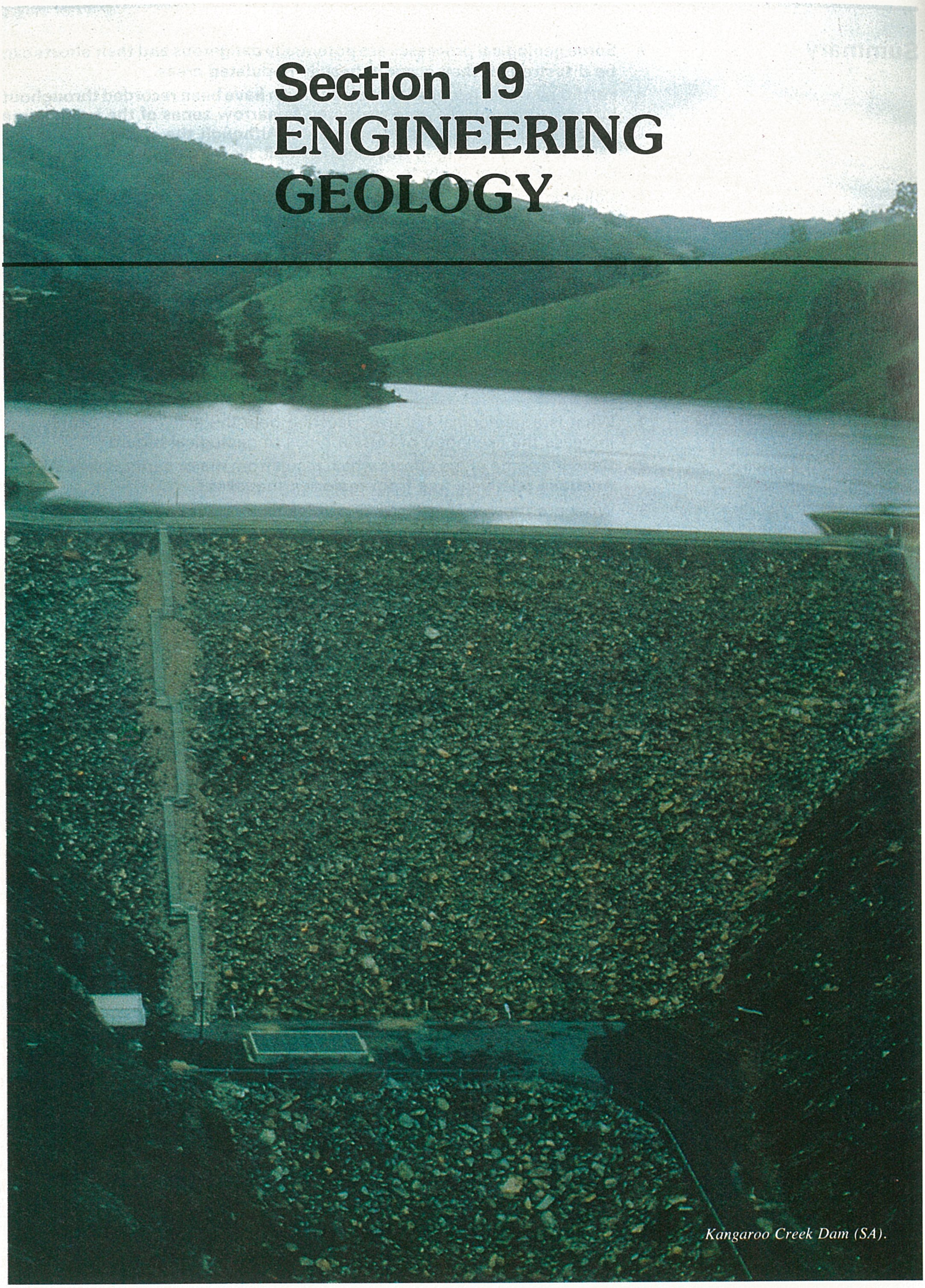
Section 19
ENGINEERING GEOLOGY



Kangaroo Creek Dam (SA).

From: Clark, I.F. and Cook, B.J. (eds.), 1983, Perspectives of the Earth. Australian Academy of Science, Canberra, 490-503.

Chapter 19a
CHOOSING A SITE

Introduction

There are many geological factors which must be considered when siting any major construction such as a multi-storey building, a bridge or a dam. In this chapter we will look at the way in which an engineering geologist approaches the task and the consequences of inappropriate advice. Failure of a dam, for example, could bring disaster to many activities downstream. There are dams near almost every major town in Australia. The siting of these depends upon geological knowledge as well as other information.

During the last thirty years increasing numbers of geologists have been involved in applied activities other than mineral exploration and mining. One of these activities is engineering geology, which is geology applied in civil engineering.

Why is geology needed in civil engineering?

The civil engineer designs, builds and maintains structures such as:

- multi-storey buildings
- bridges
- dams (for water supply, flood control, hydroelectric power generation and irrigation)
- tunnels, underground structures
- pipelines
- canals
- coast protection and land reclamation works
- roads, airfields

In carrying out this work, the civil engineer is one of the main modifiers of our environment. Many civil engineering structures provide us with some protection against natural hazards. Some examples are: dams for protection from both droughts and floods; cyclone and earthquake-resistant buildings; avalanche-deflection structures on alpine roads; and breakwaters to protect ships and harbour facilities.

Since the Second World War, the civil engineer has been assisted in his work by great improvements in construction materials, and these, together with the use of computers in design and new construction techniques and machinery, enable structures to be built which are larger, stronger, and usually more economical than before. One might imagine that with continued progress in chemistry, physics and mathematics there is no limit to the size and complexity of engineering structures, and that they should become progressively safer. In practice this has not proved to be so. All engineering structures have to be supported or 'founded' on or within natural ground which consists of soil or rock. If this natural ground is not strong enough or stable enough, the engineering structure may be damaged or even fail disastrously regardless of the degree of perfection of the man-made components.

During the last twenty years there have been eight major reservoir disasters where failure was related to inadequate understanding of the foundations. There has also been a much larger number of less disastrous, but nevertheless expensive, reservoir failures related to the foundations rather than the steel or concrete. Therefore, it is vital when building any major construction, to carefully study the ground on which it is to be built. There are no shortcuts because each site is different. Factors such as combinations of soil and rock type, presence of faults, position of the water table and many others have to be considered. Full consideration of these factors is a great challenge to the engineer who is being asked to build larger, more complex, more economical structures.

What does the engineering geologist do?

The geological work involved in the construction of any major civil engineering project can be divided into stages

Feasibility and site selection.
This stage includes the geological and engineering feasibility studies, and the environmental impact study. In the geological studies, several alternative sites are explored to check for their suitability. Geological features such as soil and rock types, faults, potential for landslides, earthquake activity and other particular features are considered. After all of the sites are investigated the most suitable one is chosen.

Design and specification
The geological information obtained in the first stage provides the basis for the design of foundations and the assessment of the availability of suitable construction materials. More detailed geological investigations are involved in this second stage. These investigations include detailed geological mapping and drawing of cross-sections. Aerial photographs and published maps may be used to provide some information, but for detailed mapping the geologist must cover the ground carefully on foot.

The map produced will show the types and distribution of the soils and rocks in the area, and it will also show the orientations of structures (often called discontinuities) such as bedding and foliations. This is important because these discontinuities affect slope stability. For example, if a road cutting is made in which the rocks are dipping towards the road, the possibility of rock falls is much greater than it would be if the road cutting was made in a position in which the rocks were flat lying or dipping away from the road (Figure 19.1). Other features which geological mapping reveals are the presence and orientations of faults which may affect the foundation of the structure.

Where excavations or tunnels are involved, it is essential to obtain information about the underground rocks and water by means of drill holes and trenches or deep pits. These not only provide information about the rock types but also provide samples for testing rock properties such as strength and permeability. The type of sampling is different for each construction. Dams, bridges or buildings require closely spaced, relatively deep drill holes, whereas sites for railways or roads need relatively shallow drill holes widely spread along their course.

The geologist must also look at the properties of the soil, especially in constructions which require shallow excavations or the design of foundations and slopes. Many different tests are carried out which indicate to the engineer the way in which the soil will behave.

In many investigations geophysical surveys are involved. These are methods which measure the physical characteristics of rocks such as density, magnetic, elastic and electrical properties. Underground structures, such as buried channels, can often be detected by using these methods. Geophysical surveys, by seismic and electrical methods, are specially useful because they provide valuable data quickly and can save the cost of extensive drilling programmes.

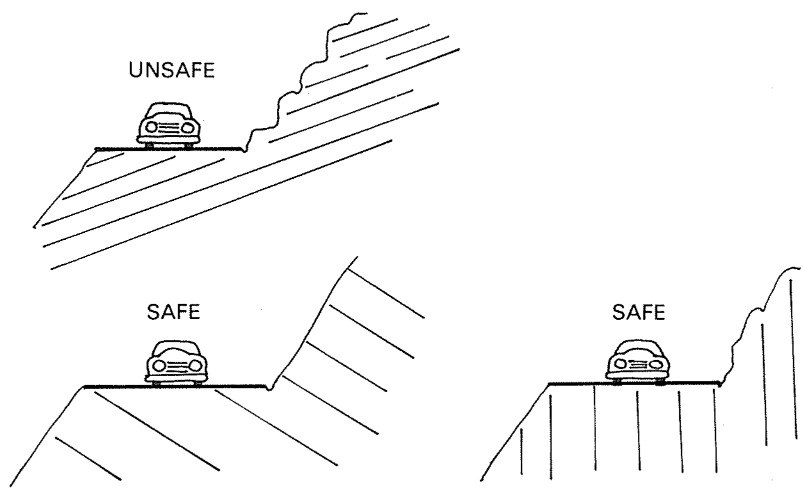
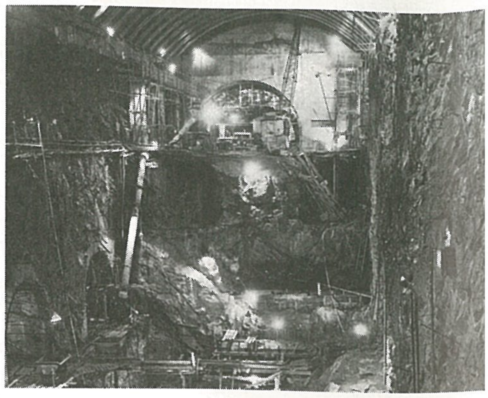


Figure 19.1
The diagrams show how the dip of bedding may produce either safe or unsafe road cuts.

Construction stage
During construction the engineering geologist works as part of the construction team making a detailed record of the geological conditions which are exposed in all excavations. As a result of these observations it may be necessary to modify designs because conditions are different from those expected. Should the project ever fail or malfunction, the observations also provide a permanent record of the geological conditions which may be used to help locate the cause.

Figure 19.2
Modern freeways should not have any sharp curves or steep grades. This means that the engineering geologist's advice will be sought as to where the deep cuts and high fills must be made.

Figure 19.3
Tunnels and underground power stations such as the one shown here must be placed where there is little danger. If there is the possibility of problems occurring, adequate precautions must be taken and here the engineering geologist's advice will be invaluable.



Operation and maintenance stage

For large and complex projects such as dams and underground buildings, the engineering geologist involved in the planning and construction stages may be included in a group which checks that the project, and the soil or rock on which it is built, are performing as assumed in the design. If foundation problems occur or are suspected, the engineering geologist can use the construction records to help discover the likely cause.

Development of engineering geology

Figure 19.4
An arch dam which failed. Proper geological studies may have prevented the failure.

In the past, many engineers who have designed major constructions have not had a good understanding of natural processes and products. On the other hand, many geologists have not had a good understanding of the problems of the civil engineer, and of the deformation and strength properties of weathered rocks and soils.

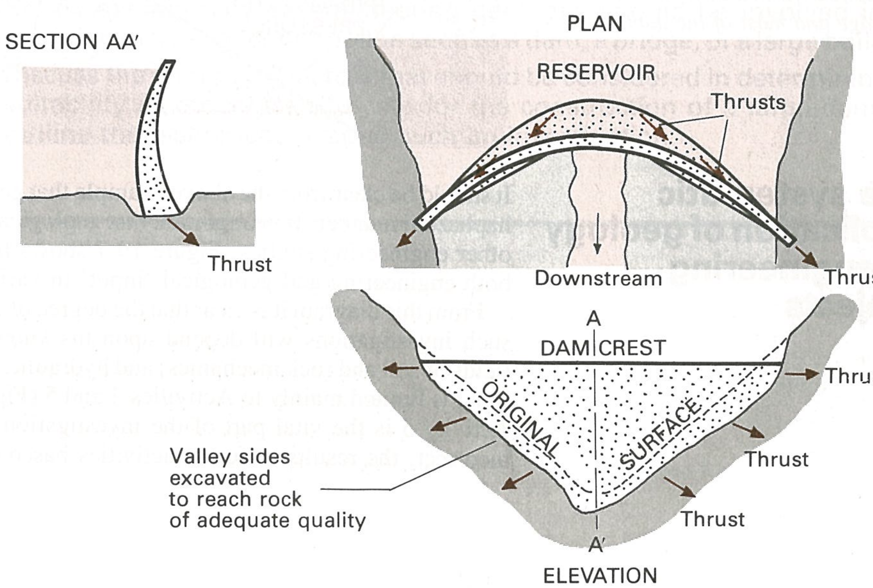
Because of these differences in knowledge, there have been times when engineers have ignored or misunderstood geological advice, and other times when the geologist has misled the engineer by providing geological information which was either inaccurate, or accurate but not relevant to the engineering project. The most serious problems have arisen when neither the engineer nor the geologist has recognised the significance of relatively minor geological features such as minor faults, joints, or thin seams of weathered rock which affected the stability of steep slopes or the foundations for dams.

Australia has been among the world leaders in overcoming these problems. The initiative for this came mostly from the civil engineering profession, which set up specialist groups to handle the geological problems on major projects. An early example of a large group of this kind was the Snowy Mountains Authority. Under the leadership of Mr D. G. Moye, this group rapidly built a world-wide reputation as it worked as a team with the engineering staff on the successful planning and construction of the Snowy Mountains Hydroelectric Project. Today in Australia there are about 300 engineering geologists working in Commonwealth and State government organisations, consulting engineering firms, and quarrying and mining companies.

What happens when bad decisions are made?

Before we consider this question, it must be remembered that most major civil engineering constructions are successful and have long lives. Nevertheless, it is useful to be aware that if an engineering geologist makes a mistake in any one of the areas described, at best the work can be wasted, but at worst it can have disastrous consequences. It is therefore necessary for engineers to study disasters and learn from any mistakes. This can be illustrated by considering the failure of an arch dam in Europe in 1958 (Figure 19.4). This type of dam imposes high, concentrated forces or 'thrusts' on its foundations, as shown in Figure 19.5.

Figure 19.5
An arch dam is a thin concrete wall or 'shell' founded on rock in the floor and sides of the valley to be dammed. As the reservoir fills, the water load against the arch causes it to flex slightly and transmit the load sideways and downwards as 'thrusts' into the foundation rock. The rock must have sufficiently high strength and elastic modulus to support these relatively large forces without deflecting more than a few millimetres. Excessive deflections can cause the concrete shell to crack.



The dam in question was built in a steep gorge cut into schist bedrock. The geological situation which was revealed *after* the failure is shown in Figure 19.6. Beneath one side of the gorge, and under the concrete wall of the dam, there was a continuous, minor fault filled with thin seams of clayey silt, lying almost at right angles to the foliation planes of the schist. The schist also contained many joints or fine cracks parallel to the foliation plane.

The fault intersected with a foliation surface to form a wedge of rock which was effectively isolated from the main mass of schist forming the valley wall. When the reservoir filled with water, this wedge of rock, including the part of the concrete dam founded on it, was forced out and downstream. This caused the concrete arch to break up and to be largely washed away. Several hundred lives were lost in the resulting flood.

The failure of this dam was caused mainly by the failure to observe and provide relevant geological data. Instead, the data provided to the engineer centred around descriptions of the mineral composition and texture of the schist. This information was probably accurate, but of little relevance to the likely behaviour of the foundation under the forces produced by the dam. The presence of thin weak seams was not revealed by the geological investigations. Indeed, it seems likely that the thin seams were not looked for, and possibly the geologist had not fully understood the principles of arch dam operation (Figure 19.5).

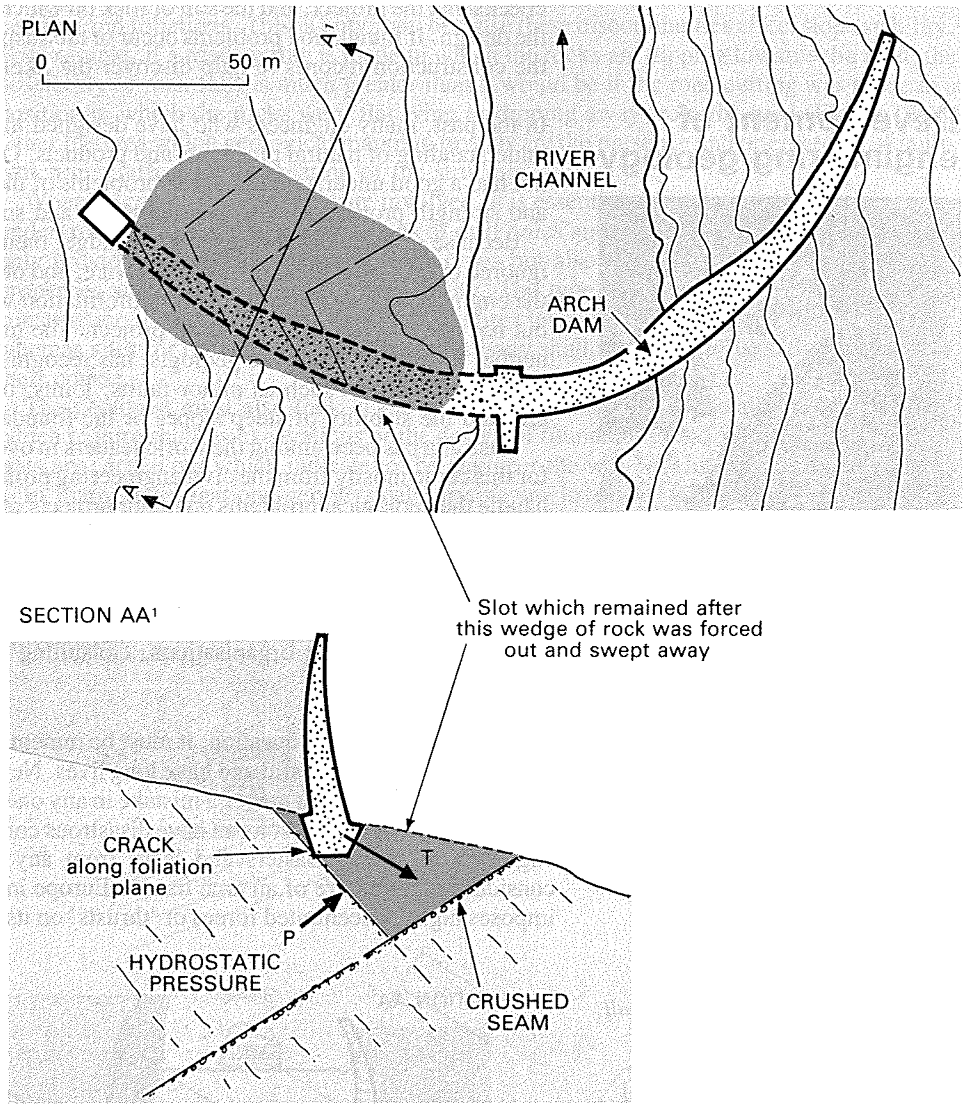


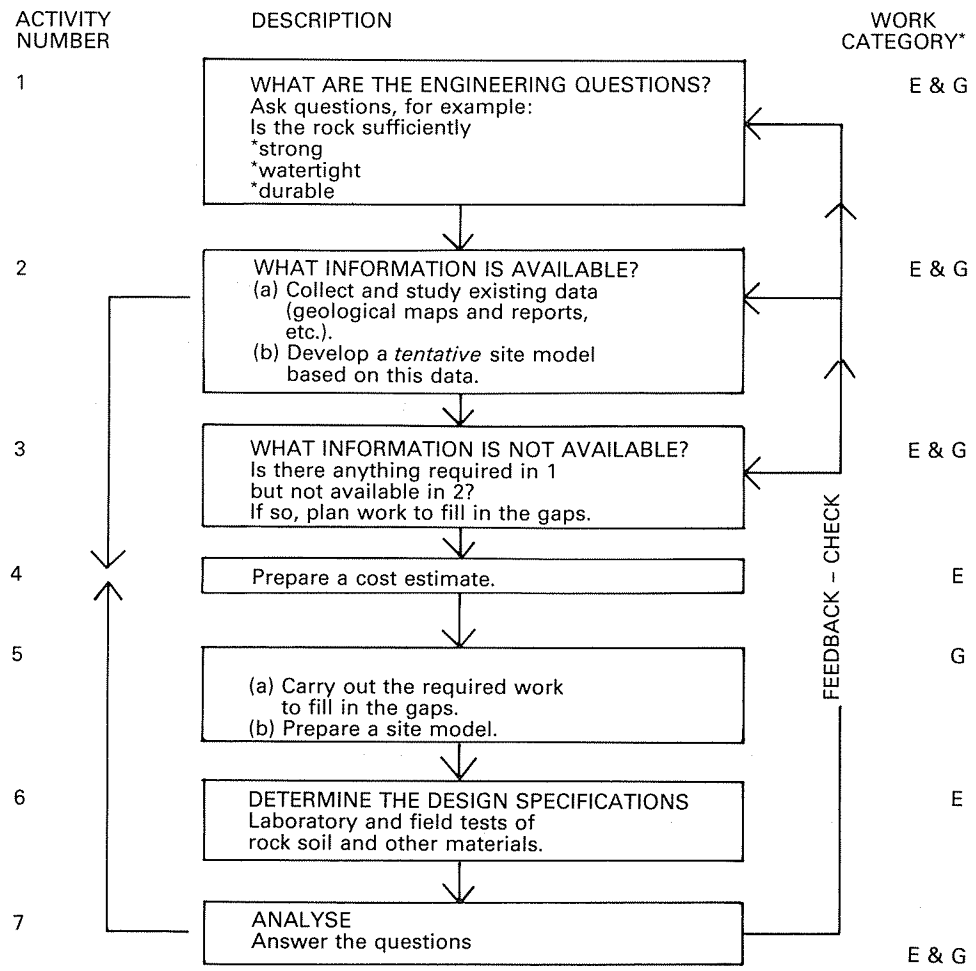
Figure 19.6
The geological situation of a dam that failed. The failure sequence was as follows:
1. *A crack parallel to foliation planes intersected with a crushed seam to effectively isolate a triangular wedge of rock under most of the left side of the dam wall.*
2. *Reservoir water seeped into this crack giving rise to some hydrostatic pressure on the upstream face of the wedge.*
3. *The wedge moved slightly under this pressure, causing slight opening of the crack. Progressive opening then occurred, with full reservoir hydrostatic pressure acting on the total area of the face of the wedge, giving rise to the very large resultant force.*
4. *The rock wedge was now being acted upon by two main forces, the dam thrust (T) and the resultant hydrostatic force (P). The resultant of these two forces was of sufficient size to force the rock wedge to move upwards and downstream, tearing away the left-hand side of the concrete arch. The rush of water which followed washed away the rock wedge and most of the dam wall.*

The systematic application of geology to engineering projects

It should be clear from the above example that geology cannot be applied to engineering in a haphazard manner. It is important that geological studies are carried out at the same time as other engineering studies. Figure 19.7 shows how such an investigation proceeds, using both engineering and geological 'input' in various activities.

From this diagram it is clear that the degree of involvement of the engineering geologist in such investigations will depend upon his knowledge and experience in the engineering fields of soil and rock mechanics, and hydraulics. Without much expertise in these areas his input is limited mainly to Activities 2 and 5 (Figure 19.7). It should be clear however that Activity 5 is the vital part of the investigation because should the geological picture be incorrect, the results of future activities based on this picture will be incorrect.

Figure 19.7
Activity flow in subsurface engineering studies.



*E: Mainly engineering
*G: Mainly geological

Summary

1. **The local geology of an area is important when planning a major construction. The role of the engineering geologist is to ensure that proper assessment of geological information is made during the planning and building of a project.**
2. **Engineering geologists prepare maps which indicate all aspects of the geology of the construction site. They also use geophysical surveys and drilling to indicate the characteristics of the rocks below the surface.**
3. **It is essential that engineering geologists have a good understanding of the problems of a civil engineer. In turn, an engineer must have a knowledge of natural processes and products.**

Revision Questions

1. Briefly explain why an engineering geologist should be involved in the planning of a major construction such as a dam, a bridge, or a large building.
2. Discuss the geological factors that should be considered in determining the suitability or otherwise of a site for the construction of a large dam and outline the techniques used in such an investigation.

Chapter 19b CASE STUDY: THE KANGAROO CREEK DAM PROJECT

Introduction

If you were designing and building a dam to provide water for a large town, where would you build it? At first the answer seems simple. You need a river which would provide enough water to fill the dam and a site where the valley is deep and not too wide. We know from the previous chapter that the geological conditions present in the site area must be considered, and we have seen the consequences of poor geological planning.

In this chapter we will work through a project from the early planning to the final site selection and design stages. A lot of time and a lot of money are spent planning all civil engineering projects, but the time and money spent are small when compared with the consequences of poor or inadequate planning.

Kangaroo Creek Dam was built during the period 1967-1970, as part of the water supply system of the city of Adelaide. The dam is located 20 kilometres north-east of the city in the gorge of the River Torrens (Figure 19.8). Downstream from the gorge this river passes through the suburbs and city, and so the consequences of a sudden dam failure would be disastrous. The history of the planning and construction of this project provides a good example of engineering geology carried out systematically and fruitfully.

Investigations for the arch dam proposal

The site for the dam was selected mainly because of its topographic suitability. Initial examination of the site showed many outcrops of schist and gneiss on both banks of the river, and it appeared possible that the rock mass at 2 to 5 metres depth might provide a good foundation for the economical construction of a thin arch dam. However, it was decided to carry out a very thorough site investigation, bearing in mind the failure a few years earlier of an arch dam in Europe (see Chapter 19a) which was located on schist and gneiss.

Questions to be answered

The site investigation had to answer the following questions.

1. How much weathered rock (overburden) will have to be removed to reach rock of sufficient strength, elastic modulus and durability?
2. How impermeable is the rock at this depth?
3. Does the rock mass contain any weak seams or zones which might erode or dissolve, or allow the dam to fail by sliding downstream?
4. Are there any potentially active faults at or near the site, and what allowance for earthquake shaking should be made in the dam design? Will filling of the dam with water cause seismic activity?
5. After completion of the dam, will the sides of the reservoir remain stable during rises and falls in the reservoir level?
6. Will the rock underlying the river bed downstream from the dam require protection from erosion when floodwaters are passed over the spillway of the dam?

The investigation took about eighteen months to complete and involved the following activities.

1. Review of the regional geology and earthquake records.
2. Air photo interpretation.
3. Detailed geological mapping on 1:2000 scale of the storage area (Figure 19.9) and 1:250 scale of the dam site (Figure 19.10) aimed mainly at the location of faults and landslip scars.

4. Geophysical (seismic refraction) traversing to check the limits of landslipped materials and of wide fault zones.
5. Excavation and mapping of test trenches to show the rock structure below the ground surface.
6. Drilling twenty diamond boreholes and logging of the rock cores obtained.
7. Permeability testing of the abutments, by pumping water under pressure into the boreholes, and measuring the leakage rates.
8. Excavation of two test tunnels in the south abutment.
9. Laboratory testing to determine the strength, elasticity and other engineering properties of the rocks and seam materials at the site.
10. Analysis of the results of all of the above activities using geological plans, cross-sections and models.

Assessment of regional geology

The site is located near the eastern edge of the Mount Lofty Ranges as shown on Figure 19.8. The ranges are formed of folded sedimentary and metamorphic rocks, mainly Precambrian in age. The first uplift was by folding and faulting during early Palaeozoic time. The mountains thus formed were subsequently almost levelled to a peneplain by weathering and erosion which dominated between the Ordovician Period and the Tertiary Period. During Tertiary time, differential block movements along some of the ancient faults gave rise to the present Mount Lofty Ranges as a series of uplifted blocks, bounded to the west by a sunken trough known as the Saint Vincent Basin. The Torrens River Gorge, in which the dam is located, has been cut down through the uplifted blocks since Tertiary time.

The published geological map showed the site to be located in a belt of schists and gneisses of older Proterozoic age. It also showed the Kitchener fault passing within a few hundred metres of the site. This fault was judged to be a northern branch of the Eden-Burnside Fault, one of the main faults along which mountain-building movements had occurred during Tertiary time. Small adjustments along the Eden-Burnside Fault at about 2 kilometres depth were believed to have caused an earthquake in 1954. A check of seismic records showed that minor seismic activity had also been recorded near the line of the Kitchener Fault, 10 to 20 kilometres north-east from the dam site.

Geological mapping at and near the site

The air photo interpretation and 1:2000 scale geological mapping showed the Kitchener Fault to pass through the storage area about 200 metres from the dam site. The valley slopes along and near the line of the fault zone showed evidence of ancient and currently active landslip movements. The largest mass of landslipped material was beneath a saddle 600 metres south-west from the dam site (Figure 19.9). This mass showed several large cracks

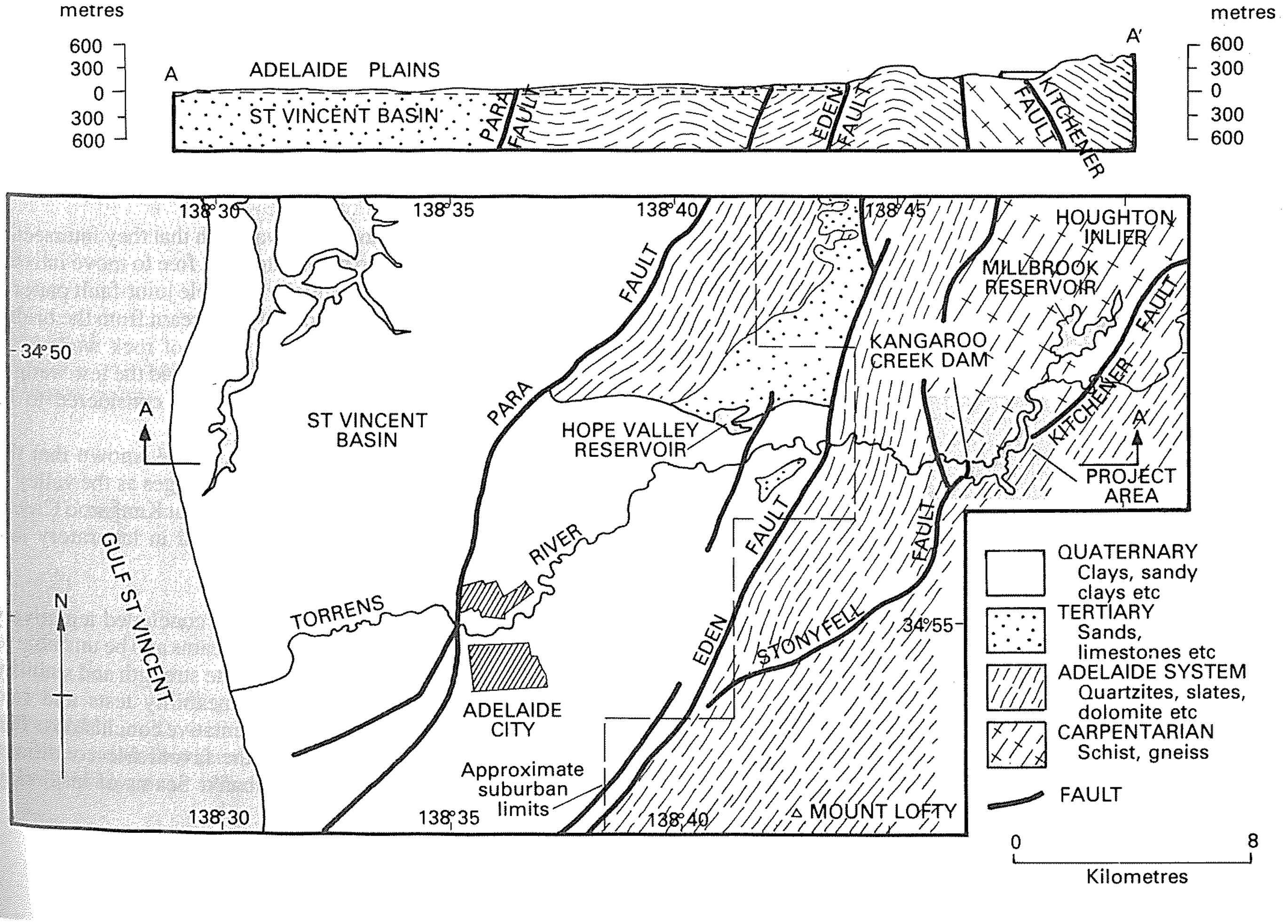


Figure 19.8
Location map for the Kangaroo Creek Dam east of Adelaide (SA).

and fresh escarpments up to 1.5 metres high. Drilling and seismic refraction traverses indicated that the depth of landslipped material could be up to 80 metres and that more than 2 million cubic metres of the hillside was affected.

From these studies it was concluded that the Kitchener Fault showed indications of continuing minor activity, and that the past and presently active landslip movements may have been triggered by earthquake shocks.

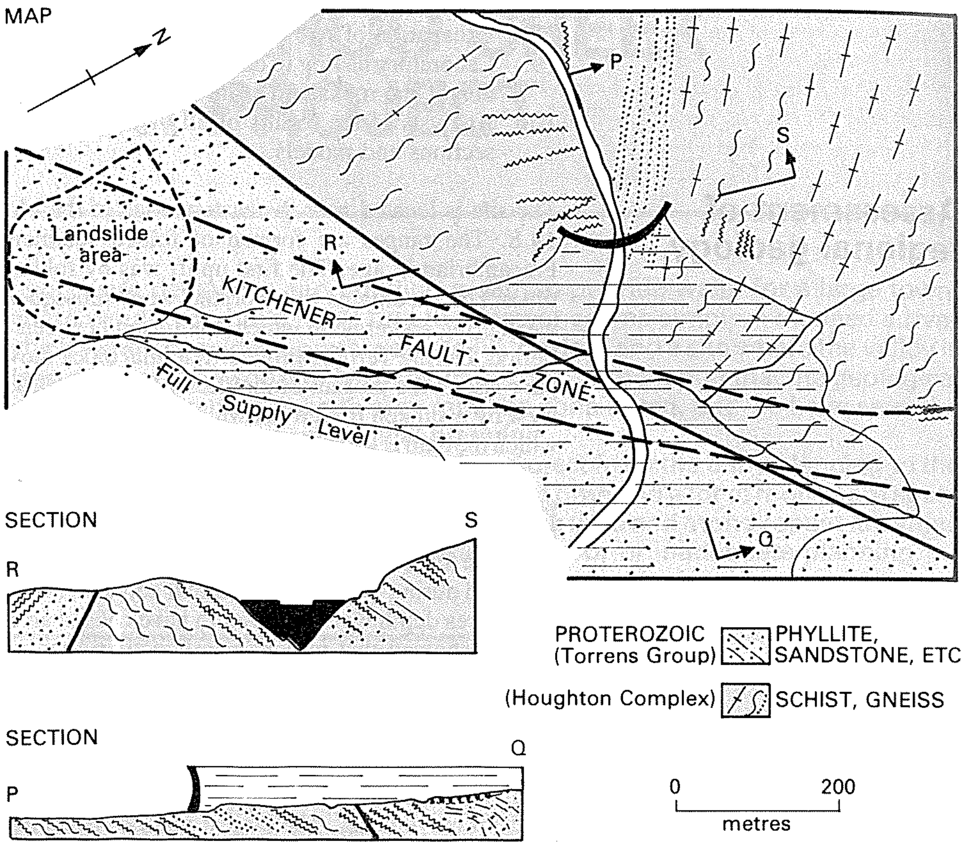


Figure 19.9
General geology of the area that was investigated for the construction of an arch dam at Kangaroo Creek (SA).

The steep-sided gorge at the dam site showed cliffs of gneiss on the northern side and scattered outcrops of quartz-sericite schist on the southern side. The very detailed outcrop mapping, summarised in Figure 19.10, showed that the foliation planes in the schist and gneiss were striking obliquely to the river and dipping 45 to 60 degrees to the north-east. Several minor faults containing sheared and crushed schist were exposed in the road cuttings, and these and similar minor faults were inferred to occur beneath the soil-covered gullies which separated the schist outcrops on the south bank. Most of the minor faults were parallel to the foliation planes in the schist and gneiss. The metamorphic rocks were also intersected by many joints.

On the south bank the pattern of the joints and minor faults was such that they intersected to form wedge-shaped masses of rock which tended to be isolated and free to move into the valley or towards the river. This was recognised as a potentially unstable joint-fault pattern, and it was inferred that the two small landslide scars immediately upstream from the bridge on Figure 19.10 had formed as a result of the downslope movement of rock wedges.

On the north bank there were less faults and joints in the gneiss cliffs, and the few wedges formed by joint-fault intersections plunged into the hillside and were considered to be stable.

From past experience, and from model and theoretical studies, it was known that the stress increases on the rock close to the bottom of all steep V-shaped gorges as the valley is deepened by river erosion (Figure 19.11). This situation was confirmed at Kangaroo Creek, when sheet-joints (Figures 19.12 and 19.13) similar to those formed in laboratory test models were found in the gneiss cliffs on the lower north bank.

Subsurface investigations

As a result of the regional and detailed geological mapping, it was concluded tentatively that the left abutment rock mass would contain a number of crushed seams and be unstable to considerable depth, and that the right bank rock would be of adequate strength and stability at shallow depth. The programme of diamond drill holes, permeability tests and two exploratory tunnels was then carried out, aimed at checking these tentative conclusions. The results of this work, summarised in Figure 19.12, confirmed the favourable conditions beneath the north bank and the worst predictions for the south bank. Seams of infill clay

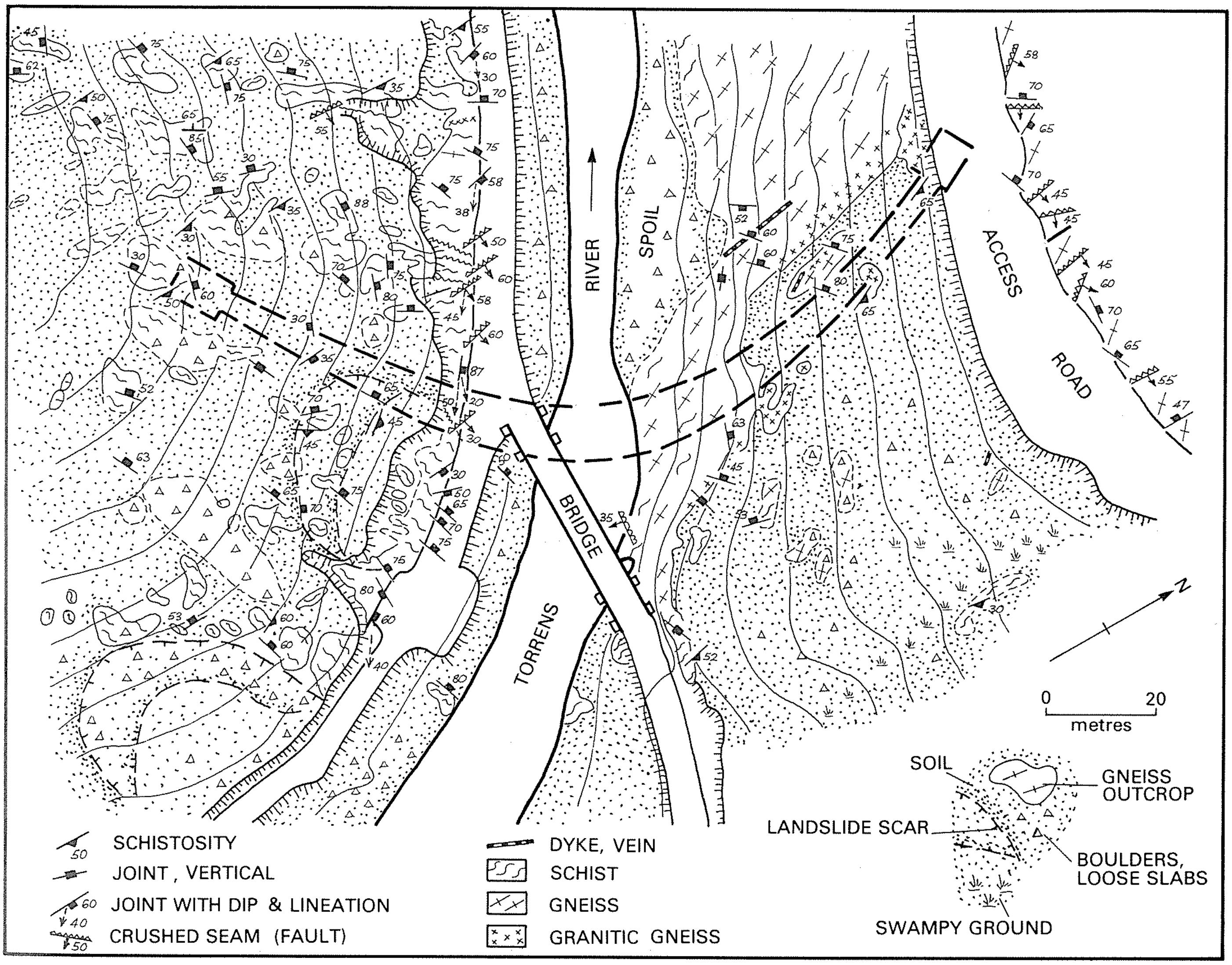


Figure 19.10
Detailed geology of the dam site.

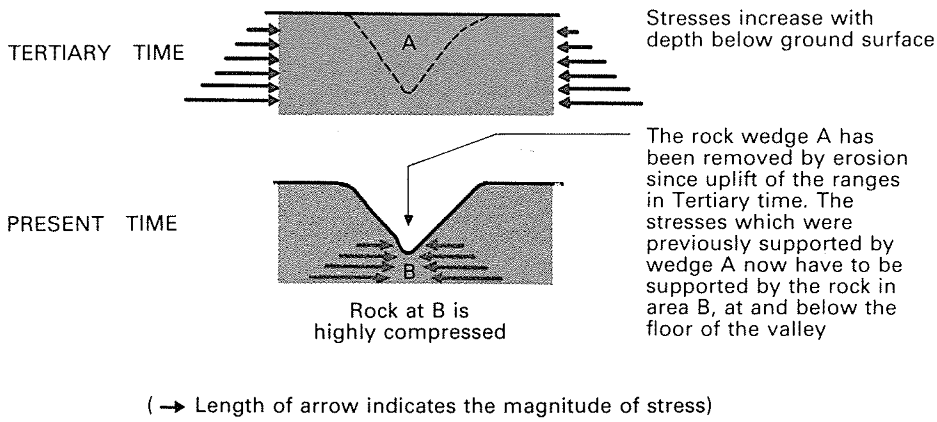


Figure 19.11
Rock stresses are high at the bottom of V-shaped valleys.

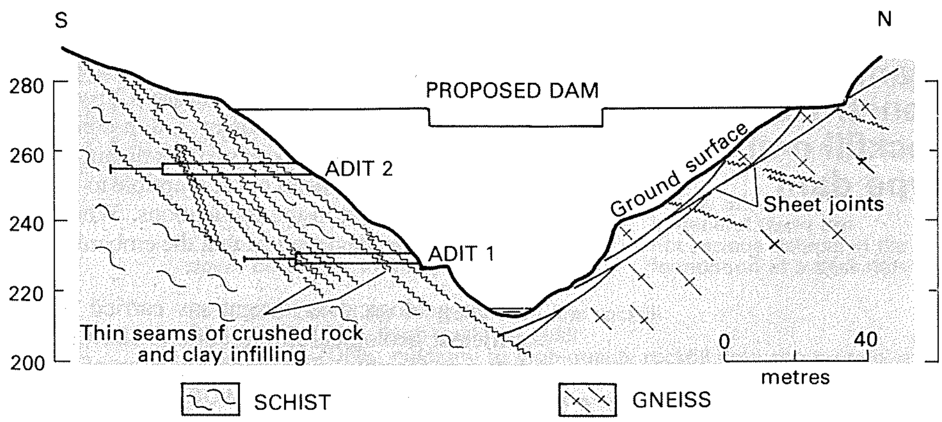


Figure 19.12
Tunnelling and drilling reveal the detailed geology of the valley walls.

which had been washed down from the surface as shown in Figure 19.14 were found to depths of 28 metres below ground surface, indicating that mechanical opening up of joints had occurred to at least that depth during the valley downcutting. Minor faults containing fine-grained crushed rock 5 to 50 millimetres thick occurred throughout the site area at all depths at intervals of 2 to 10 metres.

Reasons for abandoning the arch dam proposal

Laboratory tests on samples of the schist and gneiss showed that fresh rocks were quite adequate to support the loads which would be imposed by the proposed arch dam without excessive deformations. However, because of the seams of infill clay and crushed rock, it was appreciated that the mass of schist forming the southern side of the valley would be made weak and compressible.

Consideration was given to a proposal for washing out the seams by flushing with water down closely-spaced boreholes, but based on experience elsewhere, this was judged to be impractical. Very deep excavation to locate the foundation beneath the most unstable seams was also considered, but was not favoured because of the high cost of excavation and additional concrete, and because of likely instability of the excavation walls during construction.

It was appreciated that the investigation had not shown the construction of a safe arch dam to be impossible. Even with the exploratory tunnels and boreholes, it was not possible to predict the actual geological conditions. However, the designers took heed of the statement by an eminent foundation engineer when commenting on the failure of a dam in Europe: 'If the failure of a structure would involve heavy loss of life or property, the structure should be designed in such a way that it would not fail even under the worst foundation conditions compatible with the available data.'

At this stage the designers decided to abandon the arch in favour of an embankment type dam. Factors taken into account in making this decision included the following.

1. The foundations on the south bank were, as already discussed, unfavourable for a thin arch structure.
2. The foundations were clearly adequate for an embankment type dam.
3. An embankment type dam would be less susceptible than a thin arch dam to damage due to earthquake shaking or landslides into the storage.

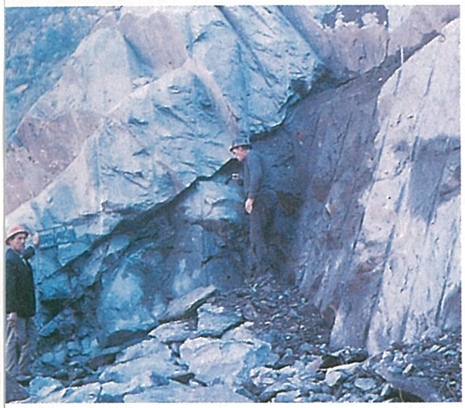


Figure 19.13
Sheet-joints are potential zones of weakness in the valley walls.

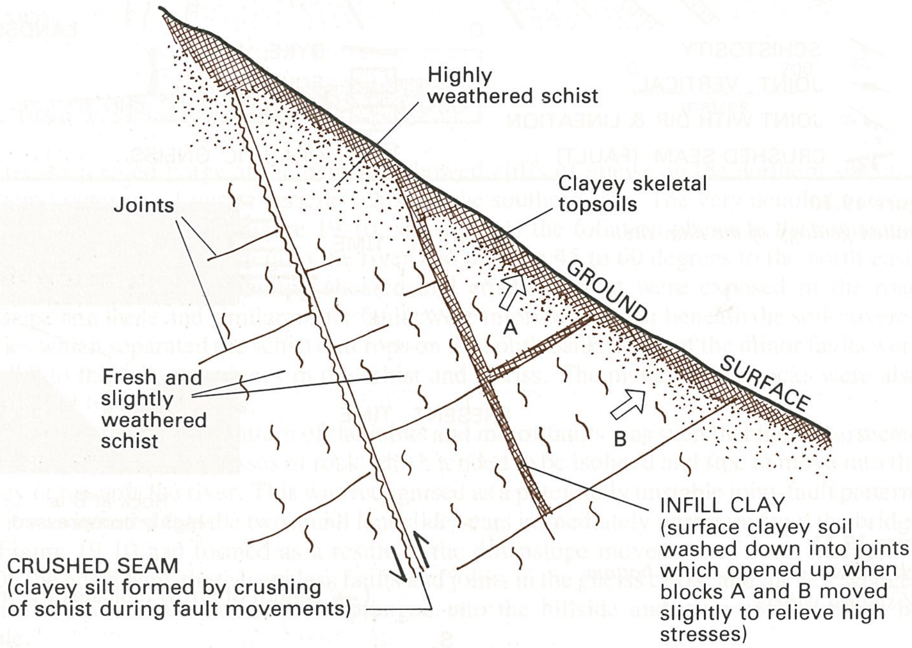


Figure 19.14
Seams and joints are sites of potential weakness in the valley sides.

Planning and construction of the rockfill embankment type dam

An embankment type dam is a very thick, stable mass of compacted earth or rock fragments, usually made effectively impervious to water by means of an internal 'core' of clayey materials (Figure 19.16) or by a thin concrete membrane or **deck** on the upstream face (Figure 19.17). Embankment dams do not impose concentrated high loads on their foundations, and are in general not susceptible to the same problems as concrete dams if thin weak seams are present in the foundations. Where unstable areas of foundation occur, the dam can usually be designed so that the embankment can act as a support to the hillside (Figure 19.18).

The geological investigations carried out for the arch dam proposal had provided sufficient geological information to show that construction of some type of embankment dam was feasible. Following rejection of the arch proposal, the project therefore moved directly to the design stage.

Figure 19.15
The major types of dam construction and details of their requirements.

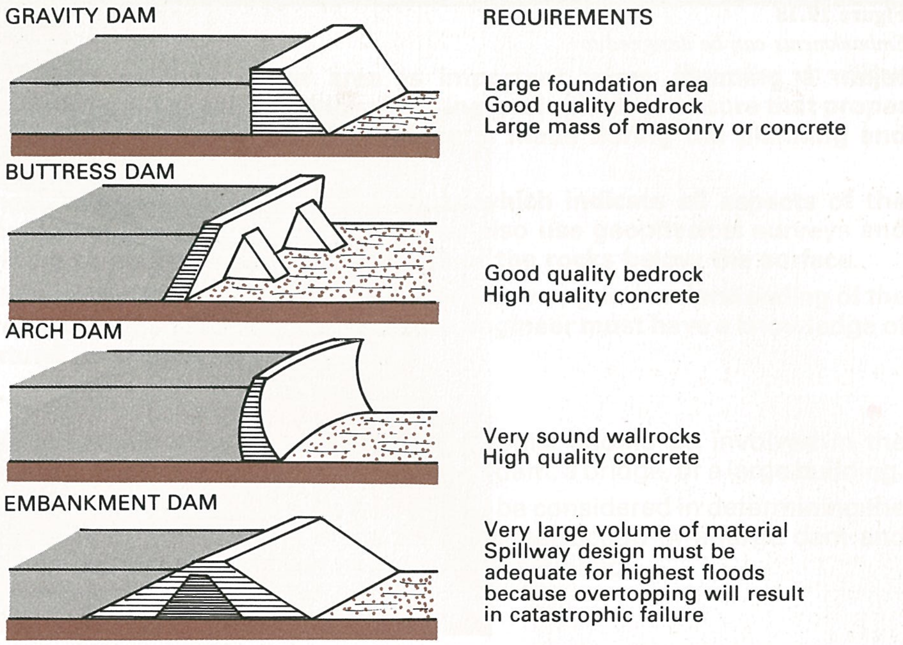
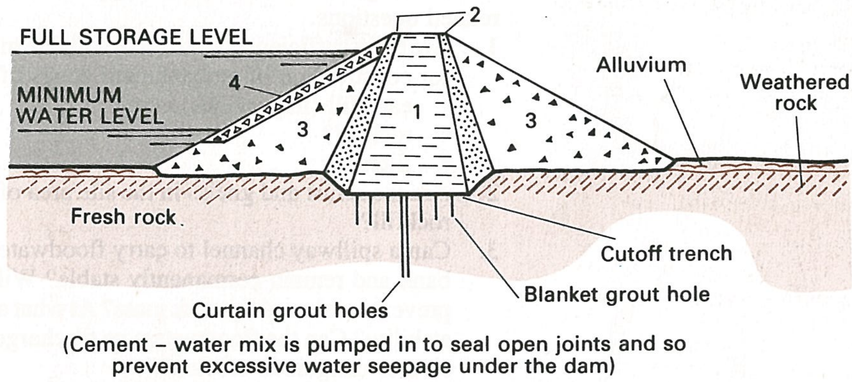
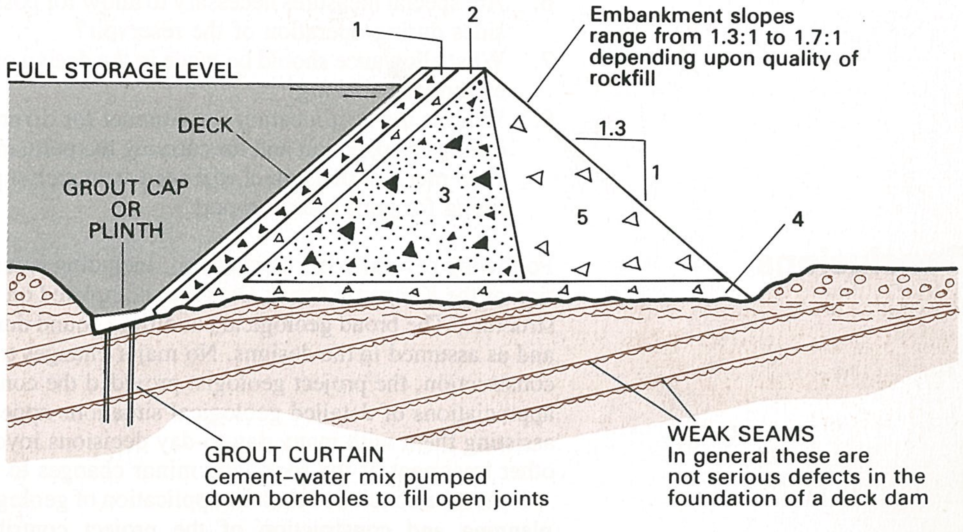


Figure 19.16
Construction details of an earth and rockfill embankment dam.



1 CORE: clayey materials, impermeable
2 FILTER: sand to prevent core material moving into voids in rockfill
3 ROCKFILL: main weight & strength of dam–quarried rock compacted in layers
4 RIP-RAP: very large rocks to protect dam against erosion by waves

Figure 19.17
Construction details of a rockfill dam with a concrete deck.



1 BEDDING ZONE: for the concrete—fine rockfill
2 DRAINAGE ZONE: high-quality rockfill
3 UPSTREAM ZONE: medium- to high-quality rockfill (low compressibility)
4 DRAINAGE ZONE: high quality rockfill
5 DOWNSTREAM ZONE: medium- or low-quality rockfill

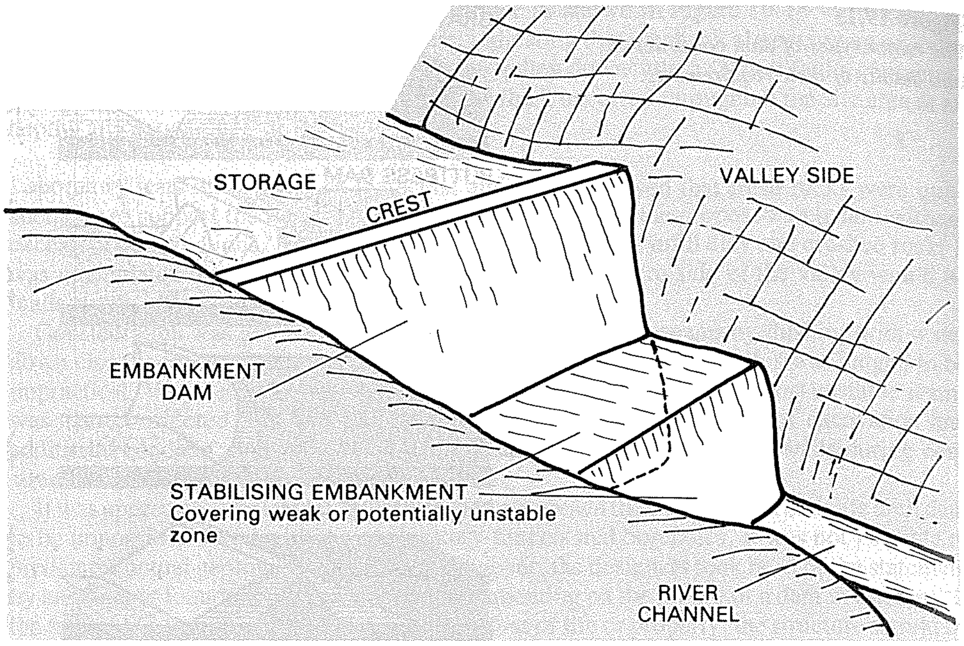


Figure 19.18
Embankments can be designed to stabilise the valley wall.

The design of an embankment type dam required answers to the following geology-related questions.

1. Are there sufficient quantities of suitable materials close to the site and readily available for construction of embankment zones of the following types:
   - earthfill (impervious) core?
   - rockfill?
   - filter?
2. Are the schist and gneiss in the site area of sufficient strength and durability for use as rockfill?
3. Can a spillway channel to carry floodwaters past the dam be excavated into the south bank and remain permanently stable? Will such a channel require concrete lining to prevent erosion of the rock mass? At what angle must slopes be cut to ensure permanent stability? Can the floodwaters be discharged from the spillway without causing excessive or dangerous erosion?
4. How much overburden (weathered rock and soil) needs to be removed to reach foundation rock which can support the weight of the embankment without excessive deformation?
5. Can rock be reached, at an economical depth, which is sufficiently watertight, strong and stable to provide the foundation of the impervious core or deck, or can it be made so by cement grouting (pumping in a cement-water mixture under pressure, to fill up any open joints)?
6. Are special measures necessary to allow for possible instability of parts of the reservoir sides during operation of the reservoir?
7. What allowance should be made in the design of the dam and outlet works for possible earthquake shaking?
8. What is the best location for a tunnel for diverting the river around the embankment during construction and for carrying the permanent water-supply pipelines to the city? How much of this tunnel will need steel arch support during construction and concrete lining for permanent support?

Conclusions

Following several years of planning, including extensive geological studies, the construction of the Kangaroo Creek Dam was completed on schedule as a concrete-decked rockfill structure. The broad geological conditions found during the construction were as predicted and as assumed in the designs. No major changes to the design were required. During the construction, the project geologist provided the contract supervisory staff with up-to-date appreciations of detailed geological situations appearing in each of the excavations, thus assisting them with many day-to-day decisions involving excavation depths, support and other treatment of the rock, and minor changes to the designs.

It must be concluded that the application of geological principles and methods during the planning and construction of the project contributed significantly to its successful completion.

Summary

1. **The local geology of an area is important when planning a major construction. The role of the engineering geologist is to ensure that proper assessment of geological information is made during the planning and building of a project.**
2. **Engineering geologists prepare maps which indicate all aspects of the geology of the construction site. They also use geophysical surveys and drilling to indicate the characteristics of the rocks below the surface.**
3. **It is essential that engineering geologists have a good understanding of the problems of a civil engineer. In turn, an engineer must have a knowledge of natural processes and products.**

Revision Questions

1. Briefly explain why an engineering geologist should be involved in the planning of a major construction such as a dam, a bridge, or a large building.
2. Discuss the geological factors that should be considered in determining the suitability or otherwise of a site for the construction of a large dam and outline the techniques used in such an investigation.