Modelling of the groundwater impact of a sunken urban motorway in Sydney, Australia

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Abstract: A sunken roadway through a sand aquifer has been modelled for its effect on groundwater flow, drawdown, and potential for subsidence during and after construction. A Commission of Inquiry found that the model predictions were reliable, and that reported house wall cracks were induced mainly by vibration.

Keywords: Groundwater, modelling, dewatering, subsidence, monitoring

INTRODUCTION

The Eastern Distributor is a 6 km long motorway that links the central business district of Sydney with Sydney Airport and the city's eastern and southern suburbs (Figure 1). It was designed to ease congestion and to reduce the time to travel from the city to the airport. Construction, which took two years and 5000 workers, was done by Leighton Contractors Proprietary Limited for Airport Motorway Limited. The scheme is privately built, owned and operated, with State government planning, support and management during construction. The motorway opened in 1999 at a cost of A$ 730 million, well in time for the Sydney 2000 Olympic Games.

The motorway consists of a bored tunnel section through sandstone and a sunken roadway and cut-and-cover tunnel through a sand aquifer. During tunnelling, three significant dykes were intersected. The tunnel section is 1.7 km in length and is said to be the widest road tunnel in the world at 24.5 m maximum. The tunnel height of 14 m accommodates three lanes of north-flowing and three lanes of south-flowing traffic at separate levels in a piggyback design. The upper roadway is supported by pre-stressed concrete planks that rest on sidewall ledges. This tunnel has been drilled beneath one of the most densely populated urban areas in Australia. For the sunken section of the motorway, which is 5 km in length, the pavement is about 5 m below street level. It falls below the water table of the only significant aquifer near Sydney that has been used for more than a century for public, industrial, agricultural and recreational water supply. The road cutting penetrates a significant portion of the sand aquifer's saturated thickness, and in places the cutoff is complete. To prevent water entry to the cutting, it is tanked by membrane-backed concrete diaphragm walls.

Scientific paper

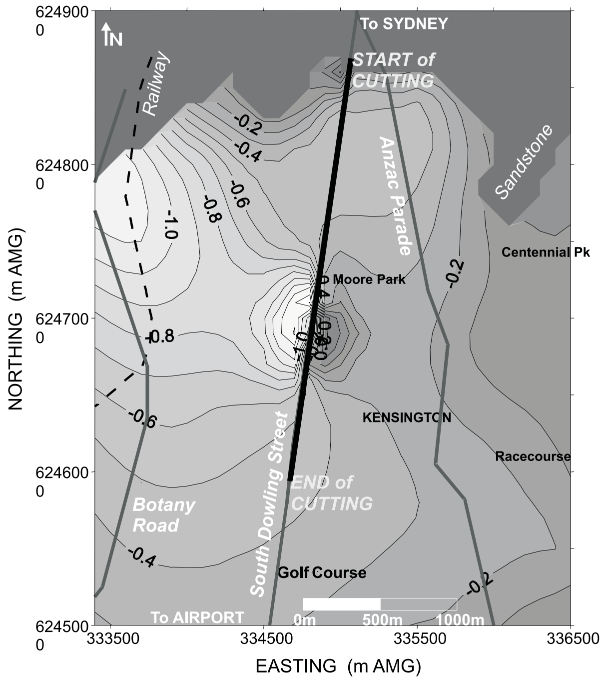

Figure 1. Location of motorway cutting, with predicted change in groundwater levels

Prior to construction there was concern that the cutting for the sunken section might act as a barrier to groundwater flow, with the effect of diverting natural flow directions, causing elevated groundwater levels on the up-gradient side, and depleted levels down-gradient. There was also concern that dewatering during construction and/or permanent drainage to the cutting might induce land subsidence and settlement of buildings. The cutting is flanked by parkland on its eastern side, and by a residential area on its western side that includes a number of heritage-value buildings. When considering the potential for subsidence induced by water-table drawdown, it is not drawdown below average levels, but drawdown below historical levels, which is significant. The lowest groundwater levels occurred in the early 1940s, when they were about 1.5 metres below average levels.

RESULTS AND DISCUSSION

In the vicinity of the sunken section of the Eastern Distributor, the aquifer is essentially unconfined and predominantly sandy, and is recharged directly by rainfall. A drilling program along the route of the motorway discovered a bedrock ridge in the central part of the cutting. At that point, sand cover is only 6 m whereas the sediment thickness reaches 36 m further north, and 23 m at the southern end of the cutting (Figure 1). This has had the effect of constricting groundwater flow and producing local hydraulic gradients in excess of 3 percent.

A regional finite element single-layer model was developed, with element sizes down to 20 m. Calibration was achieved against a regional water-table contour map, a number of hydrographs, and the water-table transect across the bedrock ridge. Given the absence of field records prior to 1973, and the dominance of rainfall recharge on aquifer response, the model was used to back-project hydrographs to the 1940s to infer the lowest historical water levels. It is at this time that buildings would have settled the most.

Additional local-scale analytical and finite-difference numerical modelling was carried out to assess the impact of dewatering during construction. Allowing for the variability in ground conditions and aquifer characteristics likely to be encountered over such a long excavation, the regional and local modelling showed broadly comparable results, indicating that the drawdown cone was likely to be shallow, and extend a significant distance away from the excavation. However, it was recognised that in reality, some locations would experience more, and some less, drawdown than predicted, owing to the effects of inhomogeneity.

Initially, the regional model was used to investigate three construction alternatives: (A) Fully tanked cutting; (B) Fully drained cutting; (C) Partially tanked/drained cutting. Subsequently, for Scenario A, three scenarios were assessed for varying degrees of wall penetration into the sands above a clay substrate: (1) Probable penetration; (2) Severe penetration; (3) Extreme penetration (complete cutoff). Each penetration scenario was examined for five rainfall conditions.

Each scenario (A1-A3) for each rainfall condition gives a "butterfly" response for the change in steady-state groundwater level relative to the pre-development steady-state response to average rainfall. An example is shown in Figure 1 for probable wall penetration and average rainfall conditions. For a distance of about 1 km along the motorway in the vicinity of the bedrock ridge, there is a drop in water level on the down-gradient side (west) of the road and a rise in water level on the up-gradient side (east). The cutting acts as an underground dam that causes backing-up of water.

The "wing-span" of the butterfly feature is typically 600 m either side of the road. The maximum decline in the water-table occurs at 100 m west of the motorway. Under normal climatic conditions the drop in water level is less than 1.5 m, which is half of the natural long-term range in water table fluctuations. Along the rest of the road, to the north of the bedrock ridge, the permanent drawdown is about 0.4 m.

Under steady low rainfall, the largest drawdown is expected to be about 2.0 m. This is about 0.5 m lower than the lowest water levels experienced in the past. However, the high drawdown areas are localised to areas of thin aquifer cover over sandstone bedrock at the northern and southern ends of the cutting. Settlement calculations based on a maximum drawdown of 2 m predicted total settlement after complete consolidation of about 20 mm. This was at the limit established for the project by the planning authority. Due to slow development of drawdown and shallow hydraulic gradients, differential settlement was expected to be much less than 10 mm across any structure. Predicted drawdown was thus generally within the range where no adverse effects were expected.

One north-south and five east-west transects of piezometers were established to monitor the water level responses during (and after) construction, which took place from January to August 1999. Many settlement monitoring points were established also, close to vulnerable properties on the western side of the motorway.

The maximum construction-induced drawdowns were in the range 2.5 to 3.0 m, within the range predicted by the modelling. Groundwater levels did fall below the historical minimum, but within the predicted amount. As also predicted by the modelling, the cone of depression appears to have been shallow, with drawdown of approximately 2.5 m at 100 m from the motorway, and 2 to 2.5 m at 200 m west of the motorway. However, the changes have not been uniform and this non-uniformity is only explicable in terms of undefined lithological variability within the aquifer.

The subsidence response to dewatering drawdown measured at settlement monitoring points was within the predicted and permitted ranges. However, after construction, many residents complained of damage to houses, ranging from minor to very substantial cracking of walls and other structures. The government response to these complaints was to set up a Commission of Inquiry … "to oversee and undertake an independent panel investigation relating to concerns expressed by the local community into alleged damage to property from the construction and operation of the Eastern Distributor". The Commission found that 41 of the 59 reported cases of property damage were attributable to the effects of construction of the motorway. Of these, 9 were attributed to subsidence caused by temporary construction dewatering, 19 to the combined effects of dewatering and vibration, and the remainder to vibration alone. Most of the damage attributed to construction dewatering was found in very localised pockets in old drainage lines. Subsequently, much of the damage initially attributed to dewatering-induced subsidence was found to be due to other causes, including leaking water pipes.

CONCLUSIONS

It can be concluded that groundwater level behaviour, both during construction and since construction, was in accordance with modelled predictions. Measured subsidence was also generally within the predicted range. The data do indicate some variability in response; this also was anticipated. In general terms, this variability in response can be attributed to the heterogeneity of the aquifer and superficial materials.

The distribution and timing of reported property damage cannot be explained by the observed changes in groundwater level or ground surface level. In many cases, detailed investigation has resulted in reported property damage being attributed to other causes, although some cases remain open.

The outcomes of this case study indicate that, where initial hydrogeological assessment shows that drawdown due to construction or permanent dewatering associated with linear infrastructure is likely to be widespread, as occurred here, then geomorphologic and geotechnical assessment should be extended to the entire area of influence, not just the project alignment.

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