checking).

4. The probable causes of breakdown origin and its mechanism

The breakdown of the shaft Do-IV is from the point of view of its causes, destruction mechanisms and the range of effect on the surface an absolutely original case in the history of the similar incidents and there exists probably no analogy in the European range (we did not find any comparative case in the literature).

Its origin, process and riders are the result of the synergic factors and causes, which originated from the natural conditions and also in the whole progress of the shaft excavation.

According to our opinion it is possible to file the following causes among the main ones:

very unfavorable natural geological conditions in the gap 0 – 100 m

- high rent and variation of watery and non-cohesive sand layers in the loam medium
- very sensitive loam rocks (slopping, flowing)

extremely unfavorable geological standards

- high watering of the rock massive
- hydraulic connection of the sand moulds with the collectors on the surface and the penetration of the surface water into the deeper groundwater bodies
- high permeability of the sandy rock layers in the gap 75 – 85 m

low strength properties of the rocks and high sensitivity to water content changes in the rocks

non-adequate technology of excavation and reinforcement in such conditions

- usage of the technology of poured concrete
- high sensitivity of the reinforcement (non-reinforced rings) to one-side loading
- permeability of the reinforcement in the loading joints of the rings (non-tight reinforcement)

eroding of the layers structure by dewatering

- suffosion of the fine particles as the result of the high amount of the pumped water

non-liquidated or non-perfectly liquidated dewatering bores

- connection of the groundwater bodies along the bores in the vertical direction
- hydrostatic pressure transfer between the sand layers

- possibility of influence of the curvature of the bores (approximation to the shaft) – the bores were not inclinometrically measured

eroding of the rock massive structure as the result of the influence of shaft breakdown in the depth 61,7 m (1986)

- origination of the large area of the eroded rocks in the shaft surrounding
- decrease of the rocks strength and increase of the rocks sensitivity to suffosion

influence of the extreme precipitation in July 1997

- increase of the inflows to the collectors in the gap 50 – 85 m
- suffosion dispatch in this gap

underrate of the influence of the suffosion effect on the shaft surrounding stability

- projecting of the technology and construction of the reinforcement, which does not correspond to the natural conditions and rock massive behavior during the excavation
- imperfections of the dewatering technology
- the way of the bores liquidations
- eroding of the rock structure in the shaft surrounding and the increase of the rock predisposition to wash out the fine particles
- anticipation of the future suffosion influence(not enough experience with the solving of the similar cases)

So we can consider synergic influence of the mentioned factors as the main causes of the shaft breakdown. These factors develop subsequently during the shaft existence.

The initiator of the acceleration (dispatch) of this process probably were:

- influence of the increased precipitation and water inflows into the permeable and eroded structures in the shaft surrounding
- possible influence of the induced vibrations.
- during the time of the shaft Do-IV breakdown even 7 wave reflections were registered and they can be a record of the breakdown process.
- before the breakdown 28th July 1998 there occurred minimally 4 SL effects with the energy 10^{+1} – 10^{+3} J in the objective area. The weakened exhibitions of instability can take minutes till tens of minutes but their influence is problematical.
- reaching of the limit values of the bearing capacity of the eroded reinforcement construction
- loam coats destruction in the boundary of the structurally eroded areas.

The mechanism of the shaft origin and development is possible to reconstruct in the individual steps as following:

1. The breakdown origin in the depth 61,7 m in 1986. The large volume of plastically pushed up rocks and the origin of the area of structurally weakened rocks with the high predisposition to wash out the fine particles.
2. The negative influence of the long-term pumping of water by the dewatering bores. The high amount of water and the suffosion influence to the rocks stability in the surrounding of the pumped bores contributed to the structural weakening of the rocks.
3. Surviving negative influence of the hydraulic connection of the watery layers of the sandy and eroded loam rocks by non-liquidated (or liquidated in a wrong way) bores HV-, Do-IV and HV-6. The nucleus of the unilaterally orientated weakened area in the bores surrounding and between them.
4. Cracks origin in the reinforcement, increasing permeability of the shaft reinforcement and the dispatch of the suffosion effects in the structurally weakened area in the surrounding of the mentioned bores (eventually also along the reinforcement because of the increased permeability in the vertical direction).
5. Long-term water supply of this area by water from the groundwater bodies in the level approx. 50 m under the shaft. Enormous increase of inflows in July 1997.
6. The origination and final creation of the suffosion of the strongly eroded rocks structure. Origination and spreading of the structural collapse (sequential cave of the hollow – creation of the fall in on the surface close to the shaft) (April 1998). Sequential filling of failing rock area by the lax mould from the "crater" of the fall in. Widening of the cracks in the reinforcement and continuing decreasing of the reinforcement bearing capacity.
7. Reaching the stage of the marginal equilibrium on the boundary of the locally reloaded reinforcement and the breaking of the ring. Initiation of this process by external and internal factors (dynamical reloading, inflows increase and the like). The "window origination in the reinforcement and fall of the watery eroded rocks into the shaft. Sequential creation and spreading of the crater along the reinforcement toward the surface. Connection of these eroded rock areas with the area of fall in influence along the shaft (28^{th} July 1998 at 4^{08} – approx. 15^{00} o'clock).

   Accelerating crater enlargement (up to the diameter 10 – 12 m) due to the sequential failure of the reinforcement rings and the uncover of the shaft sides. Creation of almost axially symmetrical shaft surrounding failure.

8. Large crater creation (evening of 28th July 1998) on the surface and sequential filling of the shaft (under the level approx. 90 m) by the eroded rocks, by constructions of the hollow tower and the shaft building. Practically complete filling of the whole shaft by the rock.

We consider this continuity of the origin and development of the breakdown as the most probable and the most corresponding to the facts monitored during the breakdown process. It corresponds to the facts recorded during the whole excavation works and in the tine of the usage of the shaft as an introductory work.

Which edification can be evaluated as the result of this case? It is possible to form them into a few points:

- the destructive influence of possible suffosion of the sands from the sand layers in the shaft surrounding was underestimated by the project and the maintain technology,
- the excavation and reinforcement technology was not chosen adequately to the complicated geological and geotechnical conditions,
- it was not possible to check the stage of the shaft (daily),
- the necessity of the absolute reliability of the dewatering bores liquidation in the shaft surrounding was underestimated,
- the suffosion was supported by the influence of the previous breakdown during the shaft excavation and by non-correct way of the pumping from the dewatering bores,
- the influence of the hydraulic connection of Quarternary water areas with the sand layers of Miocene and the influence of increased precipitation (1997) to the shaft inflows through these collectors were not hydrogeologically and technically appreciated.

The reinforcement failure analysis proved that the monitored process was a rightful result of the long-term acting of the sand suffosion in the surrounding (probably) non-liquidated pumping bore. This is also an important edification for the realization of similar structures.

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Recenzent: Prof. dr hab. inż. Jan Zych

Abstract

In July 1999 the largest breakdown of the shaft in the history of Czech mining industry occurred. Thousand and hundred meters deep shaft Do-IV, of 8,5 m of inner diameter, was buried in its whole length and the crater of volume 65.000 m^3 occurred on the surface during less than 24 hours. The main probable causes of breakdown origin in authors' opinion were: very unfavorable natural geological conditions, extremely unfavorable geological standards, low strength properties of the rocks, non-adequate technology of excavation and reinforcement, eroding of the layers structure by dewatering, non-liquidated or non-perfectly liquidated dewatering bores, eroding of the rock massive structure, influence of the extreme precipitation, underrate of the influence of the suffosion effect on the shaft surrounding stability. In the contribution the causes of breakdown will be analyzed and the conclusions for technical and technological recommendations will be formulated.