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Case Studies of Geotechnical Risk Management of Excavations Next to Live Motorway Traffic

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ABSTRACT

Upgrading existing motorways unavoidably involves construction under live motorway traffic. Geotechnical risks need to be managed to ensure the safety of the existing motorway. Three case histories involving excavation risk next to live motorway traffic are presented. Case Study 1 presents a 5.1m deep excavation to extend existing drainage pipes. Design options are compared and the associated risks and cost comparisons are highlighted. Case Study 2 presents a 7.7m deep excavation to facilitate the construction of a reinforced soil wall. The design evolvement and risk management approach is discussed. Case Study 3 presents two shallow cuts up to 3.2 m to prepare the foundations of reinforced soil walls. Construction risks are highlighted.

Keywords: case study, geotechnical risk management, excavation, live motorway traffic

1 INTRODUCTION

Upgrading existing motorways unavoidably involves construction under live motorway traffic. Construction generally takes place in stages and the excavation works often take place next to live motorway traffic. Geotechnical risks and mitigation strategies are to ensure the existing motorway's site safety. Other factors to be considered included time constraints, cost, worker safety, and nearby structures. Three case histories are presented involving excavations next to live traffic.

2 CASE STUDY 1 – A 5.1M DEEP EXCAVATION FOR DRAINAGE PIPE EXTENSION

2.1 Site description

As shown in the site plan (Figure 1), two existing drainage pipes were proposed to extend from under the existing motorway. In 2009, 1500 mm outer diameter concrete pipes were laid. A motorway embankment 3.5 m high was then constructed on top of the pipes with live westbound traffic running on the motorway. In 2011, the two existing pipes had to be extended before construction of the two eastbound lanes began.

2.2 Geotechnical risks

To expose the pipes, the existing 1H:1V side batter needed to be cut vertically. The main geotechnical risks associated with the pipe extension works are the:

- live motorway traffic is located very close to the cut face (~0.5 m).
- nearest borehole was more than 50m away from the site.

The embankment side batter was visually inspected and a test pit was excavated to 3 m below the toe of the embankment. The observed ground conditions are shown in the cross-section in Figure 2.

2.3 Design options considered

Three main design options were considered and they are illustrated in the following sections.

2.3.1 Option 1 – King posts with steel laggings

This option is shown in Figures 1 and 2 and the construction sequence is summarised in Table 1.

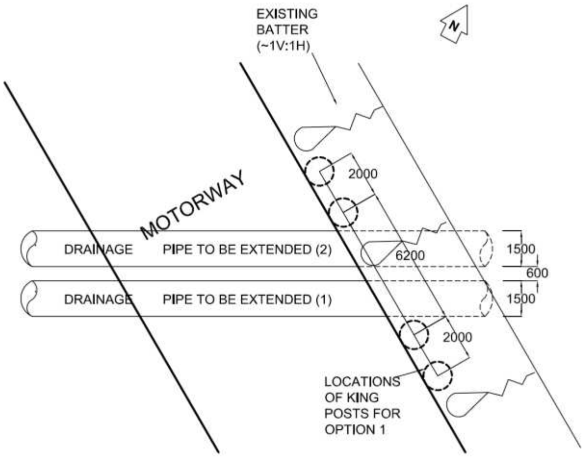

Figure 1. Site plan – Case Study 1

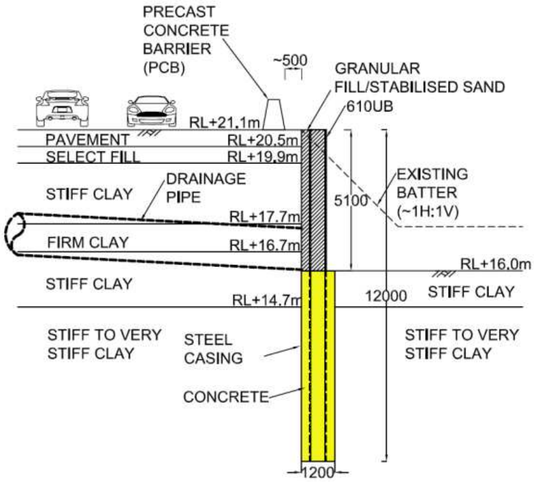

Figure 2. Cross-section – Option 1

Table 1: Construction sequence for Option 1

Stage	Description
1	Drill 4 m by 1.2 m diameter holes to 12 m deep and install 610UB king posts inside holes
2	Cast concrete in the holes below 5.1 m deep and stabilised sand above 5.1 m deep
3	Excavate between king posts and install lagging plate to the top of pipes (~3.5m deep)
4	Backfill behind lagging plate with granular fill or stabilised sand
5	Excavate to 5.1 m deep to expose the pipes; extend pipes and backfill

2.3.2 Option 2 – Pipe jacking

Option 2 is shown in Figure 3 and the construction sequence is summarised in Table 2. The pipe jacking can take place separately for the two pipes to reduce the size of box out.

Table 2: Construction sequence for Option 2

Stage	Description
1	Box out 6.4 m (L) x 5.0 m (W) x 1.7 m (H) at the toe of the batter and expose the pipes
2	Pipe jacking steel pipes with diameter slightly larger than 1.5 m to the existing concrete pipes
3	Install extension of the concrete pipes inside the steel pipes and backfill

2.3.3 Option 3 – shift traffic further away and use shoring box

Option 3 is shown in Figure 4 and the construction sequence is summarised in Table 3.

Table 3: Construction sequence for Option 3

Stage	Description
1	Shift the existing traffic further away from the edge of the batter
2	Cut a 5.1 m vertical face and expose the pipes
3	Install shoring box and steel plate; backfill gravels behind steel plate
4	Extend pipes; remove shoring box and steel plate and backfill

A comparison of the three design options is summarised in Table 4. All three options are safe for the motorway and workers in the trench. However, when compared to the other two options, Option 3 offered less construction time, much lower costs and fewer risks. Therefore Option 3 was selected as the preferred option.

Table 4: Comparison of three design options

Comparison	Option 1 – King post	Option 2 – Pipe jacking	Option 3 – Shift traffic
Estimated cost	$110,000	$100,000	$30,000
Time	5 days	4–5 days	2 days
Constraints	need to shift or temporarily close traffic to install king posts	may affect nearby existing chamber and railway	No

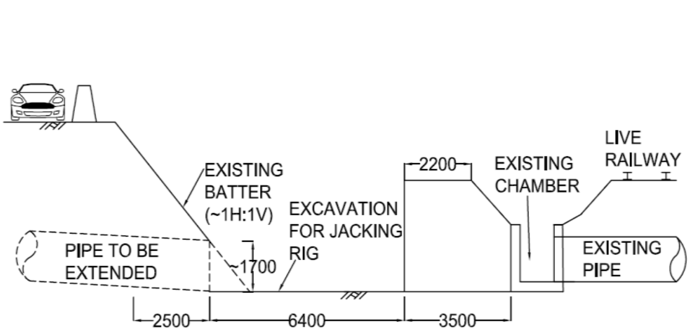

Figure 3. Cross-section – Option 2

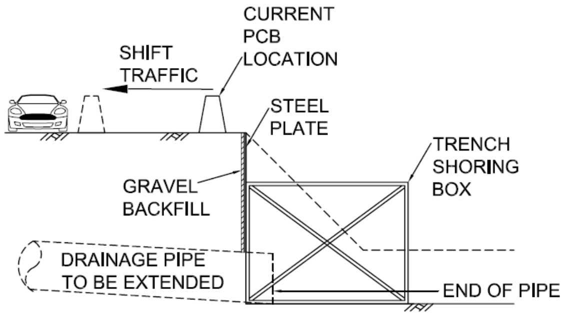

Figure 4. Cross-section – Option 3

2.4 Construction

The traffic was switched away from the edge of the motorway. The excavation started a week later; the shoring box and steel plate were installed immediately after excavation. To reduce the amount of excavation, the pipe extension took place separately. After the pipes were exposed, water flowed from them and had to be pumped out before the pipe extension works. Three settlement markers were installed on the road surface to monitor the settlement: no settlements were observed during the excavation works.

3 CASE STUDY 2 – A 7.7M DEEP EXCAVATION TO CONSTRUCT REINFORCED SOIL WALL

3.1 Site description

Figure 5 shows the site plan of Case Study 2. It involved a temporary 7.7 m high cut to construct a reinforced soil wall (RSW), namely RW266. The construction sequence of this case is summarised in Table 5.

Table 5: Construction sequence for Case Study 2

Stage	Description
1	Switch traffic to old eastbound carriageway bridge; demolish old westbound carriageway bridge
2	Install temporary soil nail wall TR202
3	Construct reinforced soil wall TR204
4	Construct new westbound carriageway bridge and switch traffic to new westbound bridge
5	Demolish old eastbound carriageway bridge
6	Demolish TR202 and construct reinforced soil nail wall RW266

At Stage 6, the existing 6.7 m high 1V:1H batter at west abutment of BR275 has to be made steeper to 3V:1H to accommodate the reinforced straps of RW266. Live traffic was running on RSW TR204 and BR280. A further 1.0 m deep vertical cut was to be made for the foundation treatment of RW266.

3.2 Geotechnical risks

The cut slope was in compacted embankment fill comprising stiff to very stiff clay. There was a gap up to 2 m wide between temporary walls TR202 and TR204. The gap was filled with clay and stabilised sand (Figure 6). The top 2.8 m high of TR204 has come out over the gap due to alignment change of the temporary traffic management design. If TR202 were totally removed, there would be an overhang from TR204 that would have to be supported.

3.3 Design evolvement

A number of design options have been considered, including sheet piles and structural supports. Sheet piles were discarded because of the high costs involved. The structural support option was to remove TR202, expose the overhang and structurally prop the overhang. This option was discarded because of high construction risks.

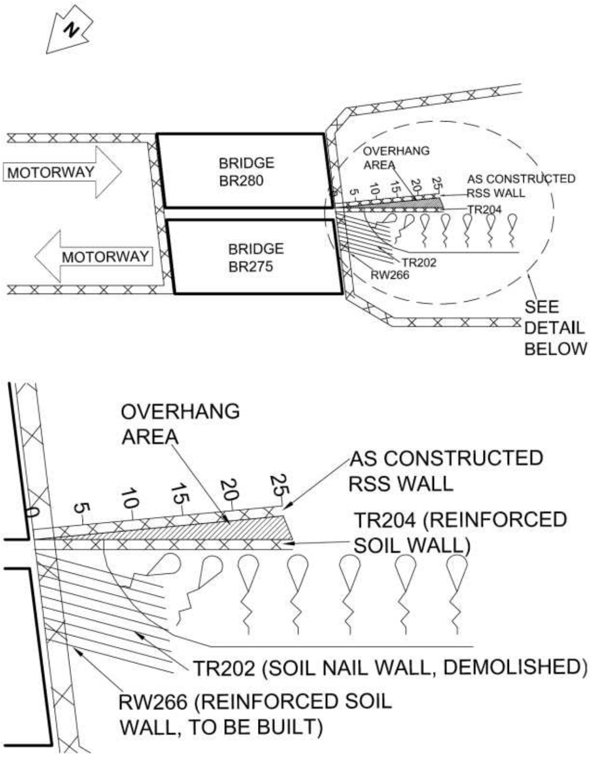

Figure 5. Site plan – Case Study 2

Figure 6. Gap between TR202 and TR204

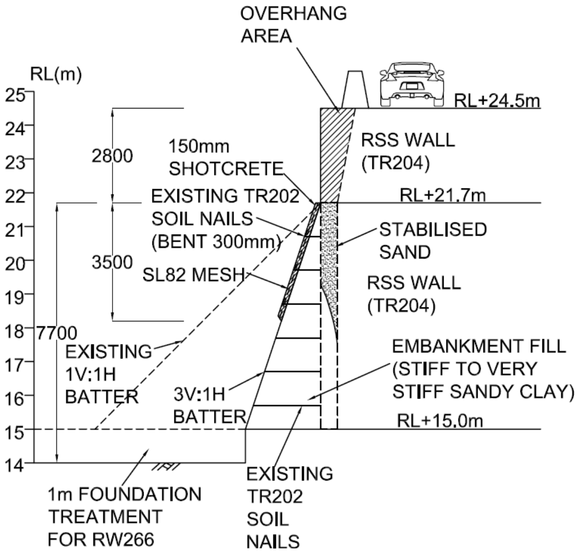

Figure 7. Cross-section – Case Study 2

It was decided the soil block underneath the overhang was to be kept and geotechnical design would have to maintain the stability of the 3V:1H batter, with the surcharge of the overhang from the top. The soil block under the overhang was not taking any horizontal load because the horizontal loads will be taken by RSW TR204. The geotechnical model was somewhat like a 7.7 m high soil block under an unconfined compression test with the applied vertical load from the overhang. The soil nails would act as reinforcement to the soil block to increase its bearing capacity.

Initial design proposed installing steel bars with 16 mm diameter and 1 m spacing into the soil block under the overhang. The steel bars would be driven by a hand-held impact hammer without grouting. They were intended to:

- reinforce the soil body to increase the bearing capacity.
- prevent localised slip failures.

Shotcrete and mesh was proposed for the whole 3V:1H surface.

After a site visit by both the design and construction teams, it was found that the soil block under the overhang was part of the previous soil nail wall TR202. The existing nails could be used as the soil reinforcing bars and no additional bars would be required. The construction team also pointed out that the lower part of the excavation would be finished within one day, including ground replacement works. It would take longer to install mesh and shotcrete than excavation and fill placement. The design was then modified to: (a) use existing soil nails; and (b) only install mesh and shotcrete at top 3.5 m of the batter (refer Figure 7).

3.4 Construction

Case Study 2 was constructed in July 2011, starting with the excavation of the top 3.5 m of the 3V:1H slope. Soil nails in wall TR202 were carefully exposed and cut to suit the slope profile. SL82 mesh and shotcrete 150 mm thick were installed on the cut face. The lower part of the 3V:1H batter was cut at a slope slightly steeper than 3V:1H. The 1 m ground replacement below the slope was carried out using hit-and miss (a primary and secondary panel s equence) excavation method. The straps for RW266 were then laid. No tension cracks were observed on the motorway surface during construction.

4 CASE STUDY 3 – TWO SHALLOW CUTS FOR REINFORCED SOIL WALL

4.1 Site description

As shown in the site plan (Figure 8), two shallow cuts were to be made next to the live motorway to make room to construct two RSW walls RW461 and RW464. Figure 9 shows the cross-section of the proposed cuts. The cut height included 1 m of ground improvement. Table 6 summarises the excavation details, including a comparison between design stage and construction stage.

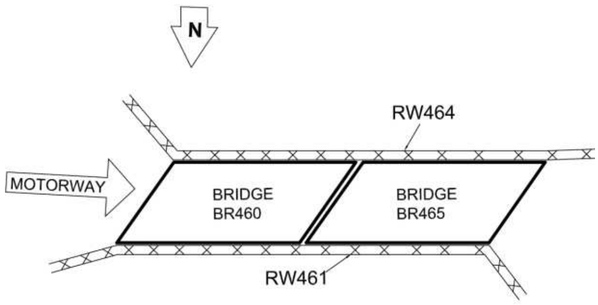

Figure 8. Site plan – Case Study 3

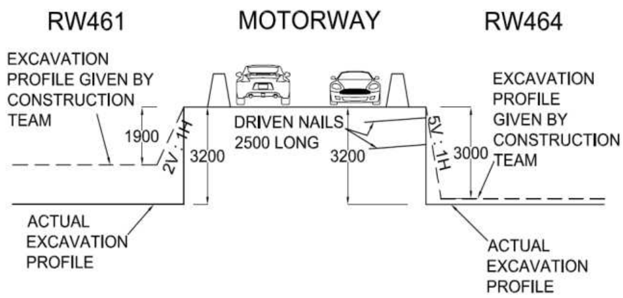

Figure 9. Cross-section – Case Study 3

Table 6: Excavation details for RW461 and RW464

	Cut for RW461		Cut for RW464	
	Design stage	Construction stage	Design stage	Construction stage
Cut height (m)	1.9	3.2 (2.2 m shotcrete + mesh, plus 1 m unsupported)	3.2	3.0
Soil condition	Firm clay	Very stiff to hard clay	Firm clay	Firm clay
Batter slope	2V:1H	Nearly vertical	5V:1H	Nearly vertical
Soil nail	Nil	Nil	Two rows of 2.5 m long ϕ20 mm	Two rows of 2.5 m long ϕ20 mm

4.2 Geotechnical risks

The geotechnical risk for Case Study 3 was mainly the uncertainty about the material underneath the current motorway. No geotechnical information was available at the time of design, the material was conservatively assumed to be firm clay, based on information from previous construction stages.

4.3 Proposed design considerations

The temporary cuts were proposed for a maximum of two months. As shown in Table 6, two rows of ungrouted driven soil nails were proposed for the cut 3.2 m high and only surface protection without soil nails were proposed for the cut 1.9 m high based on slope stability analysis results.

4.4 Construction

The excavation started at the RW461 side and soon the construction team realised that data supplied to the design team were incorrect. The excavated heights of each profile had been interposed and on the RW464 side there was a drainage line that was to be installed, which would make the cut about

3.0 m high. The geotechnical engineer was called immediately to the site. The RW461 side had been excavated to 1.5 m deep and the cut was nearly vertical as opposed to the initially proposed 2V:1H batter. However, the exposed material turned out to be better than that assumed in the design. The construction team was instructed to install mesh and shotcrete to cover the top 2.2 m slope. The lower portion of the 3.2 m cut was excavated and backfilled within two days with no extra support needed.

The excavation at the RW464 side started a few days after the RW461 excavation. The excavation was again nearly vertical and the material turned out to be similar to that assumed in the design. Two rows of soil nails were installed, together with mesh and shotcrete, immediately after excavation. The excavation proceeded to 3.0 m deep and ground treatment material was placed. Retaining walls RW461 and RW464 were then constructed.

5 DISCUSSIONS

Good planning is an important measure to eliminate or mitigate risks. Construction risks must be considered in safety in design and the early planning stage. The attitude of 'let the other guys worry about this later' is to be avoided. In Case Study 1, if the pipe installation at Stage 1 (2009) had considered the future extension, the pipes could have been installed 2–5 m longer. This would have eliminated the risk of the cut next to the live motorway. In Case Study 2, the overhang problem could be eliminated during temporary traffic management planning stage. In Case Study 3, the 'wall swapping' problem and drainage pipe problem can be identified in the planning stage.

Communication is a vital part of the design and construction process. In Case Study 1, during the option selection process, there has been constant communication among the design team, construction team, superintendent, site foreman, and survey team. This has allowed potential risks or opportunities to be identified early. In Case Study 2, as a result of effective communication between the design team and construction team, the original design was optimised to better suit site conditions. In Case Study 3, the construction team immediately notified the design team after they found the issues on site. This has allowed the design team to assess the site condition and provide prompt advice on remediation works.

For the excavations next to live motorway, the geotechnical information is usually lacking due to difficult site access. The geotechnical engineer must obtain geotechnical information from visually inspecting the exposed face (Case Studies 1 and 2) or carrying out additional geotechnical investigation such as test pits (Case Study 1). The design usually has to be conservative (Case Study 3). Any 'slope' failure involved in this type of work would be likely to be disastrous.

Case Study 3 presents a good example of construction uncertainty. Three things were unexpected from a design point of view: (1) the construction team swapped data for RW461 and RW464; (2) the drainage pipe was overlooked at RW464; (3) the site crew excavated the faces nearly vertically. Therefore, the temporary works design had to be on the conservative side. For example, the adopted factor of safety (FOS) was normally 1.2 to 1.3 for the temporary case. Considering the importance of motorway and construction uncertainty, the design FOS should be increased to 1.5 or higher to address the additional risks involved.

6 CONCLUSIONS

The following conclusions can be drawn from the three case studies about managing the risk of excavations next to live motorway traffic:

(1) Good planning is the most important measure to eliminate or mitigate potential risks. This is particularly valid for staged constructions.
(2) Communication is a vital part of the design and construction process. Effective communication can allow early identification of risks or opportunities.
(3) Adopt a more conservative design when there is lack of geotechnical information or there are greater construction uncertainties.

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