AN APPRAISAL OF THE PILLAR SUPPORT SYSTEM AT THE ST. HELENA GOLD MINE

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DECLARATION

I declare that the dissertation is all my own work and that it has not been submitted for a higher degree at another university.

Assistance was given by the C.S.I.R. in the laboratory work necessary for the derivation of Figures 21 and 22.

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INTRODUCTION:

St. Helena Gold Mines, Limited, commenced operations in 1948, and subsequently became the first mine in the Orange Free State Gold Field to produce gold from the Basal reef horizon.

Development of the Basal reef started from several shafts sunk to the sub-outcrop on the Southern edge of the property. Initially, all development was barren, either due to heavy faulting or unpayable reef exposure. When the drives exposed payable values, raises were developed at 70 ft. intervals in order to exploit the payable area rapidly and stoping commenced from these raises in 1950. Once a satisfactory production rate had been achieved, a standardized raise interval of 580 ft. was adopted.

Difficult hangingwall conditions were experienced in several of the early stopes, and eventually complete hangingwall collapse occurred. As a result of the collapses, Management decided on the pillar system of mining which is still in use today. This system consists of internal stope pillars and drive pillars and has resulted in good hangingwall conditions as the mine has spread out on strike and increased in depth. In addition no support has been required in the drives, except in areas with geologically weak strata.

Since most of the internal stope pillars are of payable reef they are removed in the sweeping stage of mining. The removal of the internal stope pillars, even at depth, has proved to be safe, and the few falls of ground that have occurred have not seriously affected mining operations. No rock bursts have occurred, either whilst stoping, or during pillar removal. However, the full effect of mining out drive pillars at depths exceeding 2,000 ft. below surface is still unknown.

The pillar system has apparently been successful in maintaining good hanging wall conditions throughout the mine, but two main

questions / ......

questions arise:-

1. Whether the extraction of drive pillars at the present mining depth of 5,000 ft. will result in rock bursts.
2. Whether the pillar system should be changed as the depth of mining increases to 6,500 ft.

Other mines operating at depths exceeding 6,000 ft. have found that pillar mining is associated with a higher rock burst incidence.

2. THE GEOLOGY AND MINING METHOD AT ST. HELENA GOLD MINES, LIMITED

St. Helena Gold Mine is situated two miles to the south-west of the town of Welkom and is one of the ten gold mines operating in the Orange Free State gold fields. Its mining lease extends from the southern sub-outcrop of the Basal reef and is bounded on the north side by Free State Geduld Gold Mine and on the east by President Brand and Welkom Gold mines. As the Basal reef is the only really economic gold bearing ore body in the Orange Free State gold field, most of the mining at St. Helena is done in this stratum. A plan of St. Helena Gold Mine and its boundaries, is shown in FIG. 1.

2.1 Geology:

The general geological section across the mine is shown in FIG. 2. A considerable thickness of fine grained footwall quartzites occurs below the Basal Reef horizon. The Main, Bird and Kimberley series above the Basal reef is about 200 ft. thick and contains the Leader reef horizon, which is payable in some areas on the mine. Above the Kimberley series lies 1,500 ft. of the Elsburg series and up to 3,300 ft. of Ventersdorp lava. These beds reduce in thickness considerably towards the sub-outcrop, where approximately 800 ft. of Karroo sediments rest unconformably upon the Basal reef sediments. The Basal reef dips from the sub-outcrop at about 25° in a north-easterly direction, and eventually reaches a depth of 5,500 ft. at the Dagbreek fault, which throws it up about 2,100 ft. In fact, the mine is divided into four distinct zones as a result of faulting and folding, as shown in FIG. 2.

The first zone is a basin whose structure has been determined mainly by surface and underground drilling. It extends to the south-west of the present mine workings. These workings on the northern limb of the basin show that the dip of the strata is steep and becomes vertical in places.

The second zone is bounded by the Basal reef sub-outcrop on its south western edge and by the 8-12 Fault on its eastern side.

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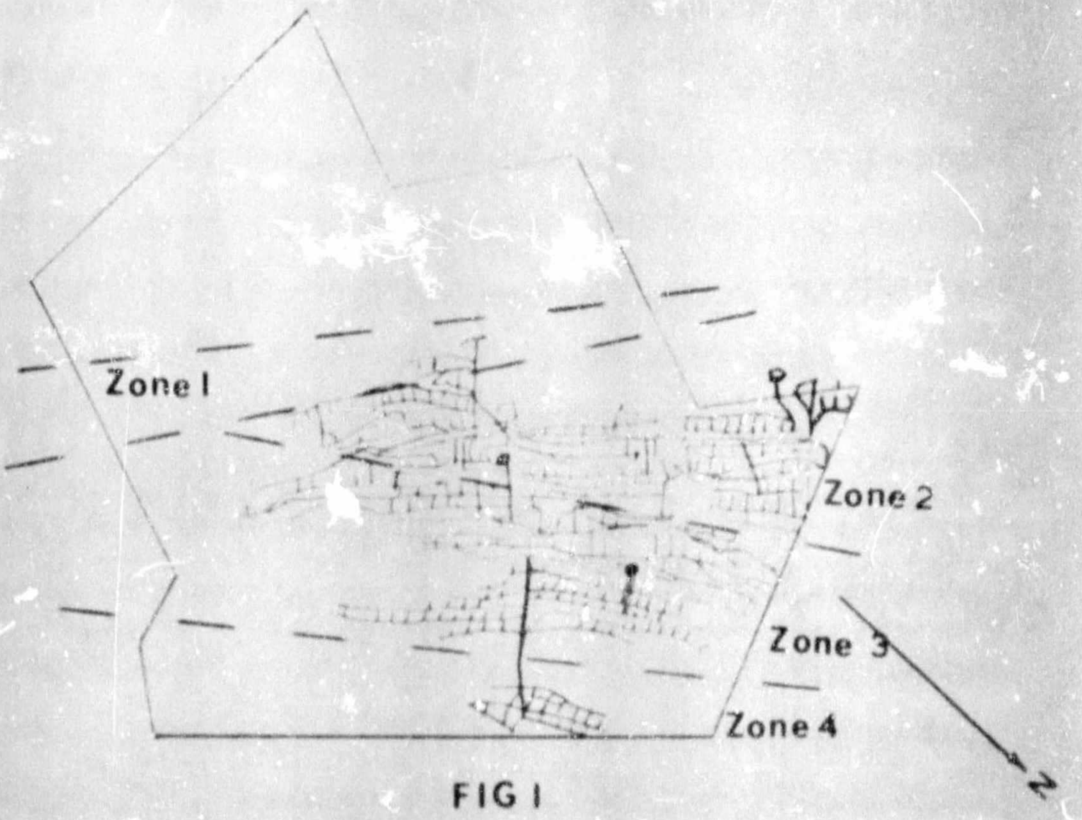

FIG I

St. Helena Gold Mines Ltd.

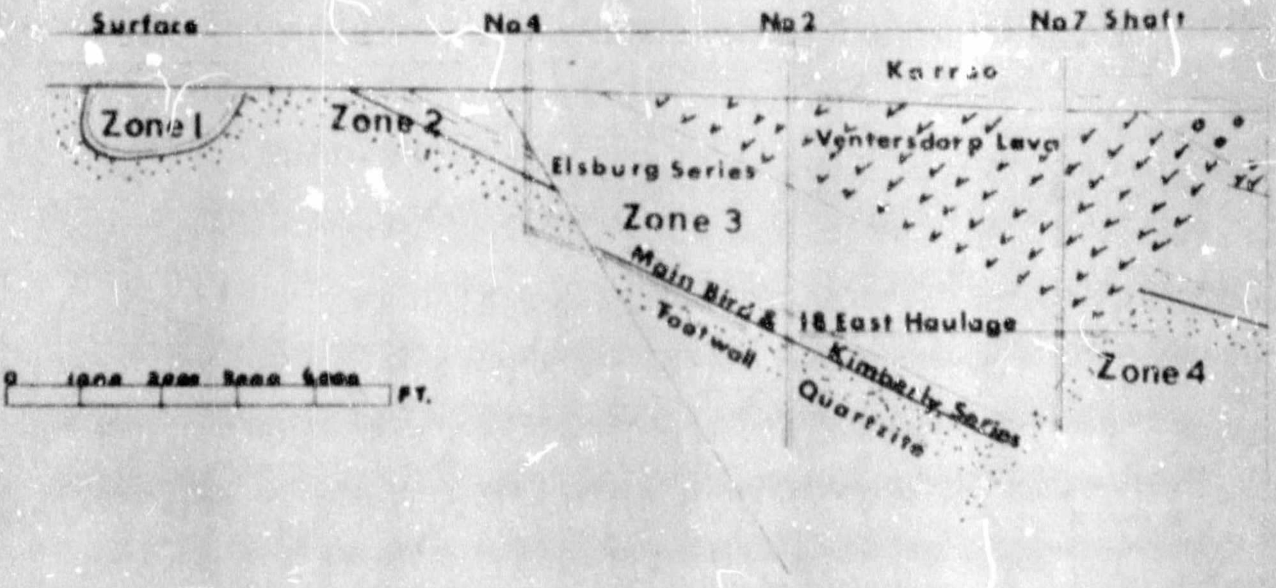

FIG 2

Generalised Section Looking North

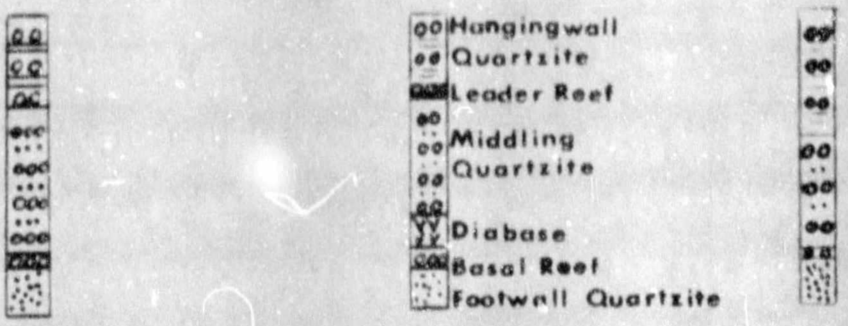

FIG 3

[illegible] Stope Sections

This zone contains the oldest workings at No. 4 Shaft. The dip of the Basal reef varies from 10° to 40°.

The third zone is bounded by the 8 - 12 Fault on the reef's up-dip side and by the V.10 Fault on the down-dip side. Access to the workings is through No. 2 Shaft. In this zone the dip of the reef is almost constant at 25° down to the V.10 Fault contact at a depth of 5,500 ft.

The fourth zone extends from V.10 Fault up to the boundary of the President Brand Gold Mine. It is served from No. 2 Shaft by a high speed haulage on 18 Level. The reef dips at about 20° in this zone.

Stoping at St. Helena commenced in zone 2 near the sub-outcrop and the geology of the hangingwall strata at three of the stopes that collapsed in this zone is shown in FIG. 3. No unusual geological conditions, except possibly the diabase sill in 424 Stope, can be found to account for the collapse of the hangingwall. The hangingwall of stopes mined subsequently in zone 2 and in other zones has been similar geologically to the sections shown.

2.2 Mine Layout:

St. Helena is the only gold mine in the Orange Free State goldfields laid out on a system using strike tracks, reef drives and pillars. These methods were designed for mining an ore body anticipated to contain erratically varying zones of payable ore. Selected mining is not considered necessary on the other nearby mines. At these mines ore removal is done by face and strike scrapers in conjunction with footwall haulages. The stopes are supported with mat-packs and stone walls, but no stope pillar support is used.

The reef drives at St. Helena are 10 ft. wide by 8 ft. high and differ in elevation by 225 ft. To accommodate locomotives for tramming, drives at fault intersections are cut with 200 ft. radii curves. The drives are protected by reef pillars 80 ft. in width above the drive and 60 ft. in width below the drive. Raises between drives are approximately 580 ft. apart and stoping is carried out as required from payable raise connections.

Production commences by ledging from the raises to create a 72 ft. long stope face on one side of the raise, starting just above the drive pillar. The second stope face of 72 ft. starts above the first and on the opposite side of the raise. The 72 ft. panels are advanced on strike for a distance of 20 ft. and then stopped for the installation of the stope tracks. Ledging of the panels opposite these faces is then commenced and the procedure repeated until the whole raise is ledged. Strike tracks operate from the face to the original raise at 24 ft. intervals on dip. The broken ore is loaded into ¼-ton end tipping cars at the face and tipped into the original raise from where it is scraped by a 30/60 h.p. winch to the stope ore pass. After the ledging and equipping of the stope, the face is cut to 20° overhand, and thereafter mining proceeds normally, until a maximum strike span of 570 ft. is reached.

2.3 Underground Support:

The standard support system used on the mine before hangingwall collapse was experienced, was 2 ft. matpacks, installed at 12 ft. centres on dip and strike, with [illegible] pack units 12 ft. by 12 ft. in area built between the "squares" [illegible] matpacks. This method was based on East Rand practice. To protect the centre gully a double row of 2 ft. 8 ins. matpacks was installed at a maximum distance of 7 ft. from the centre line of the gully.

The severe falls of hangingwall indicated the need for additional support which was provided by leaving solid reef pillars 15 ft. long on strike and 18 ft. wide on dip at about 90 ft. centres diagonally. The size of these pillars was determined largely by the track spacing and the distance apart of the pillars was taken as half the minimum span at which the severe falls had occurred. Subsequent experience has shown that, due to selective mining, it is expedient to leave an unpay pillar as a support pillar if close enough to the required position; if not, the pillar is left as additional support.

Pillars of irregular shape are also left when negotiating faults or re-raising after local falls of hangingwall have occurred.

Drive pillars were left on a standard size of 80 ft. wide above the drive and 60 ft. wide below the drive to provide drive pillar protection and ventilation control. The sizes chosen for these pillars were also based on previous experience on the East Rand. In addition to the support pillars left on a standard pattern, areas of unpayable reef and losses of ground associated with large faults also have an influence on the general strata stability.

The internal pattern of support is upset at the sweeping stage when payable pillars are removed. The small internal pillars have been removed over large areas of the mine, but mainly at depths of less than 4,000 ft., with no more serious consequences than local falls of hangingwall. Drive pillar removal has been limited in extent, but experience at 4,000 ft. indicates that timber square sets or steel arches installed in the drive, provide sufficient support for safe removal.

2.4 Uncertainties in the use of Pillar Supports:

The use of pillars as stope support has, apparently, prevented major falls of hangingwall from occurring. However, the removal of the internal stope pillars at the sweeping stage does not affect hangingwall stability. This suggests that as the stope excavation increases a re-distribution of forces occurs, and the intradosal ground is carried at abutments other than the pillars. The original pillar support system has now been in use from depths of 500 ft. to 5,000 ft. and complete collapse of the stope hangingwall has never re-occurred. However, it is generally assumed that stresses are related to depth, and a change in the pillar pattern may now be necessary.

Experience on other mines, particularly at depths greater than those on St. Helena, has shown that rock bursts are associated with pillar mining. This experience, although obtained under different methods of mining and geological conditions, indicates that a study of pillar mining and removal, is important on St. Helena Mine.

Furthermore, / ......

Furthermore, a theoretical study of the extension of the present mining method to greater depths is imperative.

The questions concerning the behaviour of stope pillars and their effect on strata movement, have lead to the institution of the present research programme. In this programme, an explanation of pillar behaviour will be attempted by using general theories of rock mechanics in conjunction with laboratory and underground tests.

3. THE BEHAVIOUR OF THE ROCK MASS AROUND A MINING EXCAVATION

Experiments on the Harmony Mine in the Orange Free State gold fields have shown that the behaviour of the rock mass around an underground haulage in virgin ground is elastic[1]. Many samples of St. Helena quartzites tested in the laboratory have proved to be elastic. Therefore the theory of elasticity has been used in this chapter to calculate stresses and displacements to a first approximation around a small excavation in virgin ground on St. Helena Mine.

However, on St. Helena, as on any mine, it can be seen that as a small excavation increases in size, rock fracture occurs and a fracture zone develops. There is an indirect relationship between the size of this zone, the size of the excavation and the depth below surface. When dealing with rock fragments the theory of elasticity does not apply, but approximate results can be obtained using the theory of the Voussoir Arch and Soil Mechanics. Beyond the fracture zone the strata is still considered to be elastic. The theory of elasticity can be used to estimate the size and shape of the fracture zone if the stress condition at the boundary of the zone is known.

This section will be devoted to the application of the theory of elasticity, and other theories, to the problem of stress and displacement around a typical St. Helena mining excavation.

3.1 Rock as an Elastic Medium:

Main development drives and raises on St. Helena are nearly square in cross-section and are developed in virgin ground. The tangential stress contours around an opening of square cross-section in a biaxial stress field[2] are shown in FIG. 4. The value 'k' is the ratio of the vertical stress to the horizontal stress.

Underground measurements have shown that the value 'k' lies between 0.1 and 0.33. The theoretical model can be applied to an underground drive or raise by assuming that the vertical applied

stress / ......

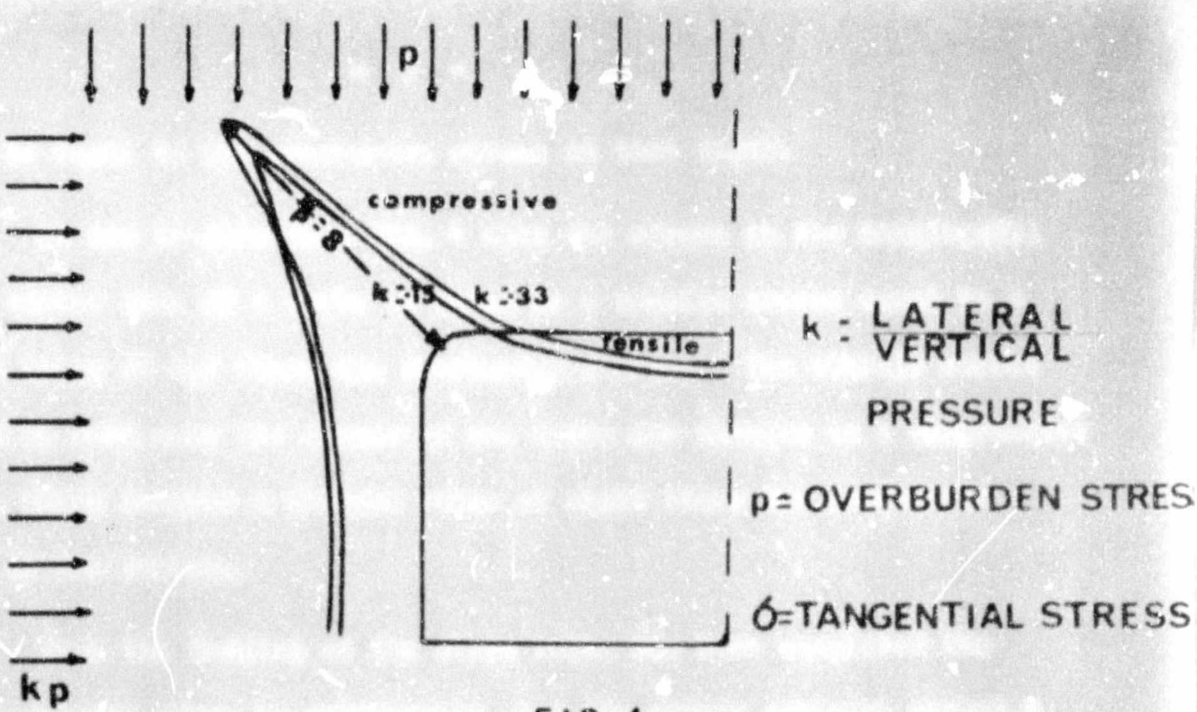

FIG 4

Stress Distribution around a Square Opening
In a Biaxial Stress Field

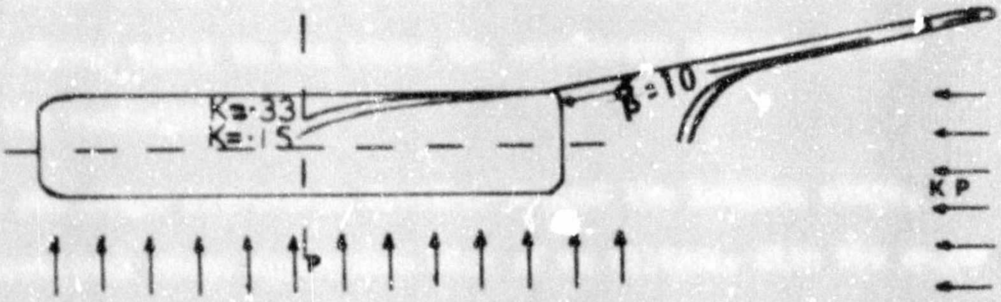

FIG 5

Stress Distribution around a Rectangular Opening

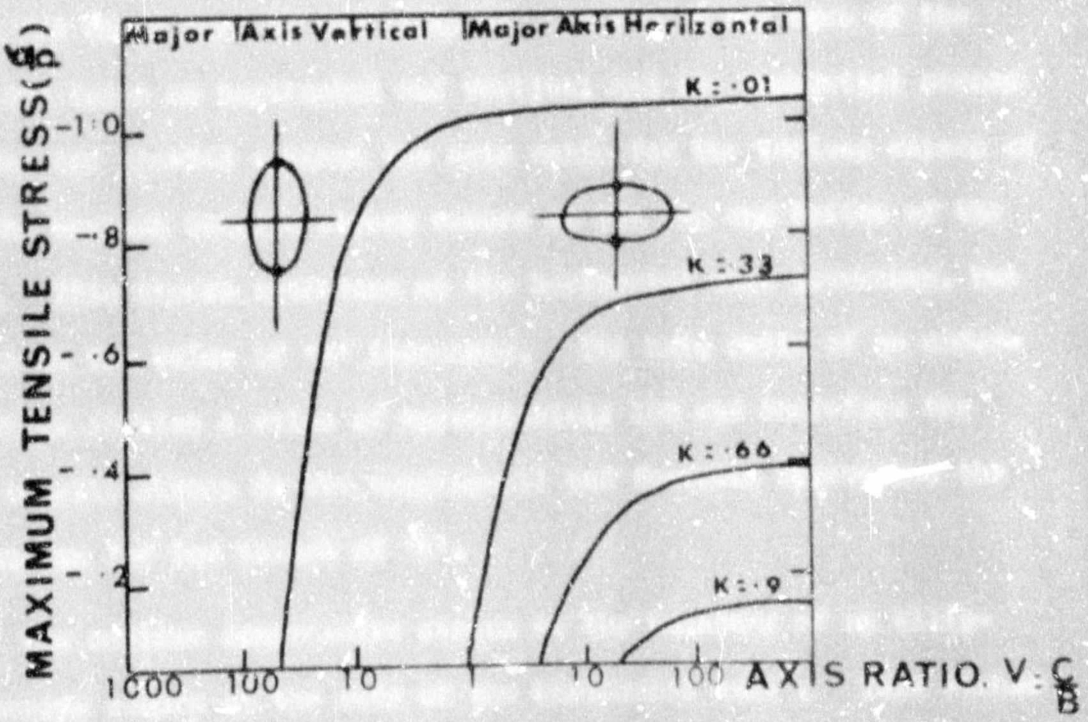

FIG 6

Maximum Tensile Stress at the Boundary
of an Elliptical Opening

stress is equal to the overburden stress at that depth.

It can be seen from FIG. 4 that the stress in the hangingwall on the centre line of a drive or raise is a tensile stress equal to a maximum value of 0.[illegible] times the overburden stress. The tensile stress reduced to zero [illegible] corners of the drive and changes to a compressive stress, which re[illegible] a maximum value of eight times the overburden stress at the corner.

When the ledging of the stope raise has been completed the cross-sectional shape is rectangular, and the stress contours around a rectangular opening in a biaxial stress field[2] are shown in FIG. 5. The stress magnitudes are similar to those for the square section. The stress changes in sign from a maximum tensile stress equal to the overburden stress at the centre point of the hangingwall, to a maximum compressive stress equal to ten times the overburden stress, at the corners of the rectangle.

As the stope excavation develops beyond the ledging stage, the cross-sectional shape approaches that of an ellipse, with the major axis horizontal. The tangential stress around an elliptical opening depends on the ratio of the principal stresses, the orientation of the ellipse with respect to the applied stress field, and the ratio of the major to the minor axes of the ellipse. In FIG. 6 the axes of the ellipse are taken as horizontal and vertical and the tangential stress magnitudes are plotted against the axis ratio for the various values of 'k'. The maximum tensile stress occurs at the top and bottom of the opening. This stress increases as the horizontal axis increases, but decreases as the value of 'k' increases. The axis ratio of an underground stope attains a value of approximately 150 and therefore the maximum tensile stress in the hangingwall and footwall approaches the virgin stress for low values of 'k'.

The maximum compressive stress at the boundary of an elliptical opening occurs at the ends of the horizontal axis[2]. This stress increases with the flatness of the ellipse, if the major axis of the ellipse is horizontal, the effect of 'k' is negligible. Furthermore,

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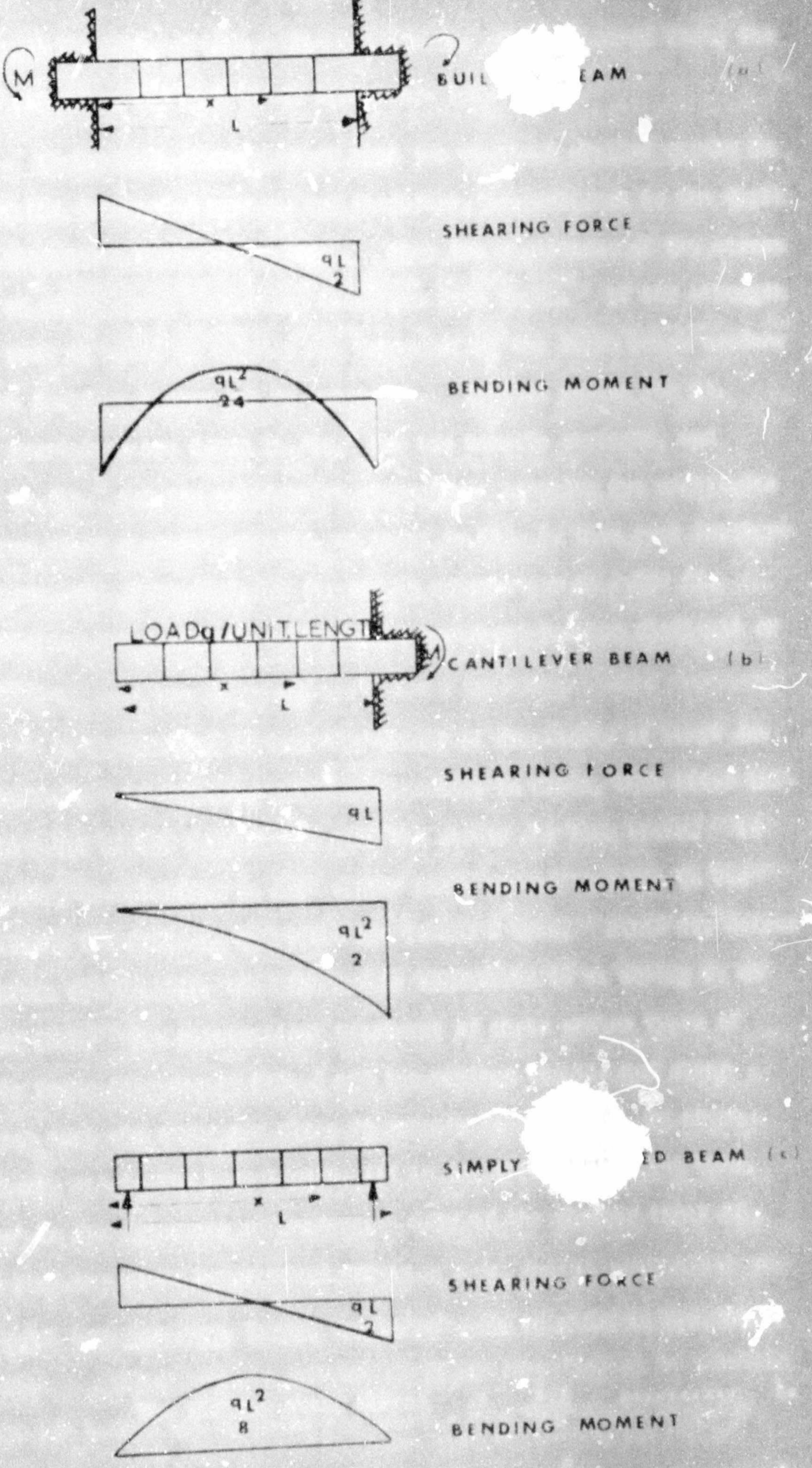

FIG 8

Uniformly Loaded Elastic Beams
Diagrams of Shearing Force and Bending Moment

the maximum compressive stress attains a value of one hundred times the applied stress as the axis ratio approaches 150.

It has been assumed above that the vertical applied stress is equal to the overburden stress, and therefore, proportional to the depth of the excavation below the surface. Thus the magnitudes of the stress around an underground excavation increases with depth. If the strength of the rock is known in tension and compression, the depth below surface at which fracture occurs can be estimated. Typical values for St. Helena quartzites are 2,000 lb./in.^{2} for the tensile strength, and 30,000 lb./in.^{2} for the compressive strength. Assuming the magnitudes of stress round a square opening, as shown in FIG. 4, then rock fracture in tension will occur at 1,800 ft. and in compression at 2,600 ft. Once fracture has occurred, mathematical treatment becomes difficult or impossible.

It is possible to take the theory of elasticity at least one step further. It has been observed generally in mines, that after initial fracture of the hangingwall mass the strata may form beams. In particular, observations in 2324 centre gully showed that due to bed separation, the middling quartzite had formed a beam. Since St. Helena quartzites are elastic, the beam may be considered to be acting as an elastic beam. The mathematical treatment of three common types of elastic beams is given in FIG. 8 and the maximum tensile and shear stresses that can occur are given in summary form below. In these equations, 'L' is the beam length, 't' is the thickness of the beam, and 'q' is the intensity of loading. Some of the various types of beams that may occur underground are :-

(a) The uniformly loaded "built-in" beam is shown in FIG. 8(a).

The maximum shear stress $= \frac{3qL}{4t}$ .... 1.

The maximum tensile stress $= \frac{qL^2}{2t^2}$ .... 2.

(b) / .....

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