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NR 15

IMPROVEMENT OF UNDERCUT-AND-FILL MINING TECHNOLOGY IN SWEDEN

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Improvement of undercut — and fill mining technology in Sweden

Key words

Mining-undercut and fill mining-cemented fill-deformation zone-field investigations-development

Abstract

The cemented-fill roof in the undercut-and-fill (UC&F) stopes at the Garpenberg Mine is loaded by its own weight and by compression due to convergence. Roof problems have occurred in the narrow sections in recent years due to sidewall convergence, resulting in compressive strains in the fill.

The fill material itself cannot sustain the large strains. A deformable zone within the fill was developed and tested as a means of eliminating these problems, and of increasing the application range of UC&F for the increased convergence expected in the future. A full-scale test on the method showed no spalling or failure of the fill roof. The experiences gained in the full-scale test were confirmed when the deformation-zone method was used in other stopes.

1. Background

1.1. The mining method

The Garpenberg Mine, owned and operated by Boliden Mineral AB, is located in central Sweden. Undercut-and-fill mining (UC&F) has been the main mining method since its itroduction in 1974. The annual production is 300 kt.

The method was developed on empirical grounds. An improved understanding of the rock mechanics of UC&F was required to allow further improvement of the method at Garpenberg and to allow its application to other mines with different rock mechanics conditions (Krauland, Stille 1993).

A horizontal cut of 5 m in height is mined from a ramp access in the steeply dipping orebody. The void is then backfilled with cemented mill tailings. The next cut is mined under the cemented fill, which now form the roof in the stope. Mining thus progresses cut by cut downwards under the artificial roof. Generally, UC&F is used where the strength of the ore is very low.

Figure 1 shows schematically the mining method and the backfill: in the lower 1,8 m of the backfill, the cement-to-sand ratio is 1:4 (20 per cent cement by weight of solids) and, in the upper part, it is 1:10 (9 per cent cement by weight of solids). The lower part is bolted by 1,8 m rebars on 1,5 m centres installed before backfilling to eliminate or reduce the effect of layering in the fill. The rebars are designed for good anchorage in the fill; they are placed in the stope immediately before the fill is poured.

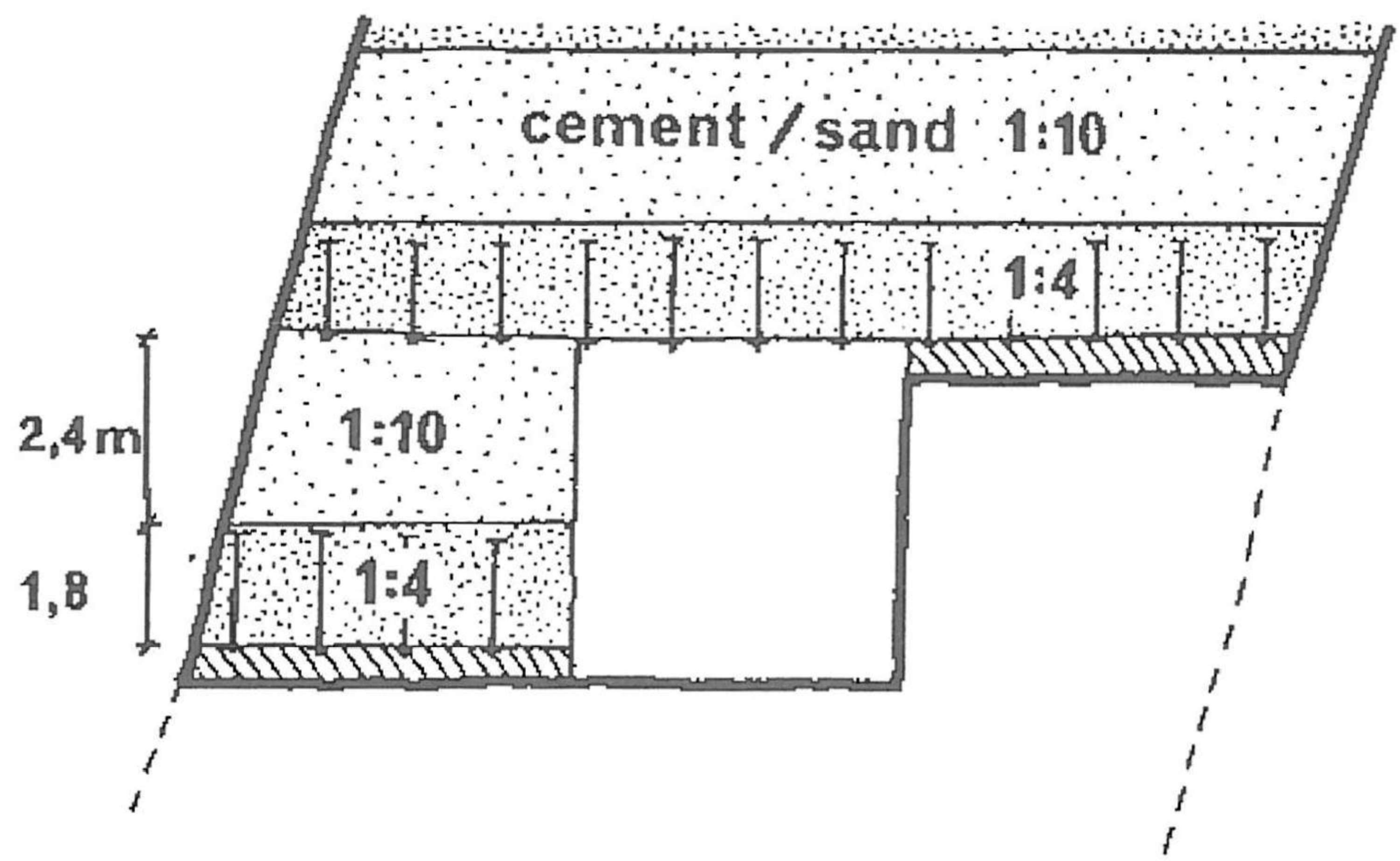


Fig. 1. Composition and reinforcement of the fill slabs in the mining of a wide orebody by the drift-and-fill method

Rys. 1. Układ i sposób wzmocnienia warstw podsadzki w przypadku eksploatacji szerszego złoża metodą zabierkową z podsadzką

When the width of the ore exceeds 8 m, it is mined in drifts of 4 to 5 m in width, which are backfilled before the adjacent drift is mined.

The cemented-fill roof in the undercut-and-fill (UC&F) stopes at the Garpenberg Mine is loaded by its own weight and by compression due to convergence (Krauland, Tjärnlund 1990, Krauland, Stille 1993). The range of application of the fill-slab design is satisfactory with regard to the ore width but, with regard to convergence, it is limited by the failure strain of the fill material, which is about 0,5 per cent. This limitation has resulted in roof problems in the narrow sections as shown in Figure 2. In Garpenberg, convergence is expected to increase considerably with depth. There is also a need to apply UC&F mining for special purposes in other mines where the convergence is much larger.

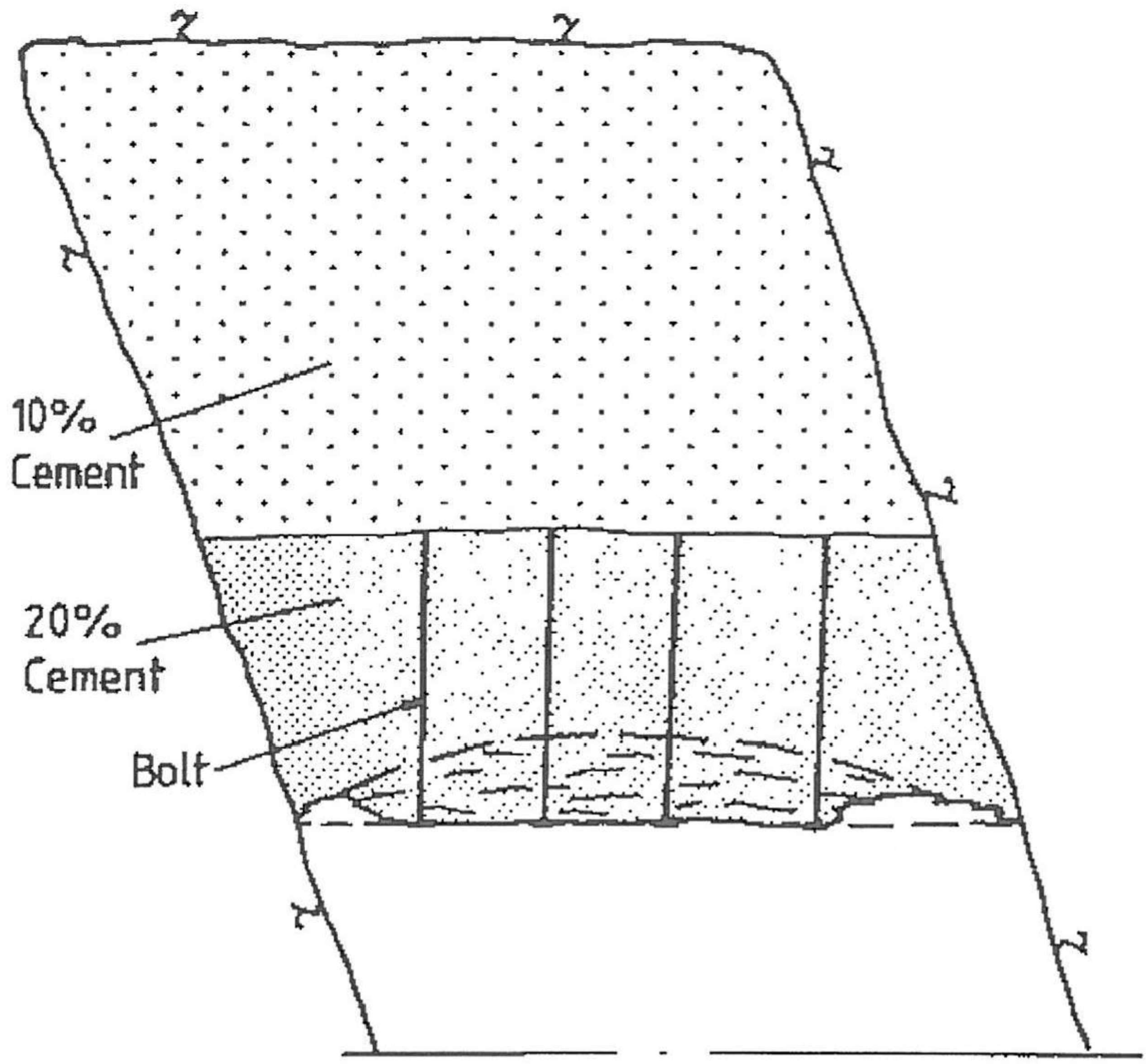


Fig. 2. Failure of a fill roof due to convergence in the narrow sections
Rys. 2. Sposób powstawania pęknięć w stropie spowodowanych konwergencją w wąskich wyrobiskach

Firstly, in order to better understand the load bearing system of the fill slab modelling of the roof fill slab was carried out.

Extensive investigations were carried out on the development of a fill material that can sustain large strains. However, the improvements achieved were not sufficient to meet the indicated need of 200 mm of compression over an ore width of 5 m, or 4 per cent compressive strain. Instead, the concept of a deformable zone within the fill was developed and tested.

Another line of improvement was to reduce the consumption of cement by the introduction of individually designed fill slabs for each stope, depending on the ore width and expected convergence. The quality of the fill was improved by a change in particle-size distribution and greater accuracy in the mixing process (Fredriksson et al 1993).

2. Modelling of the roof fill slab

2.1. Models

The field investigation of the cemented-fill roof in the UC&F stopes at the Garpenberg Mine indicated that the fill slabs are loaded by their own weight and by compression due to convergence. In the development of a tool for the further development of UC&F,

analytic and numeric models of the fill slabs were developed and compared with the observed behaviour (Hässler 1990). Analytic calculation has the advantage of giving a better phenomenological explanation of the behaviour, while the numeric model gives a more detailed picture of the stresses and deformations in a fill slab. For the analytic calculation, an elastic model was used based on average deformation modulus. In the numeric calculation, a non-linear strain-softening model was developed based on data from a comprehensive determination of the mechanical properties of the fill.

2.2. Potential and limitation of UC&F

The modelling enabled the authors to establish the range of conditions within which the design of the fill slab used in the Garpenberg Mine can be applied. The results show that the fill slab is very satisfactory with regard to the ore width, which could, in fact, readily be increased. However, its range of application with regard to convergence is poor, since increasing roof problems are encountered with depth in the narrow ore sections, see Figure 3.

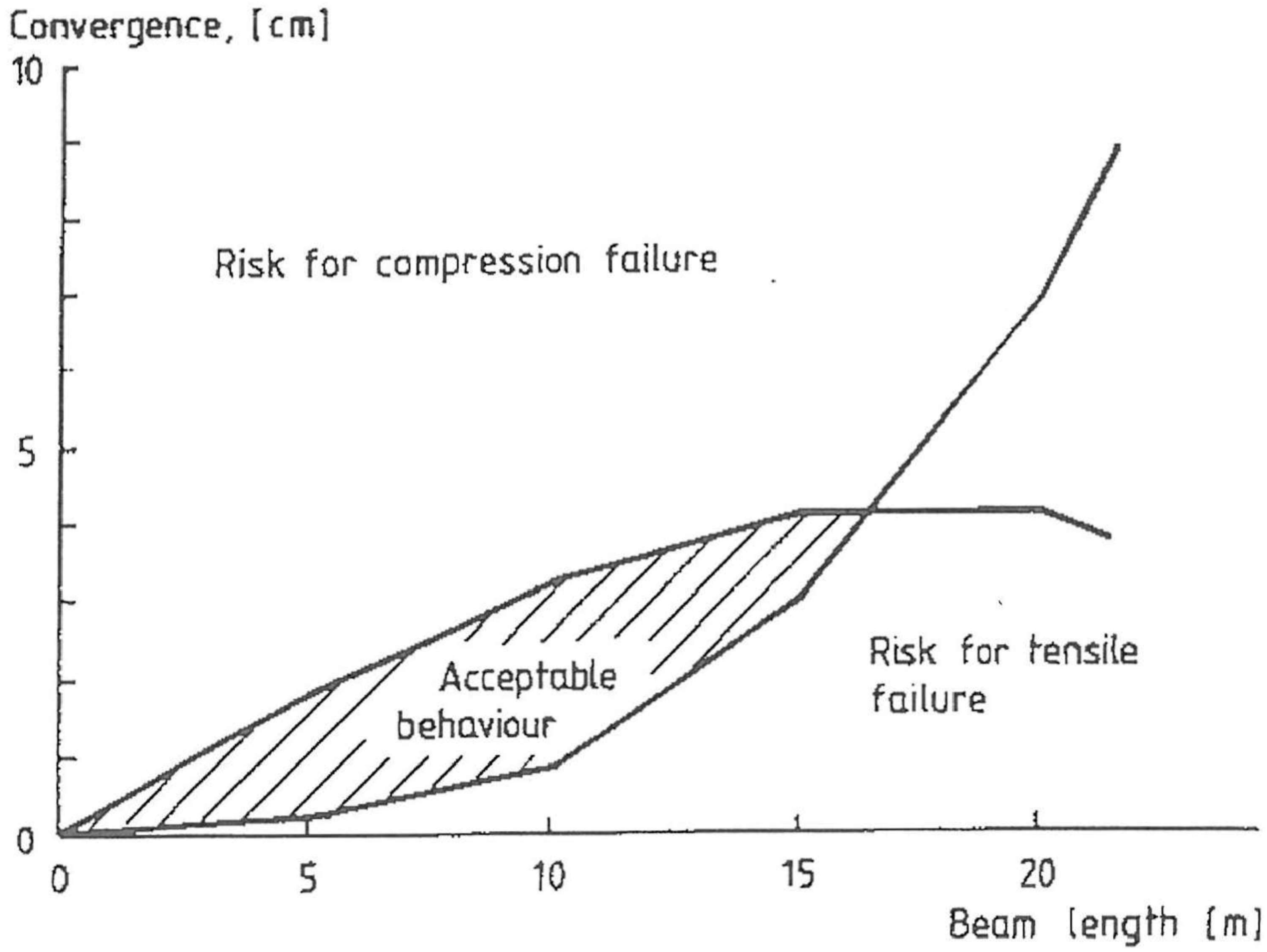


Fig. 3. The range of stable behaviour (acceptable behaviour) for combinations of convergence and beam length, and areas of unstable behaviour (failure in compression due to convergence and failure in tension due to bending

Rys. 3. Zakres stabilnego zachowania się stropu (pole zakreskowane — akceptowalne zachowanie) w zależności od wielkości konwergencji i długości belki oraz zakresy niestabilnego zachowania się (pole niezakreskowane) w przypadku spękania na skutek ściskania spowodowanego konwergencją (górna część) oraz spękania na skutek rozciągania spowodowanego ugięciem się belki (dolna część)

Attempts were made to develop a fill material that can sustain large compressive strains. Mill tailings with large variations in particle-size distribution, water content, and cement content were tested, and some exotic ballast materials were examined. The improvements in failure strain were not sufficient to meet the indicated need. As a consequence, it was decided to develop the concept of a deformable zone within the fill in order to extend the range of applicability of UC&F. The deformation zone should be able to take up large deformations due to convergence at a stress level that is high enough to prevent tensile stresses due to bending, but low enough to prevent compressive failure in the fill. Figure 4.

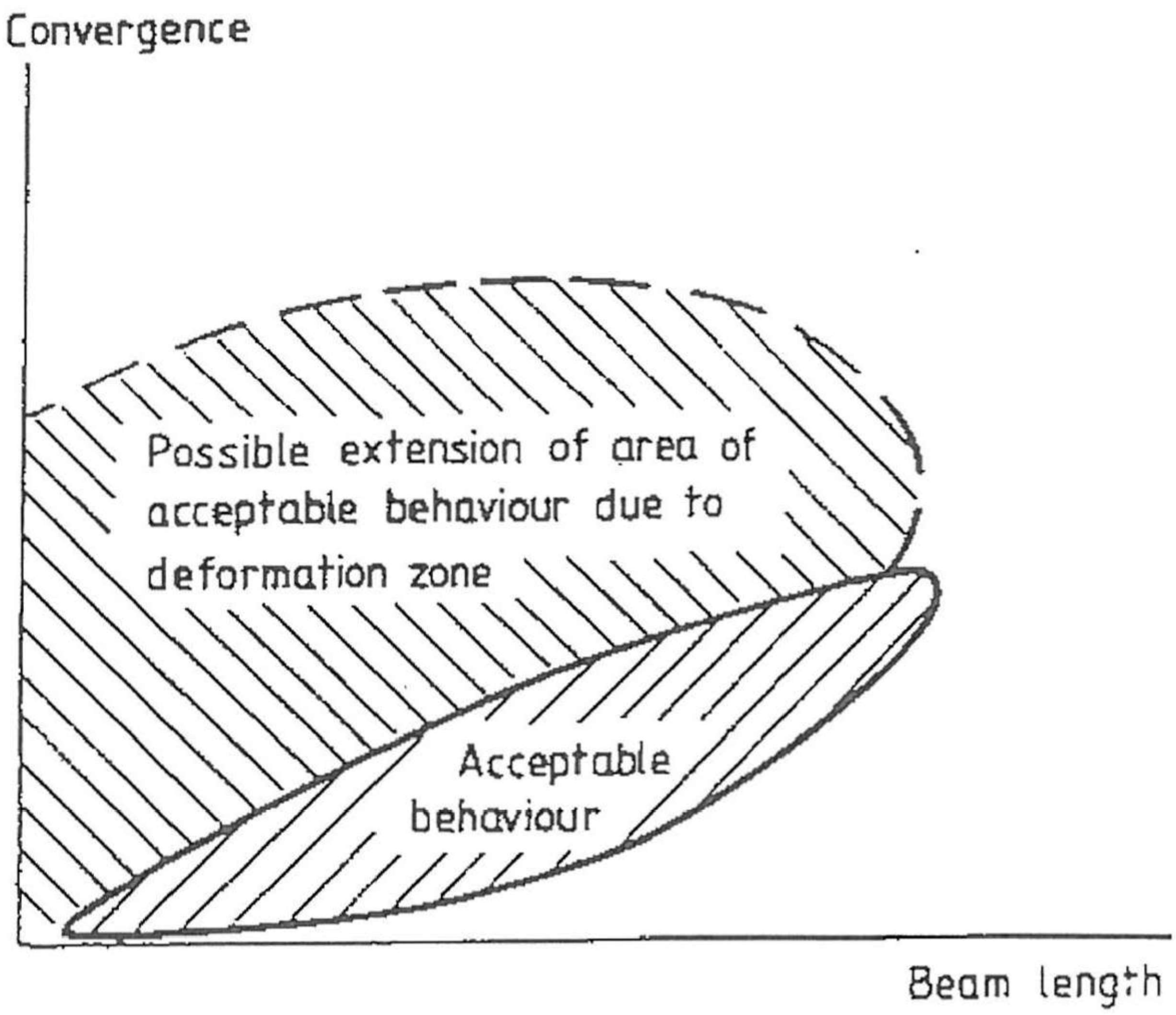


Fig. 4. Possible extension of the range of stable beam behaviour due to a deformation zone
Rys. 4. Dopuszczalne rozszerzenie zakresu stabilnego zachowania się belki w związku z powstaniem strefy deformacji

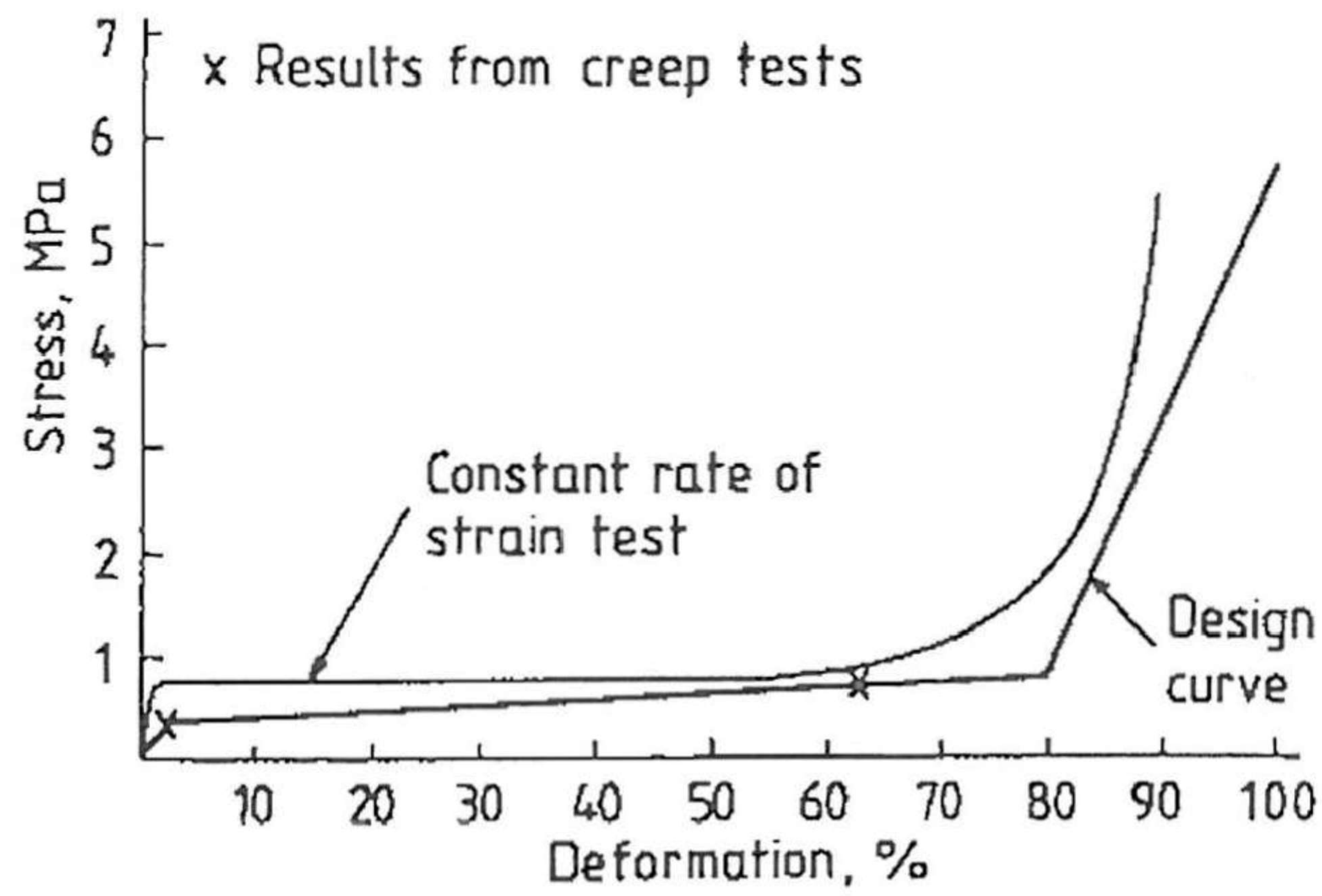
3. Deformable zone within the fill

3.1. Requirements for the deformation zone

The deformable zone within the fill, referred to as the „deformation zone", is required to take up large deformations at stress levels that are high enough to prevent tensile stresses in the fill roof, but low enough to prevent compressive failure in the cemented fill. Furthermore, the deformation zone should exhibit little or no extension in the vertical direction when the compressed in the horizontal direction. Such deformation would induce vertical strains in the adjacent fill, resulting in horizontal spalling and slabbing of the fill.

3.2. Laboratory tests

A series of laboratory tests was conducted on different types of material in an attempt to find a material with properties similar to those of ideal material. Constant-rate-of-strain tests, relaxation tests, and creep tests were performed. A suitable material made of styrene aerated plastic was found to have properties very close to requirements. Figure 5 illustrates



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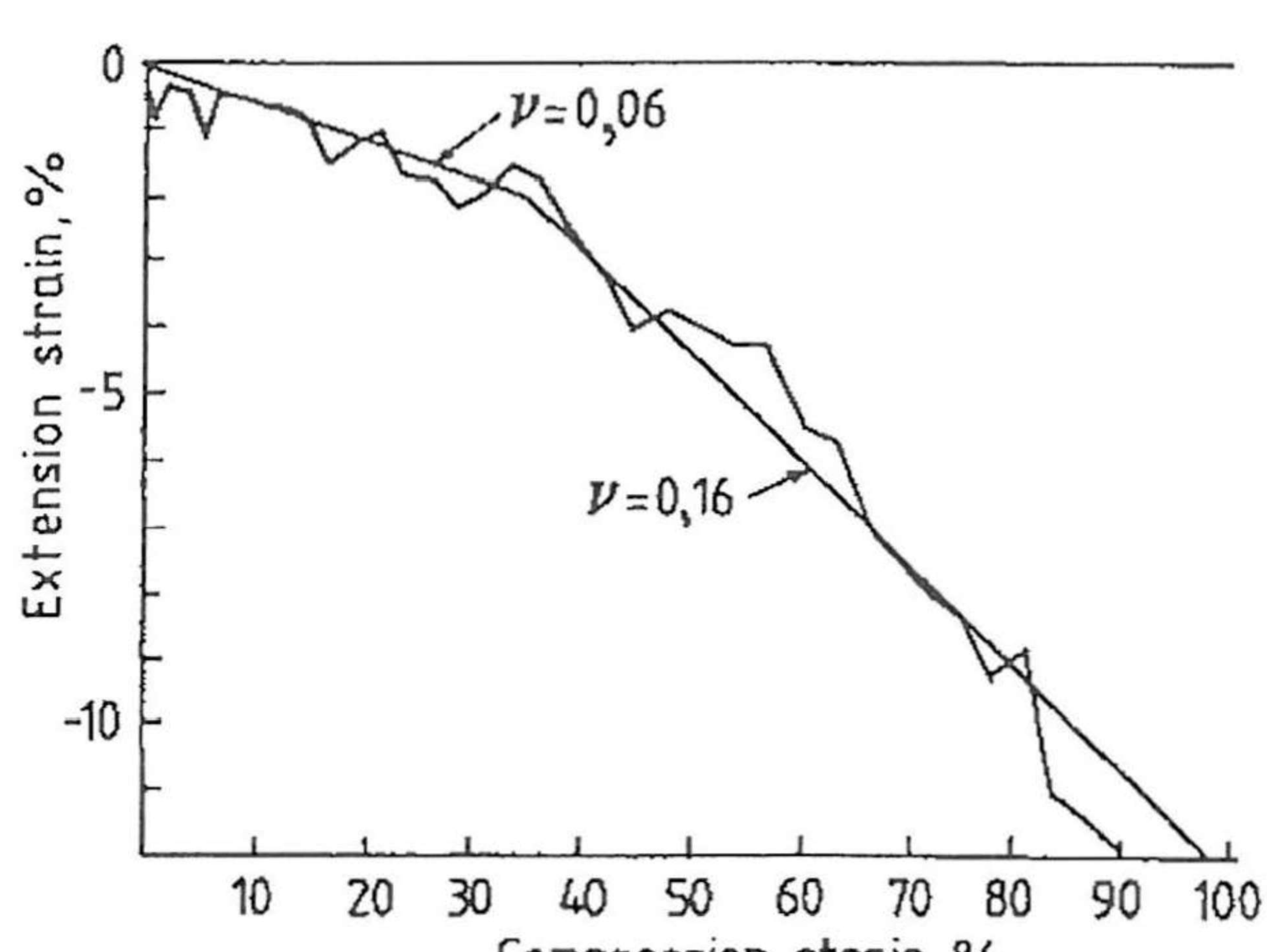

b

Fig. 5. Results of laboratory tests
(a) Load-deformation curves for the deformation zone; (b) Relationship between compressive strain and lateral extension strain (Poisson effect)
Rys. 5 Wyniki testów laboratoryjnych
a) charakterystyki naprężeniowo-deformacyjne dla strefy deformacji; b) zależność pomiędzy odkształceniem na skutek ściskania a odkształceniem na skutek bocznego rozciągania (efekt Poissona)

the measured load-deformation curves for the finally selected material. After a compression of about 2 per cent, the stress remained constant up to a compression between 70 and 80 per cent, Figure 5 (a). Thereafter, the stress increased sharply. The PoissonŐs ratio was very low up to a compression of about 40 per cent, and was then rather moderate, Figure 5 (b). It is possible to construct deformation zones of the required thickness in 50 mm steps from this commercially available material.

3.3. Full-scale test

To test the concept of a deformation zone in cemented backfill, a well-instrumented full-scale test was performed in the mine on level 520 m (Persson, Tjärnlund 1990). A thickness of 50 mm was chosen for the deformation zone, and a convergence of about 40 mm was expected in the test area. The orebody has a width of about 5 m in the test area, shown in Figure 6. Two sections were instrumented: one in the test area containing the deformation zone, and the other in a reference section (without a deformation zone) adjacent to the deformation-zone test area. The layout of the instrumentation is shown in Figure 6.

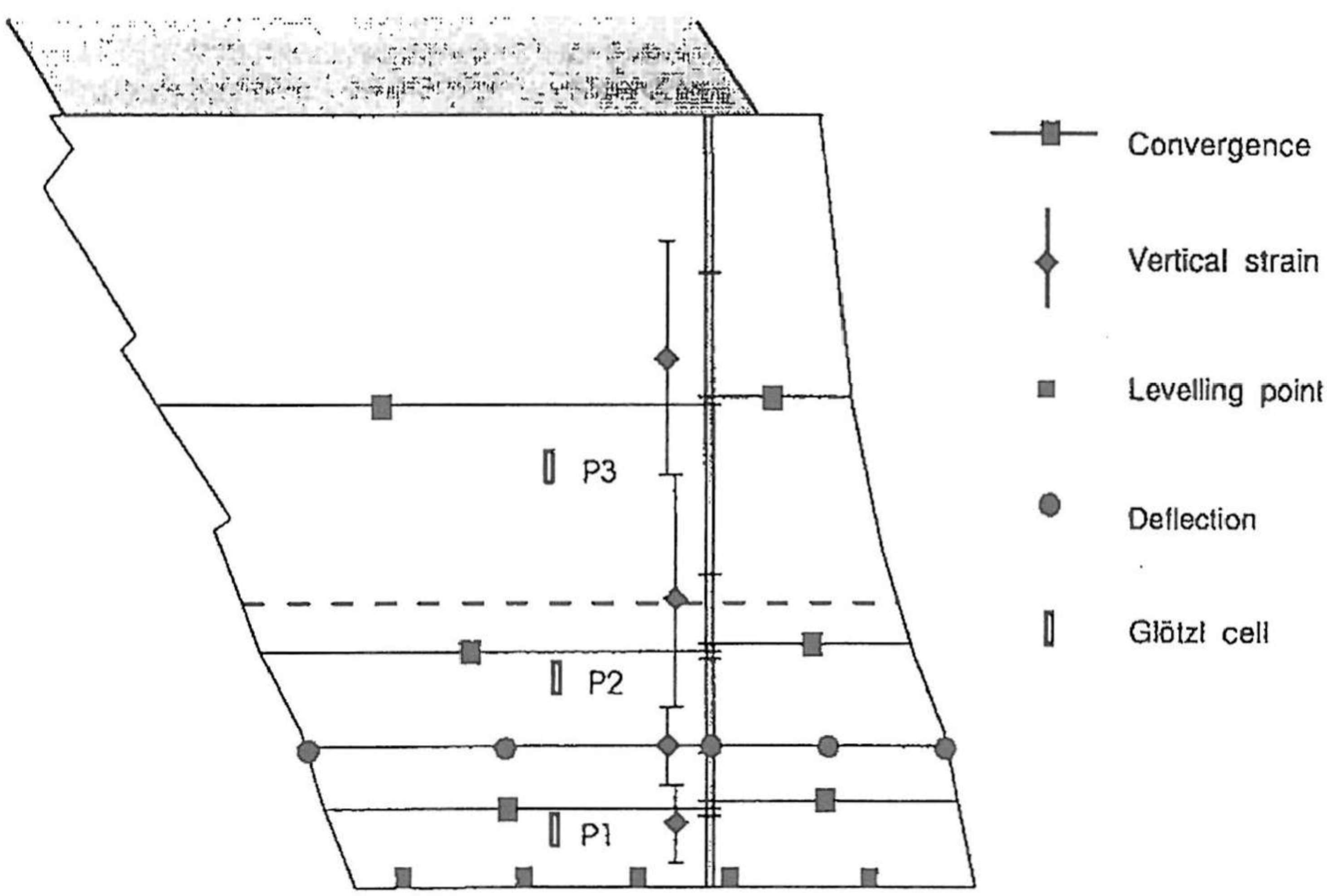

Fig. 6. Instrumentation in the test section containing the deformation zone
Rys. 6. Sposób rozmieszczenia czujników w testowanym podsadzonym wyrobisku ze strefą deformacji

Figure 7 shows the development of convergence across the fill due to mining of the ore underneath the fill. The convergence over the fill slab was small when the excavation started on the next level. When the mining process approached and passed the experimental sections, the convergence increased rapidly. Thereafter, the convergence increased at a constant low rate, as shown in Figure 7. The measurements in the section across the deformation zone show that the total convergence, 40 mm, was completely absorbed in the deformation zone.

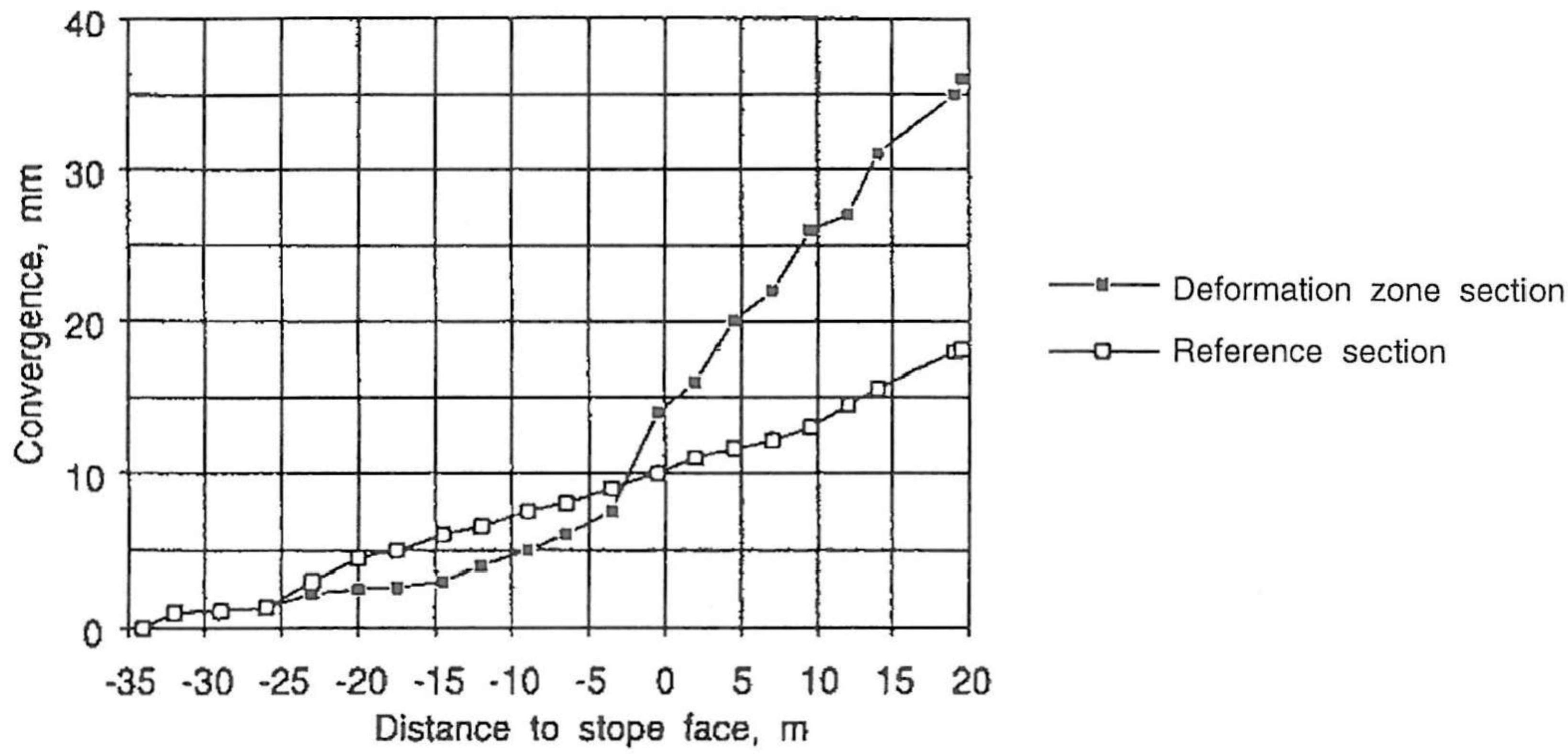

Fig. 7. Convergence between the hanging wall and footwall due to mining of the earth underneath the fill
Rys. 7. Wielkość konwergencji pomiędzy stropem i spągiem w przypadku eksploatacji poniżej podsadzki

The stress increase in the fill slab containing the deformation zone was governed by the properties of that zone. Figure 8 compares the measured stresses in the fill with the laboratory results in the deformation zone. The behaviour in the field was similar to that in the laboratory tests.

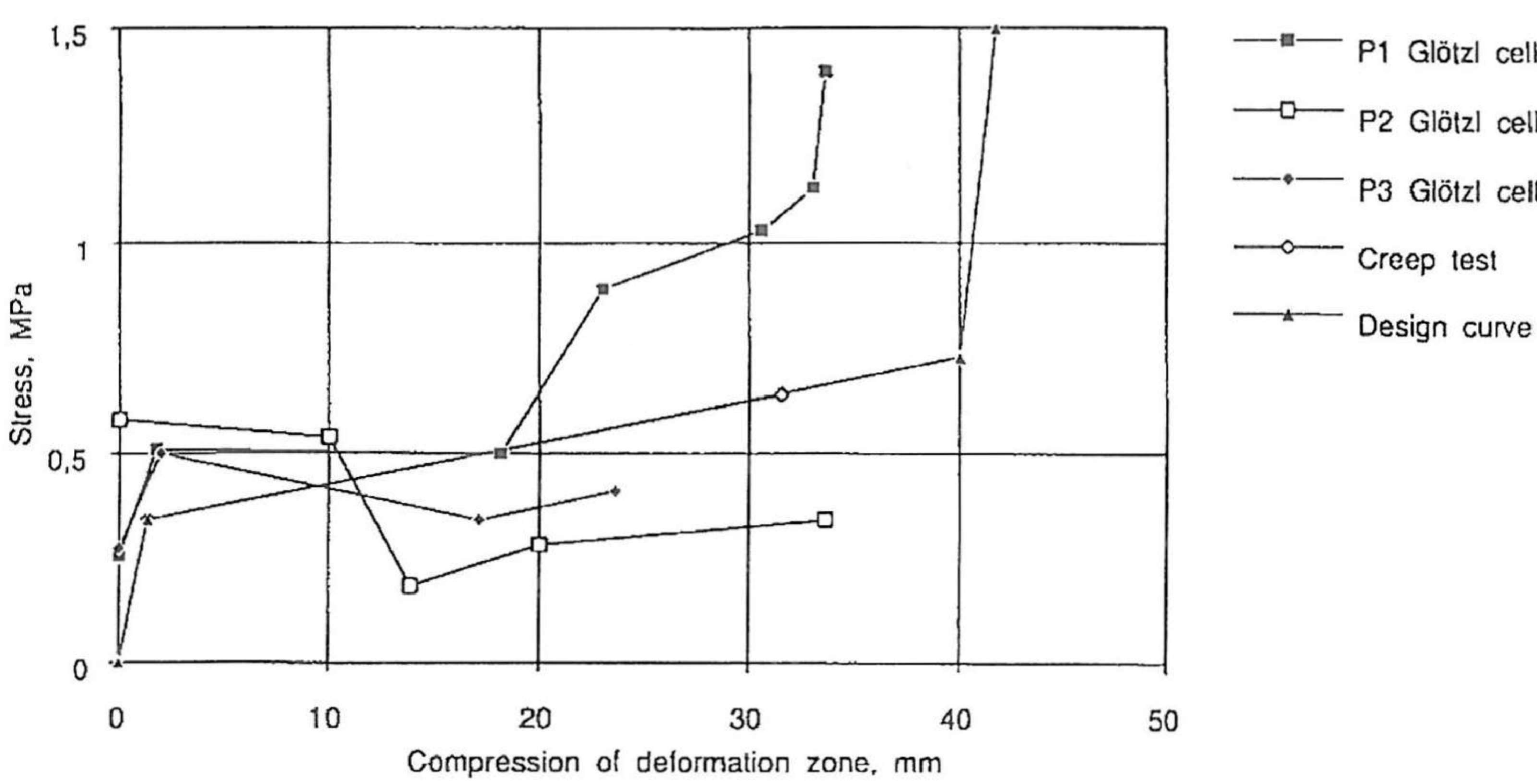

Fig. 8. Development of stresses in the fill
Rys. 8. Przebieg zmian naprężeń w podsadzce w strefie deformacji

Visual observations of the fill slab containing the deformation zone showed no spalling or failure of the fill in the roof; only vertical cracks perpendicular to the stope axis were observed. In the reference area, horizontal spalling and open cracks were observed. The rock bolts prevented the failed fill from falling down.

3.4. Practical experience

The experience gained with the deformation zone in the full-scale tests was confirmed when the concept of the deformation zone was used in other stopes. To date, December 95, the deformation zone has been used in several fill slabs in different stopes. Only minor problems were experienced during mining under these slabs. Before the introduction of the deformation zone, spalling and slabbing of the fill roof occurred in these areas. Owing to production demands, the stopes had to be filled so quickly in some instances that a deformation zone could not be installed. Generally, this meant that mining of the next cut became very troublesome.

The need for a deformation zone and its thickness depend on the magnitude of the expected convergence. The prediction of convergence is not simple, even when measurements are made in the stopes.

4. Discussion and conclusions

The development of the concept of the deformation zone and its application to practical mining have been successful. It effectively eliminated the limitations in the application of UC&F due to large convergence. The prediction of convergence measurements in the active stopes is not always reliable when the sidewall is in a state of failure. This aspect needs further improvement, and different types of measurement are being investigated. The deformation-zone method has been tested, thus far, only over the range of convergence occurring in the Garpenberg mine, although it can accomodate very large convergences (in excess of 300 mm). The deformation zone has not yeat been tested under such conditions in practical mining.

It is expected that the occurence of fill-slab failure can be eliminated, or at least drastically reduced, by the use of this method. Therefore, mine safety and production capacity will improve and mining costs will decrease.

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Udoskonalenie technologii eksploatacji zabierkowej na warstwy z podsadzką w Szwecji

Streszczenie

Strop z zacementowanej podsadzki w systemie zabierkowym na warstwie z podsadzką w kopalni Garpenberg jest obciążony własnym ciężarem oraz poddany ściskaniu spowodowanym konwergencją. Problemy ze stropem pojawiły się w wąskich zabierkach na przestrzeni ostatnich lat w związku z ociosową konwergencją i pojawieniem się w podsadzce deformacji w wyniku ściskania.

Materiał podsadzkowy nie wytrzymuje znacznych odkształceń. W celu wyeliminowania tych problemów testowano strefę skłonną do deformacji w podsadzce w skali przemysłowej. Problem ten ma znaczenie również ze względu na wzrastające stosowanie eksploatacji zabierkowej z podsadzką oraz oczekiwanego wzrostu konwergencji w wyrobiskach w przyszłości. Przeprowadzone testy nie wskazały na odspajanie się stropu ani na inne zniszczenia w podsadzonym stropie wykonanym zgodnie z opracowaną metodą. Doświadczenia zebrane podczas przeprowadzenia testu zostały potwierdzone w czasie stosowania metody „strefy deformacji" w innych wyrobiskach.