Although driveways (Figure 16/A2) from the surface to the worked seam are usually only responsible for small scale subsidence, they still should be accounted for in terms of design of overlying foundations, and, if open are a serious danger to the inquisitive public.

Most driveways were filled, however, this was largely restricted by high water levels when this was carried out. In all, ten drives were located in the Kamo area, four from the Ruatangata Mine and six from the New Kamo Mine (Figure 1, 16/A2).

**NO. 1 DRIVE:** New Kamo Mine (Figure 16/A2, 29)

**SIZE:** 2.1 metres high, 1.8 metres wide (7' x 6')

**GRADIENT:** 1:5 (11.3°)

Little is known about the present condition of the driveway or the nature of its fill, if any is present. The precise location of the driveway was not able to be determined, as the area has been covered through the leveling of an adjacent slag heap.

**NO. 2 DRIVE:** New Kamo Mine (Figure 16/A2, 29)

**SIZE:** 2.1 metres high, 1.8 metres wide (7' x 6')

**GRADIENT:** 1:6 (9.5°)

**NATURE OF FILL:** A wooden stopping was constructed 20 metres down the driveway, after which, backfilling was completed with clay and loose mine refuse.

**PRESENT STATE:** When the mine flooded No. 2 drive acted as an overflow to the below workings and water can still be found seeping out of its portal. Thus the surface is connected to the below workings with water making its way through the stopping and fill.

**NO. 3 DRIVE:** New Kamo Mine (Figure 16/A2, 29)

**SIZE:** 2.1 metres high, 2.7 metres wide (7' x 9')

**GRADIENT:** 1:3 (18.4°)

**NATURE OF FILL:** A wooden stopping was constructed 20 metres down the driveway, after which, backfilling was completed with clay and mine refuse.

**PRESENT STATE:** Subsidence has occurred along the first 15 metres of the driveway, and presently forms the course of a small stream. The concrete heading can still be found.

**NO. 4 DRIVE:** New Kamo Mine (Figure 16/A2, 29)

**SIZE:** 2.1 metre high, 1.8 metres wide (7' x 6')

**GRADIENT:** 1:6 (9.5°)

While the mine was still in operation, the drive collapsed approximately 30 metres from the surface.

**NO. 5 DRIVE:** New Kamo Mine (Figure 16/A2, 29)

**SIZE:** 1.8 metres high, 2.1 metres wide (6' x 7')

**GRADIENT:** 1:5 (11.3°) for the first 91 metres then 1:3 (18.4°) for remainder.

**NATURE OF FILL:** A concrete stopping was constructed 20 metres down the driveway, after which, backfilling was completed with clay and loose mine refuse.

**PRESENT STATE:** A concrete heading can still be found at the surface (Figure 26). There is presently no sign of subsidence on the surface beyond the heading above the drive.
Figure 26: Mr H.C. Fennell standing at the mouth of No. 5, New Kamo Mine, (W.C.C. January 1980).

NO. 6 DRIVE: New Kamo Mine (Figure 15/A2, 29)
SIZE: 2.1 metres high, 2.1 metres wide
GRADIENT: 1:3 (18.4°)
NATURE OF FILL: A wooden stopping was constructed 20 metres down the driveway, after which, backfilling was completed with clay and loose mine refuse.
PRESENT STATE: The concrete heading can still be found in a low lying swampy area 20 metres east of the railway track as shown in Figure 27. The heading has been reblocked since the mine closed to stop people entering the drive.

NO. 7 DRIVE: Ruatangata Mine (Figure 15/A2).
SIZE: 2.1 metres high, 1.8 metres wide (7' x 6')

Little is known about this driveway as no mine plans found provided proper coverage of the area. According to Mr R. Cunningham, a house has been built at the driveway entrance.

NO. 8, 9, 10 DRIVES:

Accurate location of these was also inhibited through lack of mine plans for the area, however the present manager of the Kamo Refractories recollects that a number of these drives have been filled in.
Figure 27: Present Landuse of area surrounding Driveways, New Kamo Mine.
RECOMMENDATIONS FOR TREATMENT OF DRIVES

Many of the stoppings built in the drives are wooden and are thus prone to decay with time. With the breakdown of these barriers, saturation will occur causing it to plow into the mine workings causing voids to develop in the filled drive section.

The fill material consists of poorly compacted clays and loose fill from slag heaps providing only limited competency in terms of structural support.

At present any subsidence associated with the drives of the new Kamo mine provide little danger as the area is largely covered in scrub (Fig 27). However, a proposed by-pass has been planned through the area travelling over a number of drives (Fig 28/A2). These drives would have to be made safe before construction of the by-pass proceeded. This would involve the location of any voids within the driveway through drilling geophysical methods and then filling with peagravel and grouted.

Regarding drives 8, 9 and 10 in the Kamo Refractories property, if any further construction is to be planned within the area of the plotted drives, they should be accurately located and treated accordingly.

No. 6 drive entrance has been re-blocked since the closedown of the mine to stop people entering the drive. On visiting No. 6 drive portal showed that attempts have been made to break down the block wall. If these attempts were successful, it could prove fatal to the unwary wanderer through suffocation caused by the presence of heavy mine gases. The mouth of No. 6 drive should be made secure to stop such an event occurring.
the first where there is collapse of the pillars causing total collapse of
the roof and the second, the collapse of the roof between the pillars with-
out deformation of the pillars.

When the parameters of the pillars are applied to the collapse of workings,
a number of observations can be made providing a powerful tool for susisence
prediction. Some research has been carried out in this area and an attempt
has been made to review this work.

The first observation noted is by Wardell and Wood (1965) who stated that if
the spanning beam of rock between pillars is going to remain self supporting
to the overlying strata, then, the width of span between pillars has to be
less than one fifth the depth of overburden.

![Figure 30: Calculated Stability for Spanning Beam: Wardell and Wood (1965)]

Taking the pillar width into account Orchard (1964) noted that for the stability
of pillars to be ensured, the ratio of pillar width to pillar depth has to be
greater than 0.1:

\[
\frac{\text{Pillar Width}}{\text{Pillar Depth}} > 0.1
\]

In general, with time, depending on the nature of the above strata collapse
occurs in the spanning beam (Figure 31(i)).

![Figure 31(i): Extension of Roof Failure to Ground Surface as Subsidence]
This leads to the upward migration of voids. The height at which these can extend is restricted to the de-stressed strata zone (Figure 31(i)) limited by the maximum pressure arch or dome which is formed by the redistribution of forces after mining (Figure 31(ii)).

The height of final void migration, thus the height of the maximum pressure arch is useful in the prediction of this type of collapse and has been calculated by Ackenheil and Doughery (1970) as twice the distance between the supporting pillars.

Developing this further, is the volumetric increase that occurs with the collapse of the competent material. This gives an estimation of height at which the increase in volume (decrease in density) of the fallen material in comparison to its competent counterpart may infill the void and developing arch. This has been developed by Tincklin (1956) who described this phenomenon with the expression:

$$H = \ell \left[ \frac{\delta_r}{\delta} \right] \frac{1}{1 - \frac{\gamma}{\delta}}$$

where $H =$ total height of collapse
$\ell =$ thickness of the seam (height of roadway)
$\delta_r =$ bulk density of collapsed roof materials
$\gamma =$ bulk density of roof rocks.

He found that an average $H$ was in the order of 8t.
Many of the previously cited observations can be applied to the Kamo Mines. The mines can be divided up into two general conditions. The first areas, which have been developed with roadways leaving pillars of coal such as the greater part of the Kamo mine. The second, where these pillars have been 'robbed' of coal usually leaving the roof to collapse. Such is the case with the Ruatangata Mine and much of Harrisons Mine.

1. Wardell and Wood (1965)

"... noted that as a rule when the width of span is less than one fifth the depth of overburden, then it will remain self-supporting" (Bell 1975).

This can only be applied to "shallow" workings, as, then must exist a limiting depth share 'D' must be less than a smaller fraction of the overburden in order to maintain stability.

a) New Kamo Mine (Appendix 2)

As overburden ranges from 60-310 metres, the mine does not qualify as 'shallow' workings.

b) Kamo Mine

The average spanning width as indicated by old mine plans are well within the soft supporting range.

c) Ruatangata Mine

Much of the Ruatangata Mine has been worked out with its pillars being robbed. No record was made of the size of the pillars that were left in the mine.

d) Harrisons Mine

As overburden ranges from 60-90 metres, the mine does not qualify as "shallow" workings.

2. Orchard (1964)

"... suggested that, stability can be ensured if the pillars width to depth ratio is more than 0.1" (Bell 1975).

Orchard assumes that the mine consists of a laterally 'continuous' network of roadways intersecting at 90° to each other leaving pillars of approximately the same size.

a) New Kamo Mine (Appendix 3)

The new Kamo Mine does not strictly apply to the conditions above as large blocks of coal (Fig 14) were left undeveloped within the mines limits to ensure stability.

b) Kamo Mine (Fig 34)

As shown by the graph, the pillars are unstable where there is greater than 42 metres of overburden.

c) Ruatangata Mine and Harrisons Mine

As mentioned previously, the dimensions of the majority of remaining pillars are not known.

3. Tincelin (1958)

As Tincelin's equation solely deals with overall volumetric change, it is not necessary to know pillar width and spanning widths, thus enabling application over the whole Kamo Area. The Ruatangata Sandstone overlies the coal measures
in all areas, so the relative densities of collapsed and competent materials were able to be measured (Appendix 4).

It was found that for varying conditions that might occur in the mine, if one seam was worked \((t = 2.1\text{ metres})\), the collapsed height could extend to 15.02 metres and if both seams were worked \((t = 4.2\text{ metres})\), this could increase to 30.04 metres. These results are very compatible to Tinccline estimate of 6t for sandstone from 'average' coal measures.

One other limiting factor in the region to the height of collapse is the thickness of the Ruatangata Sandstone. This ranges from 15.9 - 64.9 metres (Table 1), so it is possible, that during collapse, the climbing void may penetrate the overlying strata.

This lithology varies regionally (Section R.S., Fig 2), consisting of the Whangarei Limestone over the greater part of the area and the Kerikeri Volcanic down the western margin. Putting aside the diverse nature of the Kerikeri Volcanics, in general if their respective K.O.D.'s (Appendix 1) are taken into account, they will inhibit further void migration to the surface.
In general most coal fields are heavily faulted. When a fault is encountered during seam excavation, it is usual practice, if its throw is large, to terminate the workings against the fault. Bell (1975) noted that with workings terminated against a fault, a permanent stress will be induced at the surface in the zone of influence of the fault. A subsidence step may occur as a result of the induced stress at the outcrop of the fault (Fig 36).

![Diagram of fault and subsidence](image)

**Figure 36. The influence of faults on subsidence (Bell 1975, pp 15)**

Bell also showed that the most noticeable steps were found in areas where coal had been worked beneath the hade of the fault and that movement was essentially vertical with the extent of the step being limited to the size of the area worked.

Lee (1966) indicated that the likelihood of movement is not influenced by the depth of the seam, but mainly by the position of the face with reference to the hade of the fault.

Shepard and Faber (1978) further developed the findings by stating that normal dip slip faults do not appear to be associated with roof failure, and, if they have a small throw, hold little potential subsidence. However, normal oblique and strike slip faults are associated with severe roof failure.

A report on mining subsidence prepared by the Institution of Civil Engineers (1959) recommended that structures be set back at least 16 metres from the line of surface outcrop of the fault.
With reference to the Kamo Coal Field as Fig 35/41 indicates, the area is heavily faulted and commonly the working extend to the fault boundaries.

The faults in the area are steeply dipping ranging from 50°-85°. The movement on most of the large faults present, including Derby and Kamo faults has been oblique dip slip, however slickensiding in the mine showed many of the smaller ones to be normal dip slip faults.

One would expect subsidence steps to occur around the Kamo area, however these have not developed and indeed were not able to be found. This is due to the discontinuity of the faults between the coal measures and the surface (Fig 2). As the geological sections reveal, the Onerahi Formation and the Kerikeri volcanic have been deposited after faulting took place so many differential movement that is likely to occur will usually be absorbed by the overlying strata.

The only known area where cover is thin enough (Kear 1959) to allow faulting to extend close to the surface is south east of Mt. Derby (Fig 1) where the Onerahi Formation is less than 15 metres thick. The Derby fault extends through this area which also acts as a northern boundary to the below new Kamo mine.

A subsidence step is not presently evident in the area, however with crushing of the pillars with time or settlement of the pillars into the below fireclay, this zone holds potential for a step to develop.
Assuming that the present flow of water from No. 2 Drive represents the overflow for all of the Kamo Mines, the flooded level in the mines is given by the elevation of No. 2 Drive, 350 ft above sea level. Thus only a small area in the western extent of mines remain unflooded (Figure 35/A).

It has been previously argued that, as the mines are flooded, subsidence can only be of a very limited extent, as the water has served to replace the coal inducing roof support. The validity of this statement is questionable.

If the water is to be viewed as a structural support, it would have to be present in a 'closed' system, with no means of escape. This is not true in the case of the Kamo Mines as they are directly linked to an underground drainage system predominantly contained within the Whangarei Limestone Formation.

The presence of water indeed helps subsidence through the progressive saturation of fire clays that underlie the pillars of coal. This induces the clays to deform plastically under the constant loading causing gradual subsidence of the pillars into the basal clays as shown by Figure 37.

**Figure 37: Subsidence Due to Saturation of Basal Fireclays**

The size of the zone of saturation with time is solely dependent on the permeability of the basal clay.

Assuming that the flow of water through the workings is not significant, and that the water level does not fluctuate greatly, water does aid in preserving the wooden supports that were originally secured throughout the workings.
When extension cracks or compression features occur in a structure, over a mine area, it is not necessarily always due to the collapse of underground workings. A number of other possibilities exist that produce similar results to a mining subsidence.

1. **Sulphate Attack:**
   This is caused by the interaction between Portland cement and soluble sulphate salts in moist conditions. Mortar expands as a result causing cracks to develop in brick walls and mortar facings.
   The sulphates are derived from industry, and at present due to the limited extent of industry, in the Kamo area, this effect is negligible.

2. **Shrinkable Clays:**
   Due to the volume change of clays with the influence of changing moisture content. It has been noted that this is considerably increased (Subsidence Engineer's Handbook 1975) by the proximity of fast growing trees such as poplars and willows.

3. **Inadequate Construction of Buildings:**

4. **Occurrence of Subterranean Caverns:**
   In the Kamo area these occur as solution cavities in the Whangarei Limestone and caverns within Kerikeri Basalts. (Brown 1975).

5. **Collapse of drains and old water wells:**
Since the mines closed down, three prominent cases of subsidence have been recorded in the Kamo area.

These subsidences took two forms. The first of these involved large scale collapse of the ground surface and occurred over the No. 1 Kamo Mine (Fig 14), and parts of the Rautangata Mine. This occurred over pillared areas and was formed by the collapse of 'robbed' pillars extending to the surface. Both of these areas subsided shortly after mining activity was completed and the exact extent of each was never recorded.

The other form involved the development of crown holes which occurred at 16 Wakelin Street (Fig 1). These first developed in 1961 and has repeatedly occurred since then. (Figs 38-41). Each time the depression was filled with loose granular material. This subsidence was caused by roof failure of the below workings resulting in a void to make its way to the surface. According to Mr R. Cunningham a fault runs through the immediate vicinity providing a zone of weakness for the roof to collapse.

Other subsidences can also be found over a number of drives of the new Kamo mine and at the top of shafts. (Fig 23).
Fig. 40: Subsidence at 14 Wakelin Street September 1978

Fig. 41: Subsidence at Wakelin Street July 1979
THE QUESTION OF SUBSIDENCE IN THE KAMO AREA

Mine subsidence apart from those caused by settlement in shafts and drives, can be divided up into three categories:

1. Large scale collapse of the ground surface
2. The development of crown holes
3. The development of subsidence stops associated with faults

Large scale collapse has occurred in the area, usually within a short period after mining, over pillar areas through overburden thicknesses ranging from 15-45 metres. A number of pillar areas within this depth range occur in the Kamo and Ruatahanga Mines and as no record was made of subsidence in these areas, are potential zones of instability.

The development of crown holes is the most likely form of subsidence to occur in the Kamo area. Investigation has found that where the overburden is greater than 7t (where t = seam thickness), voids will not be able to reach the surface (Appendix 4). For similar situations in European Coal Measures 8t is cited (Tincklin 1958) and where a factor of safety is incorporated 10t is used to predict crown-hole 'free' areas.

Applying this factor of safety to the Kamo area, crown-hole 'free' areas exist where the overburden is of great enough depth.

Thus, for: 1 seam worked, $t = 2.1$ metres, :: Overburden 21 metres for stability
2 seams worked, $t = 4.2$ metres, :: Overburden 42 metres for stability

When these conditions are applied to the Kamo mines (Fig 35/A1), the areas prone to crownhole development include the western margin of the Kamo mine and a greater part of the Ruatahanga Mine (Fig 32/A1).

Potential subsidence related to the faults is restricted to the western half of the Denby Fault (Fig 35/B1).
RECOMMENDATIONS REGARDING AREAS SUBJECT TO POSSIBLE MINING SUBSIDENCE

At present areas described as potential zones for mining subsidence are defined in the City of Whangarei District Scheme of Ordinances as follows:-

4.1.2 Areas Subject to Possible Mining Subsidence

Areas subject to possible mining subsidence are shown in planning Map 2A. There may be land within those areas where such classification is not needed and there may be land outside these areas where special care on such factors is important or where actual problems exist.

Notwithstanding that development proposals may conform in all other respects with these ordinances, Town Planning approval shall not come into effect on any site within the areas classified, or other sites where a reasonable doubt as to possible mining subsidence is indicated on advice from the Director of Engineering, unless the applicant satisfies Council that the proposals give due regard to such engineering and construction factors as are appropriate, and that danger, damage or nuisance from mining subsidence is most likely to occur.

Map 2A gives a blanket cover over all of the mined areas as areas subject to possible mining subsidencies.

In the light of this report, qualifying the above ordinance, the following recommendations are suggested:-

1. The appropriate treatment and restrictions be adopted for the mine shafts as defined earlier in this report.

2. The appropriate treatment and restrictions be adopted for the mine drives as defined earlier in this report.

3. Areas subject to possible mining subsidence as shown by Figure 42/A be defined as follows:-
   i) Where one seam has been worked, for overburden thicknesses less than 21 metres.
   ii) Where both seams have been worked, for overburden thicknesses less than 42 metres.
   iii) Where pillaring has taken place, for overburden thicknesses less than 50 metres.
   iv) An area 16 metres either side of the line of surface outcrop of the Denby Fault where it abuts the new Kamo mine.
APPENDIX 1

ROCK QUALITY DESIGNATION (R.Q.D)

(All measurements in centimetres)

1. HUMTANGATA SANDSTONE - KAMO BRICKWORKS (Fig 6)

Line 1 10-15-20-20-10-5-10-15-10-25-10-10-5-15-15-30 (Fig 6)
\[ R.Q.D. = \frac{115 \times 100}{225 \times 1} = 68.9\% \quad \mu = 14 \quad \sigma = 6.9 \]

Line 2 20-20-10-10-15-5-30-20-30-5-10-20
\[ R.Q.D. = \frac{185 \times 100}{225 \times 1} = 82.2\% \quad \mu = 17 \quad \sigma = 9 \]

NOTE: Line 1 and 2 were calculated at the base and top of the unit where exposed at the brickworks.

2. WHANGAREI LIMESTONE - "THE ROCKS" (Fig 7)

Line 1 30-10-20-30-8-8-30-25-40-20-45-15-50-30 (Fig 7)
\[ R.Q.D. = \frac{335 \times 100}{361 \times 1} = 92.8\% \quad \mu = 22.6 \quad \sigma = 12.4 \]

Line 2 30-45-20-30-40-30-20-20-40-20-30
\[ R.Q.D. = \frac{355 \times 100}{355 \times 1} = 100\% \quad \mu = 30.4 \quad \sigma = 9.2 \]

\[ R.Q.D. = \frac{440 \times 100}{480 \times 1} = 91.7\% \quad \mu = 30 \quad \sigma = 29.2 \]

3. ONERAKI FORMATION

Line 1 Concretionary band of greensand (Fig 9)
10-20-5-5-7-20-27-2-8-16-10-10-40
\[ R.Q.D. = \frac{468 \times 100}{530 \times 1} = 88\% \quad \mu = 13.6 \quad \sigma = 9 \]

Line 2 Highly indurated calcaeous mudstone (Fig 10, likely matrix for breccia)
\[ R.Q.D. = \frac{1270}{1350} = 94\% \quad \mu = 31.4 \quad \sigma = 23 \]

Line 3 Medium grained glauconitic sandstone
10-20-5-10-5-5-20-16-10-30-25-5-20-5-15-10-15-10-20-10-10-10
\[ R.Q.D. = \frac{176}{286} = 61.5\% \quad \mu = 12.5 \quad \sigma = 6.93 \]
APPENDIX 2

Stability Calculations 1 - (Wardell and Wood 1965)

1) New Koro Mine:
    Overburden range = 60 - 310 metres
    - Mine does not qualify as being 'shallow'.

2) Koro Mine:
    Overburden range = 15 - 60 metres
    Average spanning width = 0.9 metres

    Maximum spanning width at minimum depths:

    \[
    \frac{15 \text{ metres}}{5} = 3 \text{ metres}
    \]

    - The average spanning width (0.9 metres) is well within this range.

3) Ruatangata Mine:
    Overburden range = 0 - 38 metres (caved workings can be found at the surface)
    - Mine worked out.

4) Harrison's Mine:
    Overburden range = 60 - 90 metres
    - Mine worked out.
APPENDIX 3

Stability Calculations 2 (Orchard 1964)

1) New Kamo Mine:
   Overburden range = 60 - 310 metres
   Average pillar width = 5.3 metres.
   - Pillar sizes of too greater range for formula to apply.

2) Kamo Mine:
   Overburden range = 15 - 60 metres
   Average pillar width = 4.1 metres

<table>
<thead>
<tr>
<th>Pillar Width</th>
<th>4.1/15</th>
<th>4.1/20</th>
<th>4.1/30</th>
<th>4.1/40</th>
<th>4.1/50</th>
<th>4.1/60</th>
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<td>Ratios</td>
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<td>0.136</td>
<td>0.103</td>
<td>0.082</td>
<td>0.068</td>
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</tbody>
</table>

Plotted on Figure 34

NOTE: All measurements in metres.

3) Ruaatangata Mine:
   Overburden range = 0 - 38 metres
   - Mine worked out.

4) Harrison's Mine:
   Overburden range = 60 - 90 metres
   - Mine worked out.
APPENDIX 4

Stability Calculations 3 (Tincelin 1958)

Five core samples were collected from outcrop using a soil sampling tube that was driven in by a peg bar. The material sampled was poorly indurated so little deformation occurred during sampling. Three samples were taken from the Ruatangata Sandstone and two from the base of the Kamo Coal Measures. Loose material was also collected representing the sandstones' collapsed equivalent. The densities of the specimens were then calculated.

1) Sampling tube specimens

<table>
<thead>
<tr>
<th>Sample</th>
<th>Saturated Kg/m³</th>
<th>Dry Kg/m³</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>1990</td>
<td>1710</td>
</tr>
<tr>
<td>2</td>
<td>2190</td>
<td>1980</td>
</tr>
<tr>
<td>3</td>
<td>2180</td>
<td>1960</td>
</tr>
<tr>
<td>4</td>
<td>2000</td>
<td>1740</td>
</tr>
<tr>
<td>5</td>
<td>1950</td>
<td>1690</td>
</tr>
</tbody>
</table>

Ruatangata Sandstone:
Average $s = 2120$ Kg/m³ Average $d = 1803.3$ Kg/m³

Basal Fine Clay, Kamo Coal Measures.
Average $s = 1975$ Kg/m³ Average $d = 1715$ Kg/m³

Loose material densities, Ruatangata Sandstone.

<table>
<thead>
<tr>
<th>Condition of Sample</th>
<th>Saturated Kg/m³</th>
<th>Dry Kg/m³</th>
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</thead>
<tbody>
<tr>
<td>Loose</td>
<td>1590</td>
<td>1120</td>
</tr>
<tr>
<td>Compacted</td>
<td>1860</td>
<td>1330</td>
</tr>
</tbody>
</table>
Application of Tinzelin's Formula: (Figure 30)

\[ H = t \left[ \frac{\gamma_r}{\gamma} \left( 1 - \frac{\gamma}{\gamma_r} \right) \right] \]

*H* = total height of collapse.
*t* = thickness of the seam (height or roadway)
*\( \gamma_r \)* = bulk density of collapsed roof material.
*\( \gamma \)* = bulk density of roof rocks

With the progressive collapsing of the roof rocks, the material will become more compacted at the base of the fallen pile. Thus the 'extreme' values are calculated in order to give a range in which the real conditions apply.

**Case 1:**
Dry roof rocks falling onto dry roadway, assuming no compaction of falling material.

\[ H = 2.1 \text{ metres} \left[ \frac{1120 \text{ kg/m}^3}{1883.3 \text{ kg/m}^3} \right] \left( 1 - \frac{1120 \text{ kg/m}^3}{1883.3 \text{ kg/m}^3} \right) \]

= 3.08 metres.

**Case 2:**
Dry roof rocks falling onto flooded roadway assuming no compaction of fallen material.

\[ H = 2.1 \left[ \frac{1590}{1883.3} \left( 1 - \frac{1590}{1883.3} \right) \right] \]

= 11.38 metres.

**Case 3:**
Dry roof rocks falling onto dry roadway then compacted.

\[ H = 2.1 \left[ \frac{1330}{1883.3} \left( 1 - \frac{1330}{1883.3} \right) \right] \]

= 5.04 metres.

**Case 4:**
Wet roof rocks falling onto flooded roadway assuming no compaction.

\[ H = 2.1 \left[ \frac{1590}{2120} \left( 1 - \frac{1590}{2120} \right) \right] \]

= 6.3 metres.
Case 5:
Wet roof rocks falling onto flooded roadway assuming compaction.

\[ H = 2.1 \left[ \frac{1860}{2120} \div 1 - \frac{1860}{2120} \right] \]

= 15.02 metres.

The value of \( t \) has been estimated as 2.1 metres, the average height for driveways in the seam. In many places both seams have been worked, one above the other, thus proportionally increasing the calculated collapse height:

1. For one seam mined: \( t = 2.1 \) metres, \( H = 3.08 - 15.02 \) metres for conditions cited previously.
2. For both seams mined: \( t = 4.2 \) metres, \( H = 6.10 - 30.64 \) metres.
Fig. 1 - Geology of the Kamo Mines Area Keele (1959)
Fig. 2 - Geological Sections for the Kamo Mines Area Keele (1959)
Fig. 3 - Sections, Kamo Coal Field Hay (1946)
Fig. 4 - Type sections for the Ruatahanga Sandstone and Kamo Coal Measures: Kamo Brick Works (W.C.C. Jan 1980)
Fig. 5 - As for Fig. 4.
Fig. 6 - Ruatahanga Sandstone: Kamo Brickworks (W.C.C. Jan 1980)
Fig. 7 - Whangarei Limestone: "The Rocks" (W.C.C. Jan 1980)
Fig. 8 - Whangarei Limestone: "The Rocks" (W.C.C. Jan 1980)
Fig. 9 - Onerahi Formation, Onerahi Beach (W.C.C. Jan 1980)
Fig. 10 - Onerahi Formation, Onerahi Beach (W.C.C. Jan 1980)
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:'Onerahi Chaos-Breccia: Further thoughts (note)


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