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SUMMARY OF 24 SURFACE CROWN PILLAR CASE STUDIES

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ABSTRACT

Surface crown pillars are important Canadian mining structures. Mines operating in the Canadian Shield usually have several, forming a first line of protection from surface elements.

Detailed technical information from 24 Canadian hard rock mines show that the deposits dip steeply and are generally either single or multiple veins. Considerable overburden usually cap the deposits. The rock mass is often altered and intersected by important discontinuities.

The designs for these types of pillars lack basic data and are based on experience rather than a scientific approach. Regardless of the competence of the rock mass, the surface crown pillar thickness to width ratios are usually less than 5. Rock bolting is, in almost every case, used as a support measure. However, there are many openings neither backfilled nor monitored.

The characteristics of openings with surface crown pillars are also examined.

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key words

surface crown pillars, Canadian Shield, case studies, overburden, rock mass, design, thickness to width ratio, rock bolting, backfill.

SOMMAIRE DE 24 HISTOIRES DE CAS DE PILIERS DE SURFACE

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RÉSUMÉ

Les piliers de surface sont des structures miniéres canadiennes importantes. Les mines situées dans le Bouclier canadien en contiennent habituellement plusieurs, formant une première ligne de protection contre les éléments de surface.

Des informations techniques détaillées de 24 mines canadiennes en roche dure démontrent que les dépôts ont un pendage élevé et consistent plus souvent de veine simple ou multiple. D'importantes quantité de morts terrains surplombent les gisements. Les massifs rocheux sont souvent altérés et intersectés par d'importantes discontinuités.

Les conceptions de ces genres de piliers manquent de données de base et sont parfaites basées sur l'expérience plutôt qu'une approche scientifique. Les facteurs épaisseur sur largeur sont habituellement moins de 5, pour toutes les diverses qualités de massif rocheux. Les boulons d'ancrage sont utilisés dans presque tous les cas. Cependant, il y a plusieurs ouvertures non-remblayées et sans suivies.

Les caractéristiques des ouvertures avec piliers de surface sont aussi examinées.

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mots clés
piliers de surface, Bouclier canadien, études de cas, morts-terrains, massif rocheux, conception, rapport épaisseur sur largeur, boulons d'ancrage, remblai.

INTRODUCTION

Two major case study campaigns have been completed by CANMET (1)(2). In all, 24 mines were examined. These were representative of the geological conditions and mining methods particular to Canadian underground hard rock mines. Five mines were located in Manitoba, eight in Ontario, nine in Quebec and two in New Brunswick.

The first campaign, Phase I, was aimed at identifying the existing information on the subject. Its two tasks, a comprehensive literature search, and the second, the approach used by 6 mines in designing surface crown pillars, demonstrated that no specific process, tried method, case study, specific terminology or any other specific information related to these structures existed for hard rock settings.

The second Phase involved the compilation of the existing technical data related to pillars of another 18 mines, including the design process and other means of dimensioning adopted by the operators.

Few projects have enrolled the participation of so many mines. The benefit of the case studies can be measured in several ways. No other Canadian mine structure has been so completely typified. No other structure requires the application of so many elements of ground control in addressing existing conditions.

Furthermore, the data included in these studies can contribute in many ways to helping the Canadian mining industry:

1) Help mining operators to know the many conditions and factors which can affect the design and stability of surface crown pillars.

2) Familiarize students with the problems associated with surface crown pillars.

3) Permit development of equipment and methods to define, monitor and/or control the conditions of these structures.

4) Serve as a reference for future studies.

The aim of this paper is to continue to provide the operators with the information and tools necessary to perform a safe and economical pillar design. More and more sources of information are being published in the field of surface crown pillars. Presently, there exist a few sources of information (3)(4) which have established the state of knowledge in this field. Bétournay's (3) integral design philosophy provides engineering based designs in a step-by-step progression.

Further governmental efforts are underway to provide the industry with working references.

SUMMARY OF CASE STUDIES

The summary is presented in three portions, representative of the main stages of surface crown pillar design: surface crown pillar characteristics, gathering of basic data and pillar creation.

Surface Crown Pillar Characteristics

21 of the 24 participating mines are located in the Canadian Shield, as are the majority of Canadian underground mines. There exist various characteristics which are apparently common to these mining environments, Table 1.

The deposit usually contains hangingwall/footwall of little competence and is covered by an important cap of overburden. The rock mass is often altered and intersected by important discontinuities. The predominating deposit form is narrow and steep dipping.

A surface crown pillar represents a rockmass of variable geometry, mineralized or not, situated above each uppermost stope of the mine and serves to permanently or temporarily ensure the stability of surface elements. A total of 132 surface crown pillars existed at the 24 mines studied. Of these, 10 (8%) were from single opening settings, 122 (92%) were from multiple opening settings, Figure 1.

Gathering of Basic Data

Table 2 shows the basic data collected by the mines and the extent to which it is examined.

Identification of general deposit condition, lines 1-4, is well covered by the mines. Geotechnical studies, with the purpose of identifying the detailed characteristics of rock and soils, are however, limited. The geological structure and soils are identified in a simple fashion. The hydrological properties of soils are obtained, but not the in-situ mechanical properties such as shear strength, compressive strength and modulus of elasticity. Few laboratory studies are made. Rock properties are also poorly covered; the only in-situ test made address natural stresses. No measure of modulus of elasticity and few permeability tests are done. The geological structure is usually identified, but it is rare that quality values, even stereographic plots, are obtained for each distinct area of the rock mass or the mass as a whole.

Lastly, perhaps because of a lack of data, the examination of basic data is almost non-existent. Few mine programs exist to specifically address the behaviour of the rock mass; only rarely is certain data graphically represented to help the design or potential problem evaluation.

Pillar Creation

Ideally, dimensioning a pillar consists of several parts: design based on scientific methods; removal of problem elements; rock mass strengthening; monitoring of openings. These are listed in table 3. Several mines preclude designs based on a scientific approach, preferring to use "experience". This was the case for 43% of the mines studied. Otherwise, 17% of the mines used numerical modelling, 35% used an empirical method such as rock mass classification, or mass rupture criteria, and 9% of the mines used analytical calculations.

A complete design requires that several different methods be used to obtain the perspectives required in comprehending surface crown pillar behaviour. Only 1 of 24 mines has used more than one method.

The thickness to width ratio, a non-scientific dimensioning approach, is often applied by operators to shape surface crown pillars. The value of this ratio, for the cases studied, fall in two well defined distributions, Figure 2. The first, containing ratio values of 0-5, includes 75% of the 132 pillars studied. The second, for values > 5, has 25% of the pillars. There are about 21 pillars in each of the 5 classes of the first distribution, 5 pillars in each of the 5 classes of the second distribution.

Figures 3-5 present a deeper analysis of this ratio. For this, the pillars have been separated into three groups: competent rock mass, moderately competent and poorly competent (This separation is based on RQD, empirical rock mass classification, structural geology problems and hangingwall/footwall problems described in the case studies. The contractor's evaluation (1)(2) and operator descriptions were also taken into consideration). The objective of this analysis was to establish the relationship between the thickness to width ratio used in various ground quality encountered. One conclusion is that beyond the total number of pillars in each group, there is little difference between the ratio used in the types of terrain: the ratio < 5 dominates for each type. It is also possible to see that there is no tendency to shift to higher ratios when going from competent to moderately competent to poorly competent ground.

On a qualitative basis, there are many more moderately competent surface crown pillar rock masses than competent or poorly competent ones.

As for support, in almost every case, as shown in Table 3, rock bolts are applied. Backfill is used in stopes where one or several problem elements occur. In certain cases, grout is used to render the mass impermeable.

Monitoring is performed in 62% of the cases, Table 3. Visual evaluation predominates; this is often paired with measuring instruments. In 32% of the cases, no monitoring nor backfill are used.

Operator Comments

When asked about surface crown pillar design, the personnel involved at these sites responded in a similar fashion.

Practical case study experience and rock property databanks are considered useful tools for addressing the stability of these structures. A step-by-step design with conservative preliminary approaches are preferred. The design factors seen as most important were: precise location of soil/rock contact, rock types, structural geology, geomechanical rock properties, mining method used, and the cost and timing involved in mining these structures.

The favoured future research efforts center around modelling of the opening and in-situ stress measurements at shallow depths.

CONCLUSIONS

The two Phases of case studies have shown that:

1) The deposits studied usually have high dipping hangingwall/footwall of poor competence and capped by an important thickness of overburden. The rock mass is often altered and intersected by important discontinuities. The deposit is usually single or multiple vein shape.

2) The design of pillars lacks basic data.

3) The design is based on experience rather than a scientific approach. Few design methods are used.

4) The surface crown pillars usually have a thickness to width ratio less than 5. This is true for the 132 pillars studied and for each group of a classification based on level of rock mass competence. It is also apparent that there is no tendency to create pillars with larger ratios when going from competent to poorly competent ground.

5) There are many more moderately competent surface crown pillar rock masses than competent or poorly competent ones.

6) The rock mass, in almost every case, is suported by rock bolts. Often, openings are neither monitored nor backfilled.

7) The 24 case studies show the uniqueness of each surface crown pillar and the need to create a specific design based on several different methods

8) Mine operating personnel consider basic data to be important in the design of surface crown pillars, but emphasize that more information should be available on the subject of surface crown pillar recovery in the context of the mining sequence.

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Table 1. Basic Characteristics of Surface Crown Pillars of Hard Rock Mines (1) (2)

MINE	1	2+	3+	4	5	6	7	8	9	10+	11	12	13	14	15	16	17	18+	19	20	21	22	23	24
Items																								
* BODY OF WATER (m)			3	(3)	-	-	-	7.6	-	( )	( )	-	20	-	-	-	-	-	11	-	-	-	13	-
* OVERBURDEN (m)	(8)	(7)	27	36	4	15	5	20	17	16	20	15	3	5	30	9	1.5	(2)	5	-	45		19	(9)
Substantial clay deposits			*	*				*	*		*	*		*								N/A	*	
* FORM OF THE DEPOSIT - tabular	*				*												*				*		*	
- single vein			*	*				*	*	*	*		*		*			*						
- multiple veins		*				*	*							*					*	*		*		
- mass												*				*								*
*Pronounced alterations	*			*	*			*						*			*		*		*		*	
*Walls of low competence	*	*	*		*			*					*	*	*	*			N/A	N/A	N/A	N/A	*	*
*Walls of high competence						*	*			*									N/A	N/A	N/A	N/A		
DIP (degrees)	70°	70°	65°	45°	72°	80°	80°	90°	45°	70°	80°	85°	45°	85°	75°	75°	33°	70°	70°	60°	50°	75°	30°	
IMPORTANT FAULT(S)		*	*	*		*		*	N/A	*	*	*	*		*	*		*	N/A	N/A	*	*	N/A	*
NUMBER OF WELL DEFINED JOINT FAMILIES	N/A	2	3	N/A	2	2	3	N/A	N/A	N/A	N/A	N/A	N/A	2	N/A	N/A	1	3	N/A	N/A		N/A	N/A	3
* MAIN MINING METHOD - stope and pillars																	*							
- shrinkage stoping					*	*	*		*													*		
- cut-and-fill			*					*					*						*		*		*	
- blasthole stoping	*	*		*						*		*		*	N/A	*		*		*				
* Surface installations on pillar(s)						*	*			*							*				*			

N/A not retrieved, or not available

() removed

(+) pillar(s) separating open pit from underground opening

\- not applicable

Table 2. Collection of basic data (1) (2)

DEPOSIT CHARACTERISTICS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
- deposit dimensions	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
- hanging/footwall conditions	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
- deposit condition	3	3	3	3	3	3	3	1	3	3	3	3	3	3	3	3	3	3	3	3	3	2	3	3
- structural geology elements	0	3	3	3	3	2	2	3	1	2	2	1	1	2	2	1	1	3	3	3	3	3	2	3
GEOTECHNICAL STUDIES																								
- in situ soil tests	–	–	2	2	1	1	1	2	1	1	2	1	1	1	1	1	1	2	2	2	3	1	1	–
- laboratory soil tests	–	–	3	3	0	0	0	2	0	0	1	2	0	1	1	0	0	3	2	2	3	0	0	–
- in situ rock tests	1	1	1	0	1	1	0	0	0	1	0	0	0	0	0	1	0	1	1	1	3	0	1	0
- laboratory rock tests	1	2	3	0	0	2	2	0	1	1	1	0	1	1	0	1	0	2	0	2	3	0	2	1
- ground quality	0	0	3	0	0	0	1	0	1	1	2	0	2	1	0	0	0	1	3	0	3	1	2	3
- structural geology	0	3	3	2	3	2	3	2	N/A	1	1	0	1	0	0	1	1	3	2	1	1	3	1	3
- hydrological	1	–	3	0	2	0	2	1	2	2	2	2	1	1	2	1	1	3	2	2	3	0	0	1
DATA ANALYSIS																								
- configuration of elements	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	2	–	0	0	3
- rock mass strength	0	1	2	0	0	1	0	0	2	0	1	0	0	0	0	0	0	2	0	2	3	0	3	0
- failure mode	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	2	3	0	3	2
- data representations	0	1	2	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	2	2	3	2	3	2

- not applicable
0 no study
1 limited study
2 in-depth study
3 complete study
N/A not retrieved, or not available

Table 3. Dimensioning of pillar(s) (1) (2)

DIMENSIONING METHOD	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
- elastic analytical calculation	3	0	0	0	0	0	0	0	0	0	0	0	0	0	-	0	0	0	0	0	0	0	0	-
- plastic analytical calculation	0	0	0	0	0	0	0	0	0	1	0	0	0	0	-	0	0	0	0	0	0	0	0	-
- numerical modelling	0	0	3	0	0	0	0	0	0	0	0	0	0	0	-	0	0	0	0	3	3	0	3	-
- probabilistic	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	0	0	0	0	0	0	0	0	-
- empirical	0	0	0	0	0	1	0	0	1	0	1	0	1	0	-	0	0	3	3	0	3	0	0	3
* REMOVAL OF PROBLEM ELEMENT																								
- drainage	-	-	-	*	-	-	-		-	*	*	-		-	-	-	-	-		-	-	-	-	-
- overburden		*																*						*
MONITORING																								
- visual	3	0	1	1	1	0	0	0	0	0	0	0	2	1	0	1	0	N/A	3	2	3	2	3	3
- instruments	2	0	0	0	0	0	0	0	0	1	0	1	0	2	0	0	0	3	2	2	3	2	3	3
* REINFORCEMENT																								
- grout injection								*				*							*					
- backfill		*	*					*	*		*	*	*	*	N/A	*		*	*	*	*		*	
- bolting		*	*		*	N/A		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*

- Not applicable
0 no study
1 limited study
2 in-depth study
3 complete study
N/A not available; not retrieved

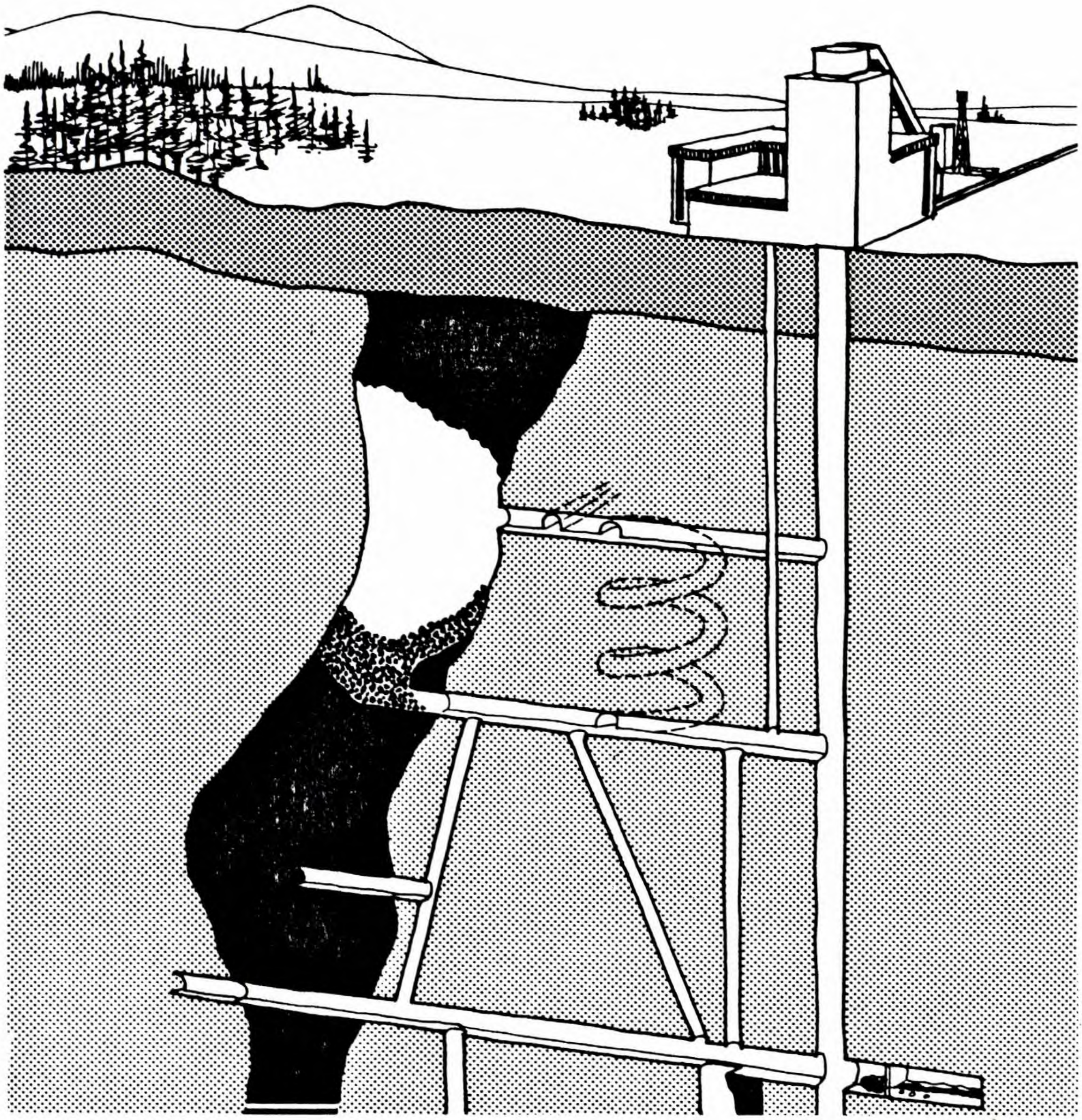

Figure 1a). - Surface crown pillar over a single opening (1).

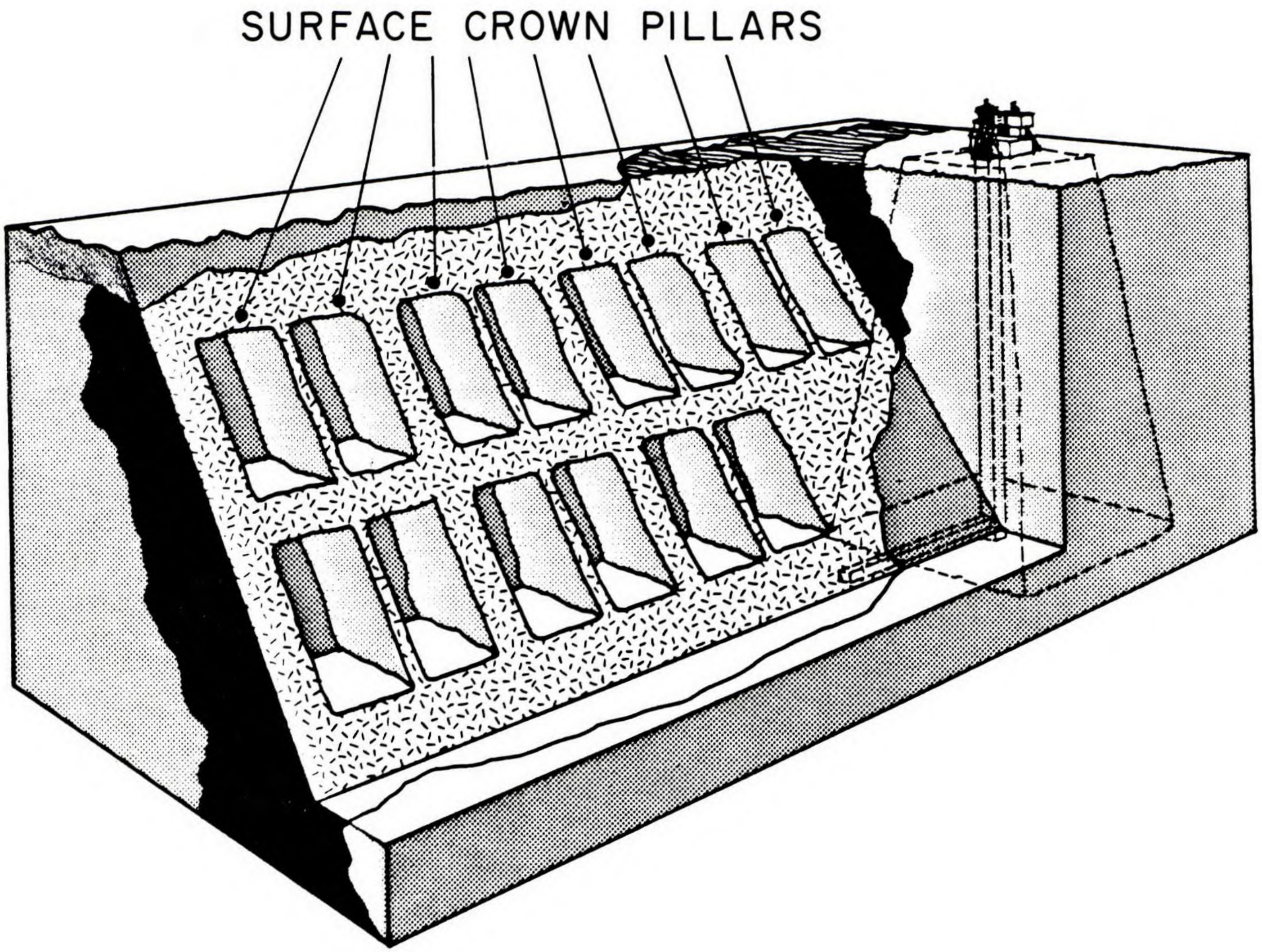

Figure 1b). - Surface crown pillars over multiple openings (1).

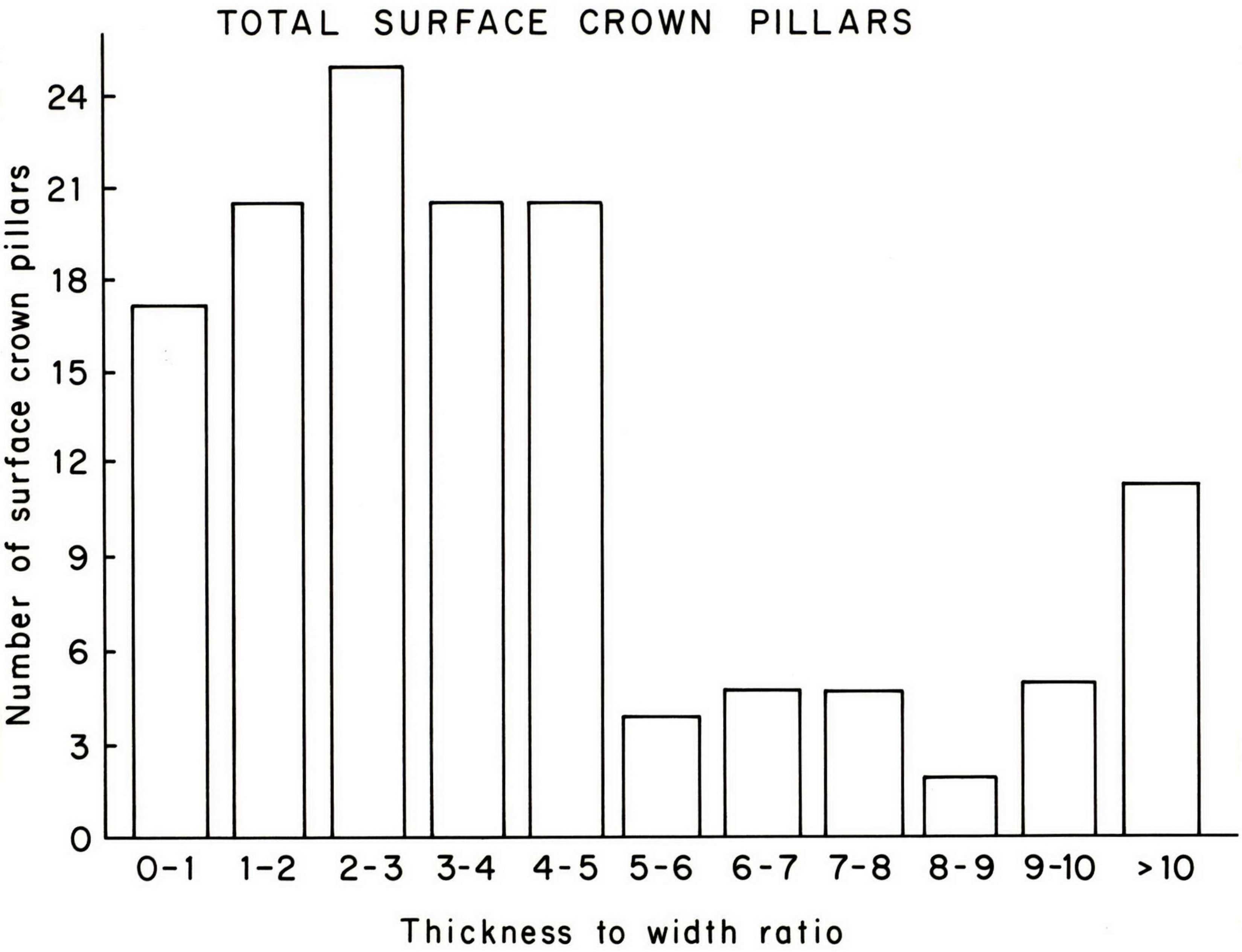

Figure 2. - Surface crown pillars: Thickness/width ratio, 132 pillars (1)(2).

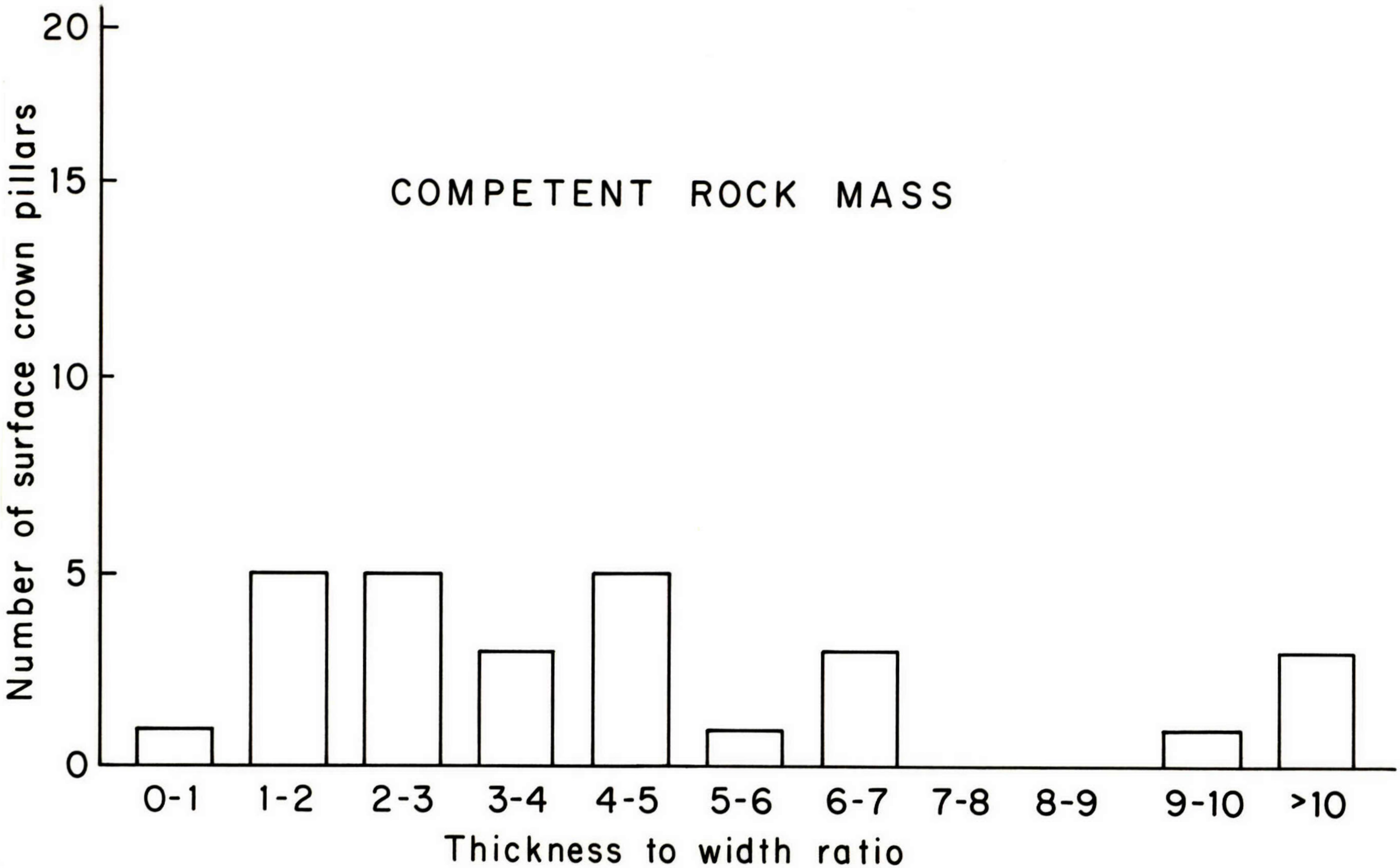

Figure 3. - Surface crown pillars: Thickness/width ratio, competent rock mass, 27 pillars (1)(2).

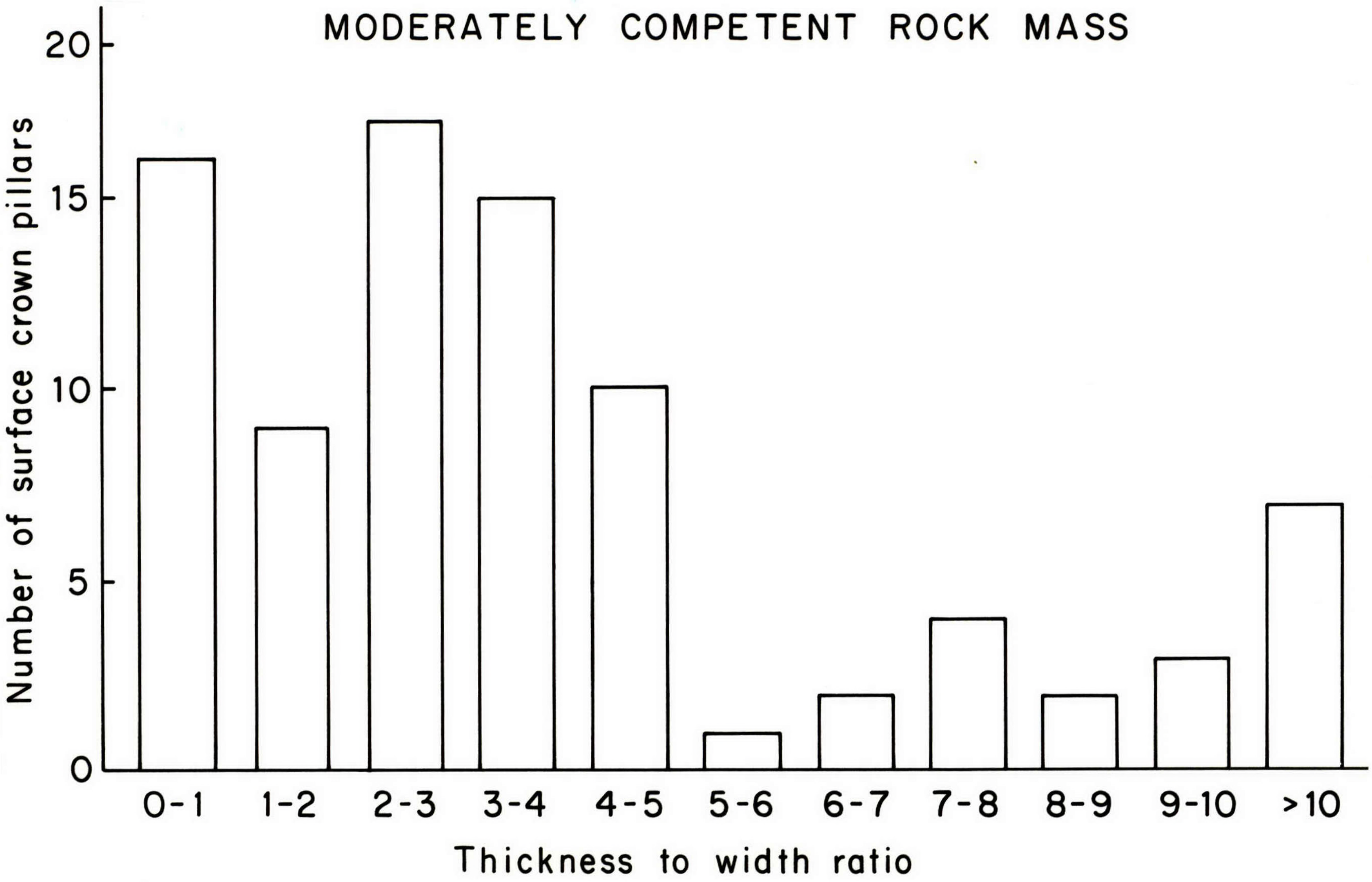

Figure 4. - Surface crown pillars: Thickness/width ratio, moderately competent rock mass, 86 pillars (1)(2).

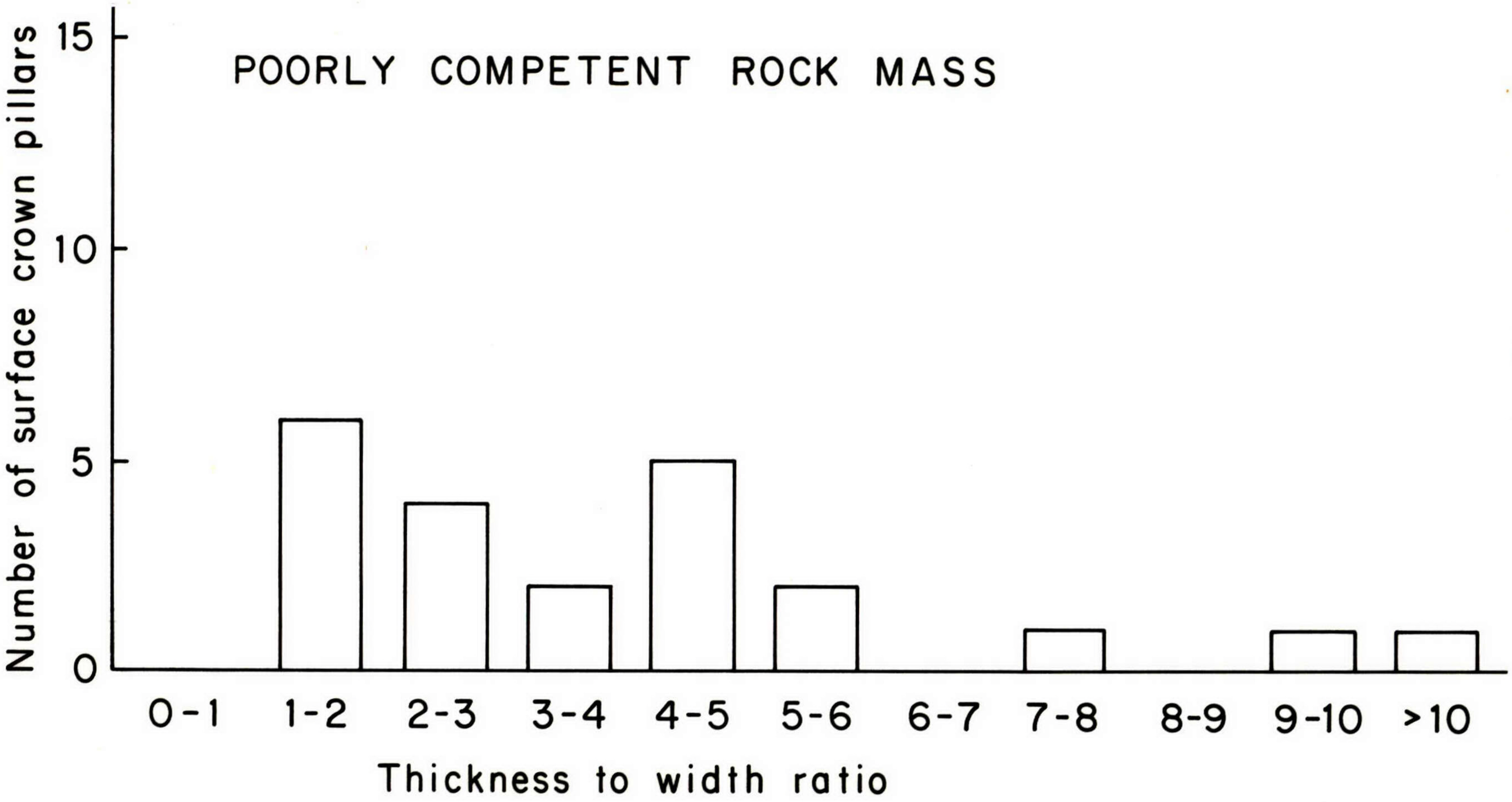

Figure 5. - Surface crown pillars: Thickness/width ratio, poorly competent rock mass, 19 pillars (1)(2).