Risk of Mine Related Subsidence at Ocean View

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SUMMARY In July 1989 a subsidence pit appeared in a residential area at Ocean View above the one hundred year old abandoned Walker No. 1 Coal Mine. Subsidence hazard for the residential area was examined. The extent of the mine was assessed together with overlying ground conditions and condition of the mine. Strata overlying the mine were found to be extremely weak. Mine workings were found to be deteriorating and in an open and flooded condition. The subsidence pit was attributed to localised catastrophic collapse of the mine roof and consequent subsidence of water charged sandy gravel into the mine opening, causing the sudden collapse at the ground surface. Other similar pits were observed above nearby abandoned mines. The risk of further subsidence pits forming was assessed to be very probable. Fourteen private properties were determined to be at risk, and the degree of risk to residents and property was assessed as 'risky to some risk'. Courses of action for the Local Authority were prepared and in August 1990 the Crown accepted some liability for the situation.

1. INTRODUCTION

On the night of 12-13 July 1989, a subsidence pit formed from the sudden collapse of the ground surface in the rear yard of a residential property in John Street, Ocean View. The Local Authority commissioned an investigation to evaluate coal mine subsidence hazard above the mine.

Ocean View is a small suburban residential area on the East Otago coast 17 km south of the City of Dunedin. Coal beds extensively underlie the Ocean View district and have been worked by underground methods in several mines until as recently as 1972. The subsidence pit occurred above the one hundred year old abandoned Walker No. 1 Coal Mine.

2. SITE DESCRIPTION

Physiographically, the site primarily incorporates a raised marine terrace some 8-10 m in height. This terrace is bound immediately to the south and east by a steep, formerly wave-cut bank and a narrow coastal plain some 100 metres wide. A modified gully drains the lower part of John Street. The mine workings underlie the high terrace. Houses are situated both on the high terrace and on the low- lying land at the foot of the terrace.

3. MINING

3.1 History

Underground coal mining commenced in 1887 below the high terrace and continued until 1893 when the mine proprietor James Reid Walker abandoned the mine and recommenced mining at a new site across the valley, 200 m further east.

Although specific details on mining activities in the mine are unavailable, it is reasonable to assume it was similar to the room and rance method deployed at the same time in other Green Island Collieries (Denniston 1877). Rooms typically 3.6 - 4.3 m wide and in places 5.5 m wide, with a "comparatively slight thickness of wall or rance between each room", were worked either side of access drives. Only the centre 1.5 - 2.1 m of the seam was worked to ensure a safe mining system, even where the seam was up to 4.9 m thick.

The soft nature of the roof and floor, loose drift sands and sandy shales affected the safety of the Green Island Collieries particularly where rooms reached maximum extension (Denniston 1877). The Annual Mine Statement of 1892 and 1893 refers to the hazardous roof conditions in the old workings at the Walker No. 1 Mine, presumably in an area worked by the room and rance method.

3.2 Mine Configuration

Two original mine plans (1890 and 1902) were located but they did not portray details of the final internal configuration of the workings. Only the access and service drives were plotted, but the plans were useful in indicating the areal extent of the workings. The mine was unable to be precisely located with this information due to the lack of surveyed control points which could be positively identified. External mine features such as the air shaft and mine portal were no longer visible.

Six mine plan overlays scaled to the topographical plan were generated in an attempt to establish an accurate orientation for the mine map. On the basis of geologic and hydrologic data the mine was believed to be confined to the area beneath the high terrace and not to extend beneath the low-lying previously swampy ground. On the basis of historic and topographic features the approximate location of the mine portal was determined to be on the north facing slope of the gully now modified to form John Street. The resulting plan overlay model is shown on Figure 1.

4. SITE INVESTIGATIONS

Most of the technical information required to evaluate subsidence hazard was derived from 7 drillholes, located as shown on Figure 1. Access for drilling was restricted. An inspection was made of the exterior surfaces of buildings in the area. No indications of large scale ground settlements were detected although significant settlement of one corner of a house was observed. The Local Authority conducted

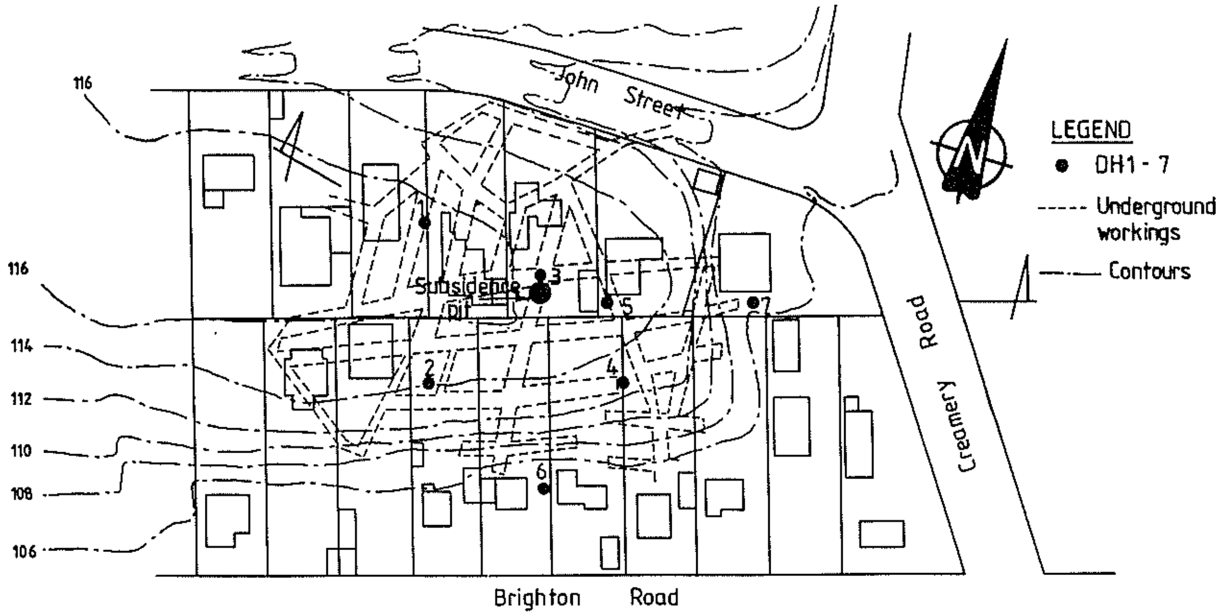

Figure 1 Site plan

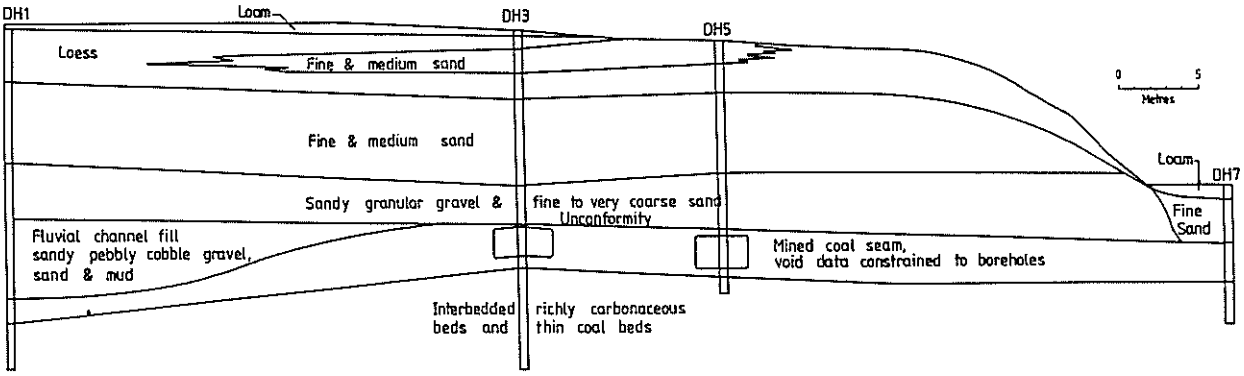

Figure 2 Geological section

a water leakage survey of pipes on John Street properties with only minor leakages being detected.

5. GROUND CONDITIONS

The ground profile in the area of the mine is depicted in Figure 2. Hillgrove Formation (Pleistocene) sediments overlie the coal bearing Taratu Formation (Upper Cretaceous). The Hillgrove Formation (9-16 m thick beneath the high terrace) consists of the following general profile:

Depth (m)	Stratum
0 - 4	Soft to stiff clay and very fine sandy mud (Loess)
1 - 9	Medium dense fine to medium sand
8 - 12	Very loose to loose sandy gravel and fine to coarse sand
12 - 16 (DH1) 8.5 - 9 (DH2)	Mud and sandy cobble gravel

These sediments unconformably overlie the Taratu Formation except to the west (DH1 & 2) where a succession of fluvial silts, sandy cobble gravels and sands, infill a channel deeply entrenched into the underlying Taratu Formation.

The Taratu Formation consists of numerous thin, laterally inconsistent fine grained carbonaceous beds of clays, silts, coal and fine sands. These sediments are extremely weak to very weak. The 1.4 - 3.6 m thick, laterally continuous, moderately strong, main coal seam occurs at or close to the top of the Formation. Beneath the high terrace the top of the coal seam varies between 11.2 and 16.0 m below ground surface. The Taratu Formation strata dip gently south eastward at 4° - 6°.

The main coal is shallowly located 3.5 - 5 m beneath the low-lying land at the foot of the high terrace. Here the sediments overlying the coal seam are predominantly loose porous fine sands.

Groundwater conditions beneath the high terrace consist of an unconfined aquifer 0.7 to 5.8 m thick occurring within the lowermost Hillgrove strata. The upper surface of the Taratu Formation defines the base of the aquifer. Groundwater level is 7.5 - 9.6 m below ground surface.

6. MINE CONDITION

Voids interpreted as excavated coal workings were intersected in 4 drillholes (DH 3, 4, 5). Drill rods fell freely into the water filled voids while drilling. In two drillholes well preserved wood, probably mine support timber or rail sleepers, were located on the coal floor.

The thickness (0.4 - 0.7 m) of typically low ash coal remaining below the floor of the worked seam, suggests that floor heave may have been a problem.

Roof or rib fall (caved) material was cored in 2 drillholes from immediately above the coal floor. In DH 3 it consisted of small coal fragments intermixed with quartz sand and well rounded granular sand (derived from Hillgrove Formation sediments). DH 3 was located immediately adjacent to the subsidence pit.

The immediate coal roof was determined to be competent, but is locally characterised by a vertical to sub-vertical cleat which might in time contribute to slabbing of the immediate roof. Water saturated conditions in the permeable strata above the worked coal seam are likely to be a significant causative factor in the deterioration of the workings. Roof strata susceptible to moisture slaking may slowly deteriorate over a long period of time before large falls develop (Krausse 1979), allowing groundwater to drain into the mine. The integrity of an entire mass of roof can be destroyed by this process (Moebs and Stateham 1986). Localised catastrophic collapse (subsidence) of the immediately overlying extremely weak, water charged sandy granular gravel sediments (of the Hillgrove Formation) will occur where significant roof failure results in the collapse of Taratu Formation strata bridging the mine roof.

7. MINE SUBSIDENCE

7.1 Characteristics

Various forms of mining result in differing effects on the strata and the ground surface. Surface subsidence related features appropriate to room and rance mining can be categorised as follows:

Subsidence pits (crown holes) are nearly circular depressions. Subsidence troughs (crown holes) are elongated depressions produced often by the coalescence of individual pits. Subsidence pits and troughs are caused by roof collapse and the ground surface may collapse suddenly.

The major mechanisms of mine deterioration in room and rance workings are roof collapse, crushing of pillars and floor heave. By far the greatest problem is roof collapse as evidenced at the Walker No. 1 Mine and nearby mines. At the cessation of mining supporting timbers would either be withdrawn or allowed to rot away allowing the roof strata to collapse into the open workings. The process of upwards collapse would continue until the workings and the collapsed ground above it were completely choke-filled with debris. Where the collapse reaches the ground surface a subsidence pit or trough (crown hole) is formed. This process is illustrated in Figure 3.

Several formulae can be found in the literature as to the maximum height of collapse that might be expected to occur. (Subsidence Engineers Handbook 1975; Healy and Head 1984). For a seam thickness of 1.2 m and a bulking factor of 15%, a conical shaped collapse could be expected to occur up to a height of 20-34 m i.e. greater than the thickness of overburden above the mine.

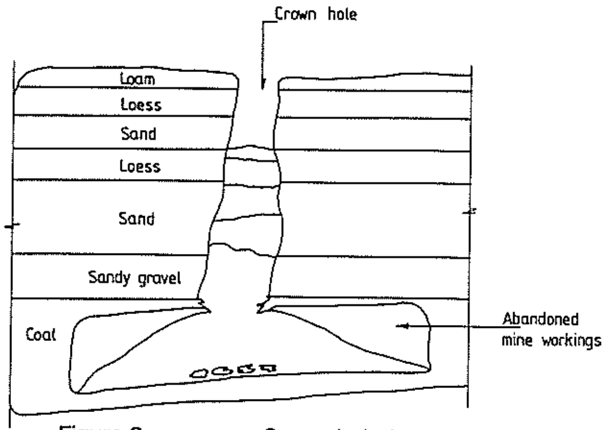

Figure 3 Crown hole formation

Dunrud and Osterwald (1980) observed that the total depth of subsidence pits may be nearly as deep as or sometimes even deeper than the height of the mine workings because collapsed material may spread laterally into the mine opening, particularly where water is present in the mine. It is believed that the surface in the John Street subsidence pit collapsed 3.5 m above flooded coal workings excavated to a height of 1.1 - 1.7 m.

7.2 The John Street Subsidence Pit

The ground surface collapsed 12 to 24 hours after an earthquake was felt in the Ocean View area. Reports and photographs indicate the surface geometry of the pit soon after collapse was circular, approximately 1.5 m wide and 3.5 m deep with vertical sidewalls. The pit widened during the succeeding months until the pit was in-filled.

7.3 Other Subsidence Features at Ocean View

Numerous subsidence pits and troughs occur 200 m to the northeast above the abandoned Walker No. 2 Mine, and 200 m to the north above the Victory Mine. The seam worked in these mines similarly occurs within the Taratu Formation. The subsidence features occur above the outer shallower workings of these mines where the overburden strata are thought to be thinnest and not capped by the relatively competent Brighton Limestone overlying the deeper workings in these areas.

Examination of aerial print photographs of the area above the Walker No. 2 Mine indicated that many of the subsidence pits and troughs currently recognisable had collapsed by 1942. One distinctive circular pit (occurring between 1976 and 1985) was located among older pits and was similar in size and shape to the John Street pit.

7.4 Subsidence and Seismicity

The John Street subsidence pit appeared within 12 to 24 hours of a magnitude 4.5 earthquake located 7.5 km offshore from Ocean View on 12 July, 1989. Considering the age and condition of the mine, the lack of competence of the overburden and temporal association of the earthquake with the appearance of the hole, it was possible that the seismic event initiated and/or accelerated the roof collapse which propagated upward over a period of hours and which was still active many days afterward. As such, the possibility of further subsidence was viewed in light of the probability of earthquakes which would produce similar or greater intensities in the area.

During a magnitude 5.0 earthquake in 1974 no subsidence pits were reported in Ocean View. The epicentres and shallow focal depths (20 km) of the 1974 and 1989 events were similar. The most recently active nearby fault, and the one probably associated with the 1974 and 1989 events, is the Akatore Fault. The surface trace of this fault is about 3 km southeast of Ocean View. Using an estimated felt intensity for the 1989 event, the probability of occurrence of the same or greater events was assessed using information from Smith and Berryman (1983). These probabilities were used in the risk analysis.

8. RISK ASSESSMENT

8.1 Introduction

In order to assess the risk of subsidence above abandoned mines it was useful to use a framework in which to evaluate and assess risk. A suitable framework has been proposed by Cole (1987) particularly in relation to construction over abandoned shallow mines. Table I relates 'Degree of Risk' categories to 'broad-band' probabilities and is based on a ratio of 10 in both directions. The concept of 'Tolerance of Risk', i.e. an increasing expectation of less exposure to risk as the public nature of risk increases, can be introduced. In Table II the 'Degree of Risk' and 'Severity of Consequences' are combined with tolerance to give a matrix of 'acceptance' or 'expectations'. Statements are obtained from the table in the following manner:

e.g. "Impairment / of property / by subsidence damage / [is] expected by the public / [to be] unlikely".

TABLE I

DEGREE OF RISK AND PROBABILITY (AFTER COLE 1987)

Annual Probability of a Total Loss Event		
DEGREE OF RISK (Nomenclature)	TO LIFE Annual risk of fatality	TO PROPERTY Annual risk of destruction
Very risky	1 in 100	1 in 10
Risky	1 in 1,000	1 in 100
Some risk	1 in 10,000	1 in 1,000
A slight chance	1 in 100,000	1 in 10,000
Unlikely	1 in 1 million	1 in 100,000
Very unlikely	1 in 10 million	1 in 1 million
Practically impossible	1 in 100 million	1 in 10 million
	1 in 42 The overall death rate	1 in 200 The overall destruction rate

There is little doubt that readers will quibble at one or more of the statements that can be obtained from Table II and this only serves to draw attention to how one's experience of risk determines one's perception of it. Generally, it can be said that there is a difference of at least one order of magnitude between what the public will accept as degree of risk and what it will expect as degree of risk.

The nature of geotechnical engineering and particularly work dealing with abandoned mines and mining subsidence, is such that the amount of data required to allow a reliable statistical analysis of the problem is seldom available or obtainable.

8.2 Degree of Risk

The degree of risk with respect to ground subsidence above the mine was assessed by taking into consideration the following facts:

- The shallow depth of workings.
- The age of workings is old, 90 to 100 years.
- The room and rance method of mining was used and the central part of the mine is recorded as being worked out.
- Roof conditions were recorded as being poor during mining; drilling revealed that the coal roof is very thin and granular deposits directly overlie this over most of the mine.
- Coal rubble and sandy granular deposits were recovered from the floor of the mine workings. The sandy sediments probably entered the mine workings through nearby roof falls.
- The workings are presently flooded.
- Support timbers in the mine may still be in good condition.
- A subsidence pit type of collapse appeared on the night of July 12-13, 1989.
- Historical evidence of possible subsidence pits prior to subdivision of the area.
- Subsidence pits are observed to be the form of subsidence occurring above nearby mines.
- The subsidence pit collapse occurred within 12 to 24 hours after a local earthquake of probable intensity MM III to MM IV. There is a greater than 10% probability of the occurrence within 50 years of another seismic event which produces the same or greater intensity, and a 100% probability within 100 years. While seismic events may not be directly responsible for the formation of subsidence pits, they may enhance the instabilities which cause them to form.

These facts led to the conclusion that the degree of risk of further subsidence pits occurring lay between two categories; 'risky' to 'some risk'. The mine workings appeared to be still open and slowly deteriorating, and the timing and frequency of further collapses was uncertain. The existence of voids that have partly migrated towards the ground surface was considered unlikely. The loose granular nature of the overburden materials was likely to lead to the rapid migration of a void to the ground surface following a roof collapse.

Using Table I, it can be seen that there was a greater risk of destruction of property than loss of life. Similarly it could be said there was a greater risk of damage to property than destruction of property and a greater risk of injury than loss of life. The evidence of previous subsidence pits in the Ocean View area indicated typical dimensions of about 4 m diameter and 2-4 m deep i.e. not large enough for a house to completely fall into, but large enough to cause severe distress to part of a house and damage to buried services in the road reserve.

TABLE II
ACCEPTANCE OR EXPECTATION OF DEGREE OF RISK OF GIVEN CONSEQUENCE (AFTER COLE 1987)

Severity of Consequence		Degree of Risk
Impairment	Total Loss	
of life : by car, aeroplane and home accidents of property : by "Act of God" circumstances **Tolerated in special circumstances**	of life : by deep sea diving or rock climbing of property : by volcano or avalanche **Not acceptable except to a minority**	**Very risky to risky**
of life : by deafness or blindness of property : by fire **Accepted by the public**	of life : by car, aeroplane and home accidents of property : by undermining or earthquake **Tolerated by the public in special circumstances**	**Some risk to a slight chance**
of life : by sickness such as chicken pox of property : by subsidence damage **Expected by the public**	of life : by public transport accidents of property : by flooding **Accepted by the public**	**Unlikely**
of life : by sickness such as rabies of property : by radiation contamination **Demanded by the public**	of life : by fatalities in public places of property : by failure of foundations on soil **Expected by the public**	**Very unlikely**
	of life : by failure of nuclear power plant of property : by failure of foundations on rock **Demanded by the public**	**Practically impossible**

8.3 Area of Risk

The 'area of risk' for ground subsidence is shown on Figure 4. It is derived from an overlay of the various mine models and comprises two areas:

1. Area of risk.
2. Possible extension to area at risk.

Results from the drilling on the low-lying area did not prove the absence of mine workings. Therefore a 'possible extension to the area at risk' was included. This area was identified as requiring further investigation to confirm whether mine workings extend below it.

9. REMEDIAL MEASURES

Two options were presented to the Local Authority.

(a) Not carry out remedial measures

If nothing was done, then when subsidence pits formed, they could be back-filled and damage to structures repaired. Regular survey monitoring may have helped to detect subsidence troughs. No further development in the area was recommended.

(b) Carry out remedial measures

To reduce the degree of risk from 'risky' to 'some risk', to either 'a slight chance', or 'unlikely', or 'very unlikely' required the same remedial works to be carried out whatever degree of risk was accepted, i.e. the remedial measures could not be designed to such tolerances as to differentiate between 'a slight chance' and 'very unlikely'.

Several options existed for remedial works:

1. bulk excavation and back-filling.
2. protect buildings against subsidence pits.
3. filling of mine working by grouting.

Option 1 was not considered feasible as it would have required the removal of all buildings in the area concerned. The depth of excavation, up to 17 m deep would have provided construction difficulties and the scale of such an operation would have been unacceptable in a urban setting.

Option 2 was not considered feasible because of the difficulty and expense of providing stiff foundations for the buildings in the area since most had brick veneers. Although buildings might be protected from damage caused by the formation of subsidence pits, the surrounding land would not be protected.

Option 3 was the most feasible method of preventing migration of voids and formation of subsidence pits. The existence of voids that had partly migrated towards the ground surface was considered unlikely. Because the

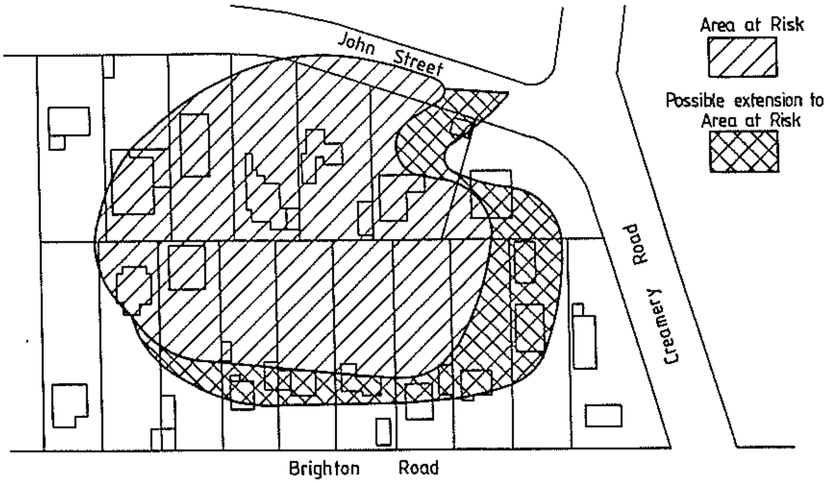

Figure 4 Areas of risk

workings were inaccessible, injection of grout would be done through drill holes. The cost of in-filling the mine by grouting was estimated as $900,000 in 1990.

In August 1990 the Crown accepted some liability for the situation and after consultation with the Local Authority and property owners, chose not to carry out remedial works. The Crown agreed to purchase the properties identified as being at risk if the owners wished to vacate, or to compensate owners wishing to remain. All the buildings on properties bought by the Crown have been demolished or relocated.

10. CONCLUSIONS

1. The ground collapse that occurred was a subsidence pit caused by the collapse of the mine roof possibly accelerated by seismic activity.
2. The degree of risk of further subsidence pits occurring above the mine was assessed to be 'risky' to 'some risk'.
3. The 'area of risk' encroached on 14 properties and part of the John Street road reserve.
4. Two options existed regarding the risk:
   - not carry out remedial works
   - carry out remedial works to reduce the degree of risk.

11. ACKNOWLEDGEMENTS

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12. REFERENCES

1. Bell, F.G. (ed) (1978). Foundation Engineering in Difficult Ground, Newnes-Butterworths, p. 322-362.

2. Cole, K. (1987). "Building over abandoned shallow mines: A strategy for the engineering decisions on treatment". Ground Engineering. v. 20, no. 4, p. 14-30.

3. Denniston, R.B. (1877). "Report on Green Island Collieries, Otago". New Zealand Geological Survey reports of geological explorations, 1876-77, v. 10, p. 143-165.

4. Barry J Douglas Geological Consultants and Worley Consultants Ltd (1990). "Investigation of Mine Related Subsidence - John Street Area Ocean View". Unpublished Report to Dunedin City Council, 63 p.

5. Dunrud, C.R. and Osterwald, F.W. (1980). "Effects of coal mine subsidence in the Sheridan, Wyoming area". Geological Survey Professional paper 1164, 49 p.

6. Healy, P.R. and Head, J.M. (1984). "Construction over abandoned mine workings". Construction Industry Research and Information Association, United Kingdom, Special publication 32.

7. Krausse, H.F. and others (1979). "Engineering study of the structural geological features of the Herrin (no. 6) Coal and associated rock in Illinois". v. 2, Summary Report, Illinois State Geological Survey report prepared for Bureau of Mines Washington, Report no. Bu Mines OFR 96(1), -80, 53 p.

8. Moebs, N.N. and Stateham, R.M. (1986). "Coal Mine Roof Instability: Categories and Causes". Bureau of Mines Information Circular, 9076, United States Department of the Interior, 15 p.

9. Sames, G.P. and Laird, R.B. (1988). "Geologic conditions affecting coal mine ground control in the Western United States". Bureau of Mines Information Circular, 9172, United States Department of the Interior, 30 p.

10. Smith, W.D. and Berryman, K.R. (1983). "Revised estimates of earthquake hazard in New Zealand". Bulletin of the New Zealand National Society for Earthquake Engineering, v. 16, no. 4, p. 259-272.

11. Subsidence Engineers' Handbook (1975). National Coal Board, Mining Department, United Kingdom.