The Influence of Mining Subsidence on Urban Development of Ipswich, Queensland

by

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SUMMARY Urban development at Ipswich in southern Queensland is extending into areas where extensive underground coal mining operations have been carried out for more than a century. An assessment of mining subsidence potential was undertaken to help rationalise future town planning of Ipswich City. Mining in the area has traditionally been by "bord and pillar" methods with pillar extraction in the latter stages of mining where conditions permit. Predictable subsidence of the ground surface occurs following pillar extraction. However, surface movements resulting from deterioration of old mine workings are not amenable to exact calculation and a classification scheme involving six "Subsidence Categories" has been evolved for general planning purposes. Information from mine plans and various other sources was assembled as overlays on a cadastral base map of the City area. The area was classified according to degree of risk of surface deformation, and overlays included locations of operating and abandoned collieries, identification of coal mining leases, individual seam workings and features of geological importance. Construction restrictions and design requirements were defined for the various categories and the nature of follow-up studies for proposed developments was specified.

1 INTRODUCTION

In the rapidly expanding City of Ipswich in south-east Queensland, demand for residential and industrial land development has spread into areas which have been subject to intensive underground coal mining activities for more than a century.

Since 1952, it has been mandatory in Queensland for mining companies to submit certified mine plans to the Department of Mines at regular intervals. These plans are maintained primarily for reasons of mine safety but they also serve as a check that mining lease conditions are being observed. Prior to 1952 however, the maintenance of plans and records was rather haphazard and in many instances, plans and records were either not kept or have long since been lost.

An awareness of some of the problems which could ensue from urban development in extensively mined areas, led the Planning Section of the Ipswich City Council to initiate a study through a private geotechnical consultant to determine areas where surface subsidence due to the extraction of coal might adversely affect future development proposals and hence assist in rationalising town planning.

The primary aims of the study were to determine where possible:-

- the location and extent of all land subject to coal mining operations
- the anticipated life of current mining operations
- details relating to type of mining methods employed and any proposals for extension or reduction of operations
- details of future mining proposals
- areas of "potential" surface subsidence
- location and status of abandoned workings
- the status of existing coal mining leases including duration and general lease conditions

This paper outlines the approach adopted for the assessment of mining subsidence for an area of approximately 160 square kilometres, and the conclusions and recommendations reached from the study.

(a) History of the Field

There are more than 125 collieries which have operated in the West Moreton Coalfield since work first commenced around 1846. The mining method used has traditionally followed the "bord and pillar" system where the coal is removed from a room-shaped area termed a "bord" with the roof supported by pillars of intact coal.

The amount of coal removed in first workings was generally about 50 percent of the total area of the workings. The thickness of seam worked has varied from less than 1 m in early workings to about 3 m in current mines. Early mining was generally on a small scale, using hand methods, while current operations are highly mechanised. The general dip of the beds is up to 1 in 4 and early mining was concentrated around the outcrop of seams rather than deeper underground. Consequently a large proportion of the early workings fall into the "shallow" category.

(b) Geological Setting

Geological formations of the Palaeozoic, Mesozoic and Tertiary Eras are represented in the general area of the West Moreton Coalfield (Ref.1). Of these, the Middle-Upper Triassic Brassal Sub Group (Ref.2) of the Ipswich Coal Measures forms the main coal bearing stratum.The measures have a general dip to the south-south east of about 15^{o} and are folded about the axis of the Bundamba anticline which trends west-north-west through the central part of the area.

The Brassal Sub Group contains 24 exploitable coal seams and has a total thickness of approximately 900 m in which shales and sandstones predominate over lesser developments of ironstone and calcareous rocks. Many of the beds have lenticular cross sections which result in frequent changes in rock type in any given horizontal plane. Faulting is very prevalent throughout the field and the dominant strike of the major faults is south-easterly.

2 THE SUBSIDENCE PROBLEM

Surface subsidence occurs as a result of most forms of coal extraction procedures. The magnitude of surface movements is dependent on a number of factors, but may be greatly reduced by the technique of partial extraction where only 40 to 50 percent of the coal is taken during first workings. Alternatively, if long-wall mining techniques or pillar extraction are carried out, the maximum subsidence may be as much as 90 percent of the worked seam thickness. Pillar extraction is commonly practised in the later stages of the "bord and pillar" system of mining to increase the percentage of coal won. The removal of pillars over a wide area causes the roof of the mine to collapse and subsidence effects are,in general, similar to that of the long wall system. The long-wall mining technique involves the extraction of a coal seam across an entire working panel using temporary supports close to the face while allowing the mine roof to cave in a controlled manner some distance behind the working face.

The relative proportions of subsidence expressed as a percentage of worked seam thickness is shown for partial and total extraction systems in Fig.1 (Ref.5). The values are summarised from measurements made in British mines as no serious attempt has to date been made to obtain this type of data from the Ipswich area.

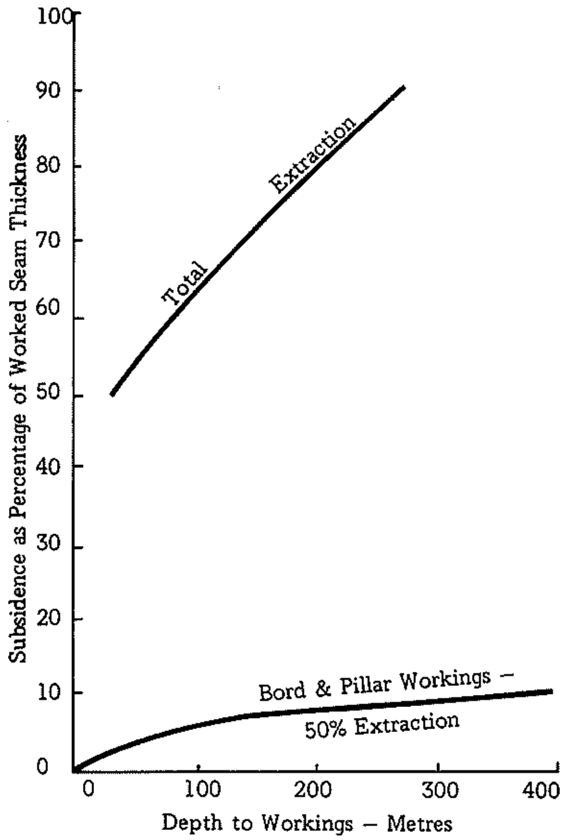

Fig.1 Subsidence expressed as a percentage of the worked seam thickness for total and partial extraction systems.

(a) Mechanisms of Subsidence

Subsidence effects can be considered in two categories:

* subsidence related to continuing mining operations, and occurring within a short period of time; this may be termed "predictable" subsidence.
* subsidence related to old mine workings, occurring as a result of deterioration of the mine environment; this may be termed "random" subsidence.

(i) Predictable subsidence

The subsidence resulting from mining operations occurs in the form of a surface trough (Ref.3). The central part of the trough subsides vertically, while the periphery of the trough moves inwards as well as downwards. The vertical component of the resultant movement is defined as the subsidence. The direction of movement occurring at a number of points at the surface is shown diagrammatically in Fig.2 (Ref.3).

The differential subsidence of adjacent points results in tilting and curvature of the ground surface. The differential horizontal displacement of adjacent points results in horizontal extension (tension) or contraction (compression) of the ground. These horizontal strains are a major cause of damage to structures in a zone of subsidence.

The main factors affecting subsidence due to partial extraction are:

* Seam thickness
* Method of mining
* Depth and width of the extracted area
* Pillar width to height ratio in bord and pillar operation
* Limit angle or angle of draw which defines the limit of detectable ground movement away from the mined area and is related to the nature of the strata overlying the seam and presence of faults
* Stowing of mine waste in the mined-out area in an effort to reduce subsidence. The fill material is generally appreciably compressible, and the method is not normally economic under present conditions.
* Inclination of the strata since in dipping strata the surface position of the subsidence trough is displaced down dip in comparison with horizontal seam workings.
* Geology variations in the types of strata lying between the seam and the surface may have a significant effect on the maximum amount of subsidence. The presence of rigid beds such as massive sandstone will affect the mode of surface subsidence. Also the presence of alluvium or material having soil properties in appreciable thickness at the surface may affect both the area of subsidence, and in the case of shallow workings, the roof conditions overlying the seam. Faults cause concentration of differential movements, and a subsidence step may occur along the surface trace of the fault plane.

Where a thorough knowledge of the foregoing factors is available surface subsidence effects can be calculated and predicted with reasonable accuracy.

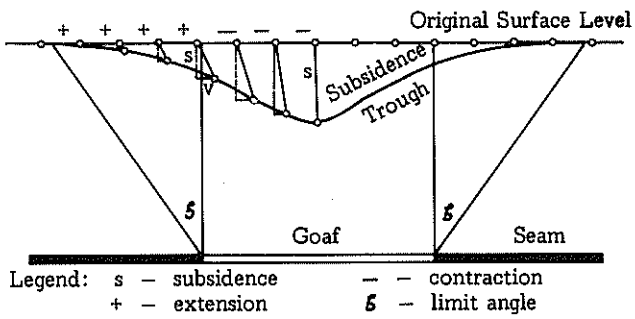

Fig.2 The differential subsidence of adjacent points results in tilt and curvature of the ground surface.

(ii) Random subsidence

Where building development is to take place over old workings of the bord and pillar type, considerable uncertainty exists as to the likely subsidence which may occur (Ref.4). Under a favourable combination of circumstances, such as a large depth of competent rock overburden, all the subsidence may have already taken place, and additional deformation due to the new loading will than be negligible. However, in an unfavourable set of circumstances, for thin overburden of a weak and friable nature, there is a risk that the additional load imposed by the new structure will cause breakdown in a roof which is already partially collapsed, leading to local subsidence of the "crown hole" type. In a particular case, partial subsidence may have occurred due to pushing of a pillar into a soft or weak mine floor, and the additional load of a structure may increase this form of subsidence.

Pillar failure may arise from one of three general causes:

* reduction of pillar dimension by slaking of the coal, erosion of the pillar sides, or by loss of material in burning following spontaneous combustion.
* reduction of pillar strength or stiffness by weathering, oxidation, or opening up of joints due to removal of lateral restraint.
* increase in load acting on the pillar from additional structural load, lowering of groundwater table, transfer of load from an adjacent failed pillar, or from renewed mining in a lower seam.

In many mining operations pillars were normally proportioned to have a factor of safety only slightly in excess of 1, and were only required to perform as a structural member during the relatively short working life of the mine. Instances have occurred both in the Ipswich area and in overseas mines where pillar failure has occurred unexpectedly during the mining operation.

Movement along a fault or the presence of rigid beds such as massive sandstones near the mine roof may form a capping which hangs up during pillar extraction and later suddenly falls over considerable areas. This is a hazardous mining condition and pillars may become overstressed even before pillar extraction occurs, giving rise to the condition locally termed a creep or crush; the term refers to progressive failure of pillars due to inadequate dimensions for the prevailing conditions.

Roof collapse into the void created by mining may be caused by one of three general conditions:

* Span widening beyond a safe limit by failure of nearby pillars, by deterioration of temporary support such as timber props, or from the progressive caving of jointed rock causing void migration upwards.
* Increased pore pressure from infiltration of water from local heavy rain or from gas pressure or rarefaction resulting from a nearby gas or dust explosion.
* Loss in shear strength due to softening, slaking or weathering of strata containing clay minerals.

(iii) Subsidence related to old mine shafts

Surface subsidence commonly result from settlement of loose fill in old access or ventilation shafts. In old abandoned mining areas common practice was to backfill shafts on a timber platform close to the surface to reduce the amount of filling required. Later rotting or dislocation of the platform may allow the fill to drop giving rise to the sudden appearance of a collapse hole at the surface. The surface collapse induced in this fashion may be considerably larger than the original dimensions of the shaft. Plate I shows a collapse hole which appeared after a period of prolonged rainfall had caused dislocation of a temporary fill platform. Subsequent filling of the shaft indicated that the previously unfilled depth of the shaft was in the order of 80 m. It is extremely important therefore to be aware of and accurately record the locations of shafts and tunnels, as generally with the passage of time, surface expression of these features becomes obliterated.

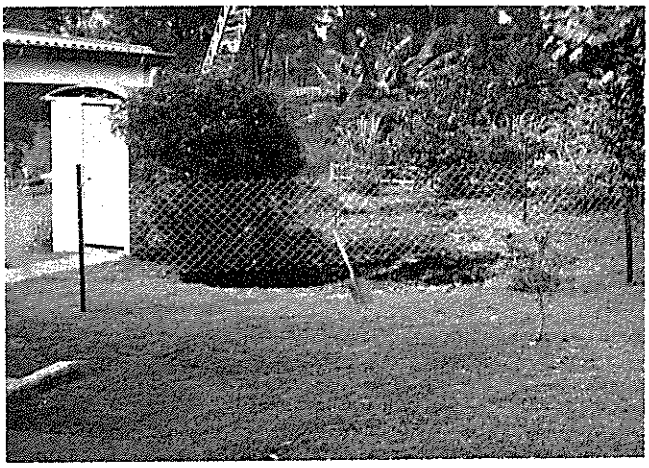

PLATE I

(iv) Relationship between geological conditions and subsidence

The effect of minor changes in geological conditions on the surface subsidence is considered by Orchard (Ref.5) to be insignificant in comparison with dimensional factors. The influence of the depth and width of the workings were felt to override geological variations unless special features were found which differed from the usual cyclic sedimentary sequence found in all coalfields.

However, accurate geological mapping is of value in assessing the areas likely to have been mined prior to the compulsory recording of accurate mine plans. The line of outcrop of the productive seams marks the zone in which old uncharted shallow workings would occur.

In parts of the Ipswich area, Tertiary sediments consisting of stiff clays occur in thicknesses up to 100 m. Where mining has occurred under this Tertiary cover, local experience suggests that it is prudent to consider only the strength of the "competent" Mesozoic rocks covering the seam when assessing subsidence potential. Accordingly, areas where considerable thicknesses of Tertiary sediments had been mapped within the Ipswich area, were considered to fall into a special category (Section 3(a)) for critical examination with respect to the possibility of void migration to the surface or the possible development of abnormally high strains for the apparent depth of cover due to random subsidence.

The surface trace of faults has an important bearing on surface movement concentrations. Geological maps, reports and supplementary air photo study may be used to define these features in a detailed assessment.

(v) Mining restrictions in relation to surface subsidence

Prior to an application for a Coal Mining Lease being approved, certain conditions or restrictions on mining are imposed by the Chief Inspector of Mines. Lease conditions vary from area to area depending on local geological conditions, proximity to abandoned workings or other possible hazards. The restrictions imposed are aimed primarily at establishing safe working conditions within the mine. However, in areas where residential development is already present on the surface, coal extraction is generally limited to 40 percent of the total available area, i.e. 60 percent of coal must be left in the form of pillars to support the overlying strata.

With this restriction surface subsidence is expected to be minimal with surface strains being less than 0.03 percent (Section 3(b)(i)). If no development has taken place or is proposed at the time of granting of the lease,and provided pillar extraction has not been specifically excluded under the conditions of the lease, it may be taken that the mining company will, wherever possible, work the pillars, the only statutory requirement being to give due notice of the intention to extract pillars.

It is also significant that lease restrictions imposed at the time of granting of the lease are valid for a period of 21 years with an option of renewal by the Lessee under the existing conditions for an additional period of 21 years. Consequently, any surface property development which has been initiated after the establishment of the lease conditions will be subject to the lease encumbrances for the duration of the lease. Thus, for any development proposal within an area held under a coal mining lease, lease conditions need to be critically examined to determine their possible impact on the development. If total extraction or random subsidence occurs, subsidence and strain effects will be large enough to cause damage to buildings above the area mined at considerable depth.

3 SUBSIDENCE ASSESSMENT

In view of the overall complexity of the subsidence problem and of economic limitations, it was clear that detailed subsidence calculation and prediction was not feasible, particularly in consideration of the size and geological complexity of the study area. A classification scheme was eventually devised which was based primarily on the cover thickness and to a lesser extent, the nature of the strata overlying the worked seam, assuming a constant thickness of workings over the entire area. Prime importance was placed on attempting to differentiate between areas in which subsidence effects were likely to intersect the surface as evidenced by the formation of crown holes, and those areas likely to be subjected to varying degrees of trough subsidence.

(a) Subsidence Categories

For the purposes of the planning study six categories of mining activity corresponding broadly to six orders of increasing severity of surface subsidence are defined in Table I. A special subdivision was erected for categories 3, 4 and 5 where less than 40 m of Mesozoic cover was included in the overlying strata.

TABLE I
DESCRIPTION OF SUBSIDENCE CATEGORIES

Category Number	Mining Activity	Thickness of Competent Cover (m)	Remarks
1	Unmined	–	Not under lease
2	Unmined	–	Lease current
2a	Unmined	–	Lease current and/or within area of potential coal reserves*
3	Mined	> 100	Single seam workings
4	Mined	>100	Multiple seam workings
5	Mined	40–100	Single or multiple seam workings
6	Mined	< 40	Single or multiple seam workings

* Potential coal reserves as determined and published by the Geological Survey of Queensland

(b) Subsidence Calculations and Predictions

(i) Bord and pillar workings

Under normal design conditions, the subsidence occurring over bord and pillar workings has been empirically related by Orchard (Ref.5) to a parabolic function of the depth (Refer Fig.1).

In a typical case, a seam 2.5 m thick mined at a depth of 100 m would produce a subsidence of 125 mm at the surface. Orchard (Ref.5) states that no normal partial extraction scheme is likely to cause horizontal strain in excess of about 0.03 percent which would cause only very slight to negligible damage to normal surface structures.

(ii) Longwall workings

Brauner (Ref.7) lists five main aspects under which calculations have been made to predict the ground movements occurring from total extraction of a coal seam by longwall methods, or alternately by extraction of pillars in a bord and pillar operation.

Kapp (Ref.8) reports measurements made at Kemira Colliery, New South Wales, over longwall panels at depths of 120 to 520 m below ground surface. The seam was mined to a thickness of 1.8 m and the maximum surface subsidence observed was 1.1 m. By comparison with a calculation based on the profile function method (Refs. 9 and 10), the following conclusions were drawn:

* The maximum subsidence observed was only 60 to 80 percent of the value calculated from British experience. The average proportion of sandstone in the strata was 70 percent compared with 35 percent in typical United Kingdom conditions.
* The observed surface strains were greater than those calculated from British precedents by 30 to 50 percent. This was because the observed subsidence profile was much sharper than calculated.
* Surface strains from 0.02 to 0.04 percent caused surface fissuring in the ground with measured widths up to 25 mm.

It may be inferred therefore, that until local experience is accumulated from actual surface measurements, accepted European calculation techniques for settlement and surface strain will give only very approximate answers, with likely errors in the range of 20 to 50 percent compared to the actual values.

(c) Origin of Depth Limits for Subsidence Categories

(i) Shallow mine workings

The stability of the mine roof in relation to the upward migration of voids produced by caving may be affected in one of two general conditions:-

* In the case where pronounced vertical jointing exerts a major influence, the width of the collapse zone will remain relatively constant since it is determined by the joint pattern.
* Where the bedding plane discontinuities have a major influence and the roof strata act as a series of beams, the breaks from the collapse of succeeding beams will tend to encroach into the mine opening until a natural pressure arch forms.

The continuing progress of either caving mechanism depends on whether the fallen material remains in place, or is removed, and on the bulking effect of the broken rock.

The bulking factor varies from about 1.5 for single-sized rock fill to about 1.1 for weak friable rock such as shale which breaks into widely-varying sizes which have a lower percentage of voids. The theoretical maximum height to which a collapse can penetrate above the mine roof for an intact muck pile is given by seam thickness divided by relative increase in volume of the rock pile (Ref.11).

For a bulking value of 110 percent, the height becomes 10 times the seam thickness (m). Sossong (Ref.12) quotes a mine in Pennsylvania where caving reached 40 feet above a 4 foot seam.

If the muck pile is removed, the upward migration of the void may continue. In the case of a steeply dipping seam where the angle of repose of the muck is relatively flat, the caved material may spread over a wide area before reaching the roof of the opening.

Wardell (Ref.13) suggests the ultimate height of collapse through solid strata may be as little as twice or as much as ten times the thickness of the seam workings. He states that a problem must be considered to exist where old mine workings are present at a depth of less than ten times the seam thickness below rock head. Germanis and Smith (Ref.14) describe in the Newcastle area (N.S.W.) the occurrence of surface depressions or potholes formed from old workings at depths from 6 m to 30 m beneath the surface.

The depth of exploration for foundation investigation required in areas containing shallow mine workings was suggested by Price, Malkin and Knill (Ref.11) to be 15 m plus the possible depth of caving which for a seam thickness of 2.5 m would be 25 m making a total depth of exploration of 40 m.

From consideration of the various reference sources and from limited local experience, a value of 40 metres was adopted as the boundary between subsidence categories 5 and 6 where the change in mode of subsidence from crown hole to trough subsidence is considered to occur. Recent experience in the Ipswich area has indicated that this value may be conservative. However, for planning purposes, it was considered to be a satisfactory upper limit.

(ii) Deeper mine workings

The upper depth limit for subsidence categories 3 and 4 was chosen at 100 metres because of the general body of local experience which had found that structural damage arising from mining operations carried out below this depth ranged in its effect from "slight" to "appreciable" without being "severe".

An analysis of the likely surface strain which might result from the hypothetical collapse of workings at a depth of 100 m, further substantiates the depth value chosen. Assuming an extraction ratio of 50 percent and a typical seam thickness of say, 2 m, the values of surface subsidence and developed strain would be approximately one half the values which would be attributable to total extraction techniques carried out under the same circumstances. Adopting the expressions for surface subsidence and developed strain given by the National Coal Board (Ref. 9), surface subsidence of 0.9 m could be expected with maximum developed tensile strain of 0.6 percent which is the approximate upper limit of permissible surface strain for conventional residential structures without special protection (Refs. 9 and 15).

(d) Data Collection and Interpretation

(i) Data sources

A search was made of all mine plans held at the office of the Mines Department, Booval and the G.S.Q. Coal Section, Goodna. Supplementary data was also obtained from the Department of Mines, Brisbane and from the respective Coal Mining Companies. All relevant publications and reports published by the Geological Survey of Queensland since prior to the turn of the century and the Powell Duffryn Report (Ref.16) were used as reference data sources.

(ii) Data interpretation

Following data collection, all mine plans were processed and seam workings identified. The outline of individual seam workings were delineated and the location of access tunnels and shafts were noted. Areas where pillar extraction was indicated were also recorded. In many instances, mine plans were found to be poorly or insufficiently annotated and in these circumstances major reliance was placed on the comprehensive report by A.K. Denmead (Ref.1) for seam identification and colliery details.

(iii) Isopach map construction

To facilitate the final subsidence assessment, an isopach (equal depth) plan covering a significant proportion of the City area was produced. This showed the depth in metres of a particular seam or sequence of seams below natural ground surface. The plan was developed by combining structural contours from geological reports with surface contour information. Thicknesses of intervening strata between seams were also determined.

Information from a large number of boreholes drilled by the Geological Survey and others was used to assist in extrapolation of cover thickness in areas where geological reports were not available. In this manner, a reasonably accurate and reliable method for delineation of the subsidence assessment categories was produced.

(e) Date Presentation – Map Overlay System

Plans relating to the subsidence assessment were prepared and presented in the form of a series of composite overlays at a scale of 1:10,000 related to a new series of topographic and cadastral base maps of the City area prepared in connection with the new Town Plan. Three types of overlays were prepared for the study, these included :

(i) Reference data overlay

The information included on the overlay was as follows:

* Identification and extent of Mining Leases held in the Ipswich Mining District as on the 1st January, 1972.
* Identification and location of working and abandoned collieries and other named workings.
* Approximate location and identification of major faults and other significant geological features.
* Location and extent of open cut mining operations.

The reference data overlays also provided a key to the appendix presented with the main report. The appendix included summary details of current coal mining leases together with details of operations of abandoned and working collieries. This information could then be related to cadastral detail by superimposing the overlay on the appropriate cadastral base plan.

(ii) Subsidence assessment overlay

The subsidence assessment overlay was a composite plan of mine workings classified according to the terms of reference described for Subsidence Categories. Areas where pillars have been extracted and the location of all known or suspected shaft and tunnel openings were included on the assessment overlay. In the case of operating collieries the direction of advance of the present working face was indicated.

(iii) Seam workings overlay

Individual composite overlay plans for each of the seams worked were prepared. In addition to the outline of the seam workings, boundaries of measured or estimated reserves known for particular seams were included identified by the particular reference source from which the information was obtained. In most cases, the extent of reserves was determined from Mines Department geological reports. In some areas, additional reserves had been proven by private drilling operations conducted by individual mining companies. However, the results of private exploration were not normally made available.

5 SUBSIDENCE CATEGORIES AND PLANNING CONSIDERATIONS

There are few areas which are entirely unsuitable for development provided adequate investigation and construction funds are available, one possible exception being in areas which are subject to continuing or periodic burning of an underlying coal seam. In relatively shallow workings, it may prove economic to fill or grout the old working to achieve an acceptable measure of stability. In assessing the likely effect of subsidence on various forms of development, the following factors must be considered and an engineering judgement made:

* What type of subsidence is likely to occur?
* What is the risk or probability of such subsidence occurring?
* What is the likely magnitude of structural damage as a result of differential settlement and surface strains?
* What will be the effect of the anticipated movements on associated services?
* What levels of structural damage are tolerable?

To satisfy the planning requirement, general recommendations were made and design criteria for structures in subsidence prone areas (Ref.14) were specified.

General recommendations and restrictions for individual subsidence categories are summarised as follows:

Subsidence Category 1: No restriction.

Subsidence Category 2: Restrictions determined by future mining proposals and mining lease conditions. Where practicable, co-ordinate development with cessation of mining activity.

Subsidence Category 3: (1) Mining activity complete: no restrictions. (2) Mining activity continuing: assess likely level of disturbance to developments proposed.

Subsidence Category 4: (1) Mining activity complete: provision of structural protection may be required subject to analysis of local conditions. (2) Mining activity continuing: limit development to single or double storey timber, brick veneer or other semi-flexible construction, with provision for flexible jointing of underground services.

Subsidence Category 5: For continuing mining activity, there is an increasing risk of appreciable damage to surface structures. Limit these areas to residential or light industrial buildings, maximum height of two storeys all flexibly jointed or with flexible cladding, with provision for flexible jointing of underground services. No major structures or major public utilities without individual site analysis.

Subsidence Category 6: These were considered high risk areas requiring supplementary investigation to establish development potential. Alternatively, they should be retained as open space or recreational areas. No major fuel or water storage areas or major public utilities. Any underground services to have flexible joints.

(a) Follow-on Investigations

The scope of this study was designed to produce information of sufficient detail to satisfy the requirements of broad scale Town Planning. In the interests of public safety, it was stressed that it would be essential to carry out more detailed studies within the mined-out and proposed mining areas to upgrade the findings of this study. It was envisaged that the cost of such additional studies would be met by the Property Developer.

The level of investigation required would vary depending on the occurrence of particular subsidence categories defined by the study within the proposed development area.

(i) Stages of investigation

The following form of staged investigation approach was suggested for areas requiring follow-up studies.

* Review and supplement all available mining data; check alternative sources - mining companies, local knowledge, libraries etc.
* If currently under lease, interview mining companies concerning proposed mining operations.

* Study air photographs to locate any faults or major lines of weakness, and any suspected old surface workings, shafts etc.
* Carry out walk-over reconnaissance of proposed development area.
* Establish overall feasibility of proposed design.
* Process data and prepare isopach plan where large developments are proposed.
* Calculate potential subsidence and produce a detailed subsidence assessment plan.
* Review assessment with proposed design and make recommendations.
* Prepare interim/final reports noting any areas requiring additional information.

The most detailed level of site investigation would be confined to critical areas where geological conditions or the status and location of old workings are uncertain. This would require a more comprehensive level of investigation, possibly including exploratory drilling, geophysical investigation or borehole camera techniques to further clarify the position.

6 CONCLUSIONS

Surface subsidence can be expected to occur either due to a continuing mining operation or to random causes which relate mainly to the presence and condition of previous mine workings. The magnitude of the surface movements are to a large extent predictable and can be calculated from a knowledge of the depth and nature of cover over seam workings, thickness of workings, percentage of extraction and mining geometry.

Of the methods available for the calculation of subsidence effects, most of these relate to experience gained in other countries or in New South Wales. There is very little information available relating to subsidence case histories in the Ipswich mining area. It would be desirable for studies to be initiated for the monitoring of subsidence movements by some suitable authority in order to develop a set of parameters applicable to the local conditions.

The approach adopted for the assessment of mining subsidence potential was adequate to satisfy the general town planning requirement. However, more detailed studies would be necessary to prove the feasibility of future development in certain areas.

The assessment of the long term stability of an area proposed for development may involve a complex and lengthy site investigation to which a staged approach is particularly suited. Investigations may require the incorporation of special design features to withstand possible subsidence effects. These measures will be more costly than investigations carried out under normal circumstances and the developer should make due allowance for the additional costs likely to be incurred when developing a current or previously mined area. Adequate preliminary investigation should dictate the most economical forms of development.

To avoid possible sterilization of important energy resources or of the future development potential of surface areas, it was suggested that consideration be given to the establishment of a scheme for compensation for damage to property due to mining subsidence along similar lines to that presently operating in New South Wales. The background to the establishment of the legislation is given in Ref.17.

Where possible, through co-ordinated planning between the mining companies, the property developer and the City Council, areas where mining operations are planned and approved should be mined prior to the commencement of the construction phase of any development, so that valuable coal will not be sterilised and the development may proceed at a later date without high risk of property damage once the mining operations have ceased or moved away from the area to be developed.

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