Bridge Abutment Remediation – A Case Study

Mogana Sundaram, *Senior Engineer, Geologist, Engineering and Technology Branch, the Department of Transport and Main Roads; email: mogana.z.sundaram@tmr.qld.gov.au*
Jun Sugawara, *Director, Geotechnical Section, Engineering and Technology Branch, the Department of Transport and Main Roads; email: jun.z.sugawara@tmr.qld.gov.au*
Siva Sivakumar, *Manager, Geotechnical Section Engineering and Technology Branch, the Department of Transport and Main Roads; email: siva.sivakumar@tmr.qld.gov.au*

ABSTRACT: *Record-breaking rainfall events in parts of eastern Australia—particularly, most recently, in Queensland—resulted in severe flooding and property damage. Transport and Main Roads assets were not spared from destruction caused by these events. The severe rainfall and flooding resulted in debris slides, rockfalls, embankment slips, creek bank scours and erosion, bridge abutment failures, sinkholes, and reactivation of old landslides, causing closure of road networks. This paper focuses on the safety measures and remediation work that were undertaken on a failed abutment of a 40-year-old bridge on one of the major highways. The concrete abutment protection of the highway slipped and toppled over the bridge pier, causing concern for the stability of the highway above. As there was a prediction of further rain, it was deemed necessary to close the road below the bridge and maintain a close surveillance of the highway for potential hazards until an assessment was completed. As one of the main priorities of the department, these networks had to be reopened in a safe and timely manner for the public to resume use. The paper discusses the interim measures implemented and the design and construction of permanent remedial works. The paper also highlights the challenges of working in changing conditions, and the tight workspace adjacent to a busy, heavy traffic flow.*

KEYWORDS: Transport and Main Roads, rainfall, failures, remediation, temporary works, permanent works

SITE LOCATION: Geo-Database

INTRODUCTION

Transport and Main Roads (TMR) Queensland, Australia, manages a network of about 34,000 kilometers statewide-controlled roads. The road network traverses about 540 kilometers of mountainous road terrain, 3,700 kilometers of rolling road terrain, and 29,100 kilometers of level road terrain. The department also manages more than 3,000 bridges and more than 10,000 culverts. The state-controlled road network comprises of about 20 per cent of Queensland's total road network, yet it carries 80 per cent of state traffic flow (Lester, J. 2015). As the asset manager, TMR has a strategic role in providing a safe and accessible transport system that contributes to the economic and social development of the state.

Rainfall Events

From November 2021 to May 2022, four weather events affected the east coast of Australia. During this period, Southeast Queensland experienced a cumulative rainfall of >1,800 millimeters (Figure 1).

The scale of the failures to road networks varied from small to large, involving loss of embankment slopes, failures of cut slopes, debris slides, deep scouring of bridge foundation, reactivation of dormant landslides, failures of bridge abutments, and numerous other damages.

One such failure occurred on a 40-year-old bridge abutment on a busy highway-overpass located over an important rail network and local council-controlled roads. The failure did not result in the closure of the highway to traffic; however, it

Submitted: 6 July 2022; Published: 28 December 2022
Reference: Sundaram, M., Sugawara, J. and Sivakumar, S. (2022). Bridge Abutment Remediation – A Case Study. International Journal of Geoengineering Case Histories, Volume 7, Issue 4, pp. 1-7,
doi: 10.4417/IJGCH-07-04-01

required immediate action from the department to ensure it was made safe to operate until a permanent remediation work was completed. This paper presents the temporary support measures and permanent remediation works which were completed at this abutment.

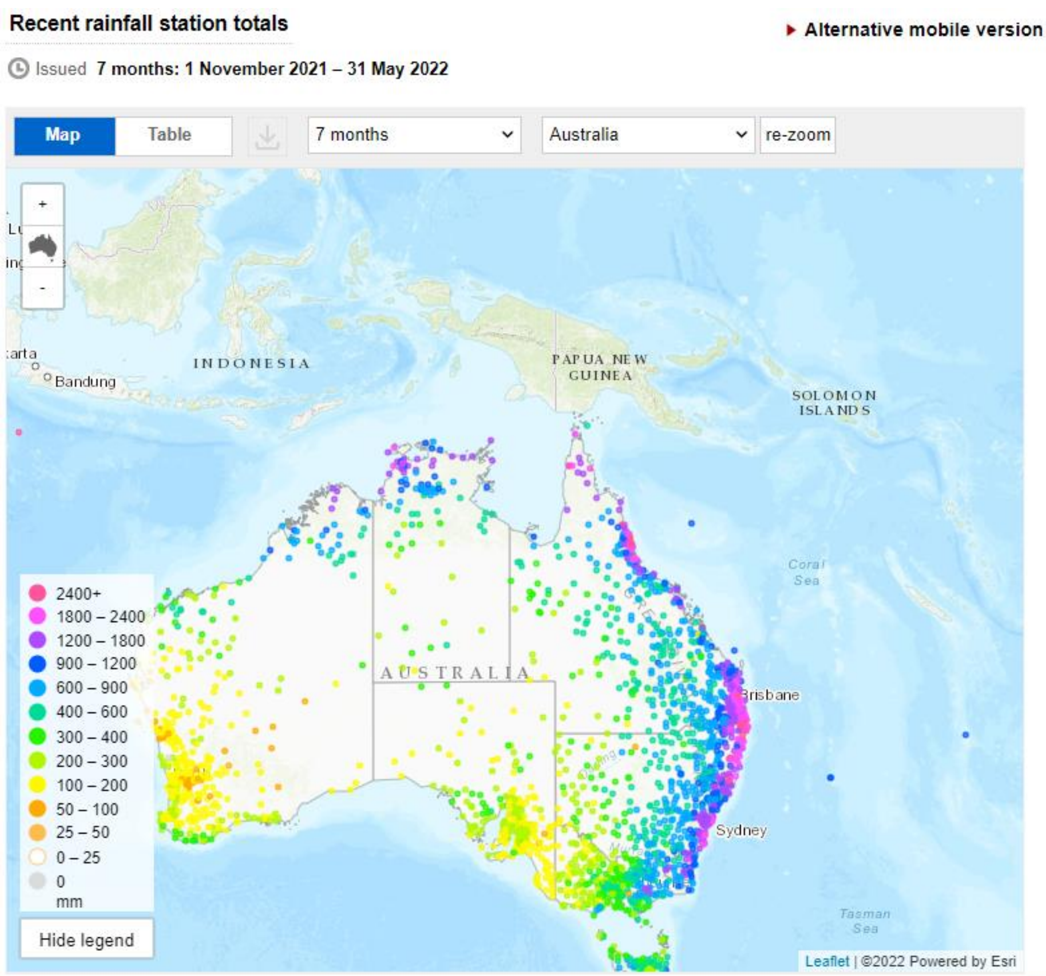


Figure 1. Cumulative rainfall between Nov. 2021 and May 2022 in east coast of Queensland and Australia wide (Australian rainfall update (bom.gov.au)).

BACKGROUND TO FAILURE

The bridge abutment was constructed in the mid 80s. It was comprised of fill material won from adjacent cuts in Marburg Formation, which mainly consists of sandstone with interbeds of siltstone, mudstone, and conglomerate, and the minor presence of thin coal seams. These rocks are weathered to different degrees. The material within the abutment fill was mainly comprised of silty clay compacted to the Transport and Main Roads specification. In addition to this, the six-meter high, 55^{o} abutment spill through was protected with 200 millimeters thick reinforced concrete panels with a row of weep holes located at two meters center to center distance, and 0.5 meters from the toe of the panels.

In November 2021, after a downpour, fill material from the crest of the abutment started to move, causing the concrete panels to slip and buckle, and to eventually topple onto the pier below and the guard rails. About 50 cubic meters of material failed from the abutment (Figure 2). However, the bridge pier prevented further movement of the fill material, containing it within the toe of the slope.

A total of 112 millimeters of rainfall was experienced in the month prior to the failure, which was almost double the mean annual rainfall. An additional 30 millimeters fell on the day of failure. The failed material was saturated and fluidized near the surface. A seepage line was identified two meters below the headstock and was visible to about six meters from edge of the abutment. It is likely that water infiltration from pavement edges may have saturated the abutment fill behind the panels. Therefore, the main cause of the failure is thought to be excessive pore water pressure buildup behind the panels, pearched water within the embankment, blockage of weepholes, and softening of the fill material from infiltrated stormwater.

Two grab samples were taken for laboratory testing from above and below the seepage line. Based on particle size distribution analysis and Atterberg Limit tests, the soil was classified as medium plasticity sandy silty clay (Cl) with traces of gravel. Other properties tested include liquid limit (37-39%), plastic limit (15-16%), linear shrinkage (11-11.5%), and moisture content (1.4-9.4%). Apart from the higher moisture content in the sample collected below the seepage line, there were no significant variations in all other material properties tested.

Figure 2. Abutment condition after failure.

RISK MITIGATION AND TEMPORARY REMEDIATION

Due to a forecast of further rainfall in the days following the failure, there was an urgent requirement to making the abutment safe and prevent further slips from the exposed surface. The following immediate and urgent mitigation measures were implemented within 24 hours (Figure 3):

- Removal of failed material from batter face and abutting against slope toe to provide passive support.
- Installation of two rows of 1-m long drainage pipes.
- Installation of three rows of 2-meter long, 20-millimeters diameter cogged steel reinforcement bars (driven) at 1-meter spacing.
- Application of 160 millimeters (average) thick shotcrete with SL82 mesh.
- Closure of one lane on the road below with temporary traffic lights with contra flow.
- Risk management advice included daily inspections of the site (to later be reduced to weekly, granted there were no further movements) and checks after rainfall events.

An additional control measure considered was to reduce the posted speed limit of 100 to 80 kilometers per hour (or lower) on the highway in case conditions deteriorated. This was not implemented, as no signs of further deterioration were observed on the highway or on the immediate works applied to the abutment slope. Water seepage was continuously occurring, but at a diminishing rate, through the drainage holes after the temporary remediation was installed.

The above measures appeared to have worked well, with no further movement observed on the abutment slope which withstood subsequent rainfall events.

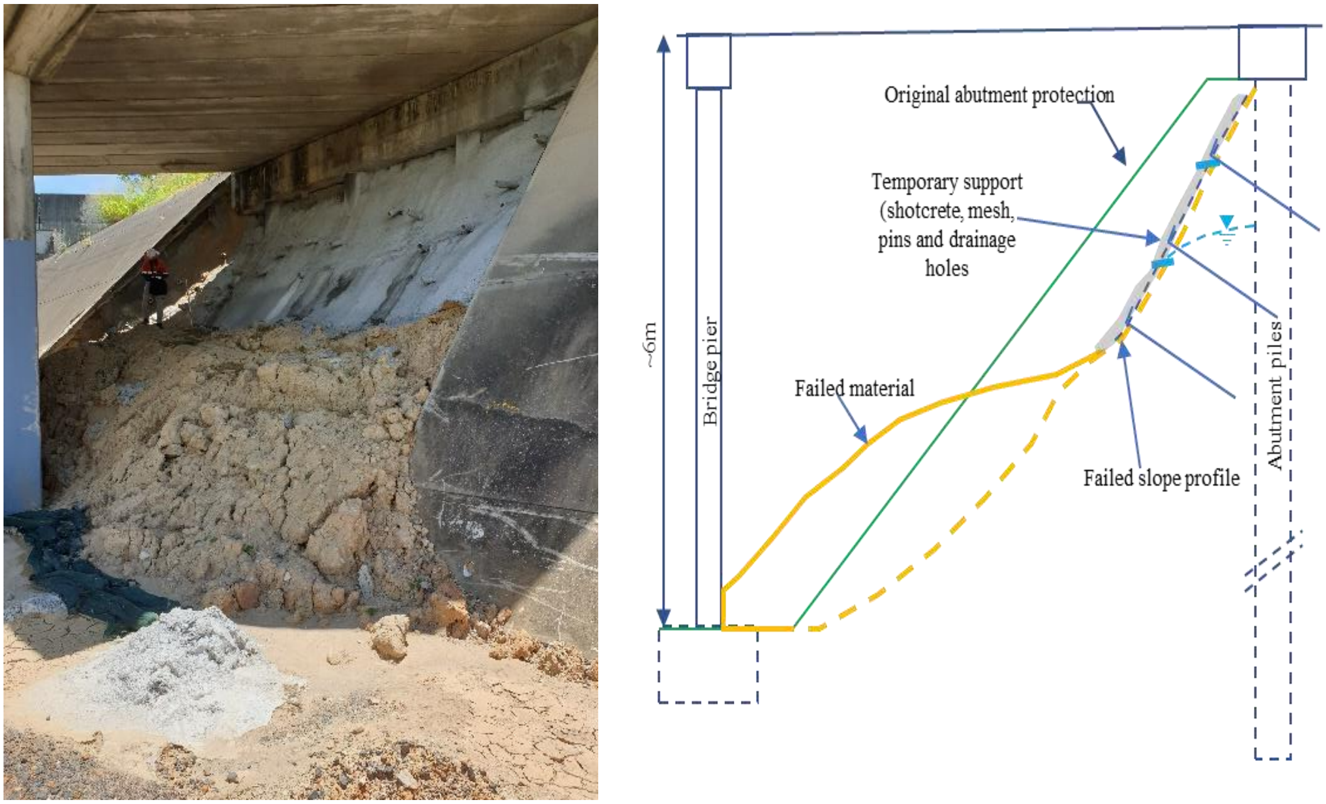


Figure 3. Temporary remediation (shotcrete with mesh, drainage holes, and driven pins) installed within 24 hours of the failure. The sketch illustrates the slope profile and temporary remediation installed. Seepage continued to occur two meters below the headstock at a reducing rate.

PERMANENT REMEDIATION

The permanent works of an abutment require a minimum design life of 50 years. To achieve the lifespan, a number of options were considered, including a reinforced retaining wall on piles/micropiles, a soil nail wall with shotcrete, and a gabion wall with rockfill. Any remediation proposed had to take into consideration the limited space available (approximately 4 meters wide and 6 meters high), required clearance (of minimum 0.5 meters from the pier footing), equipment and material availability, and the constructability and performance of the design life. Due to the constraints of constructing in a tight space, limited material availability, and limited availability of contractors, a gabion wall with rockfill was chosen. The choice was also based on the flexibility and modifications that could be made relatively easily if the site conditions were different to what was anticipated. To construct the gabion wall (or any other remediation method, for that matter) the abutted material at the toe had to be removed and the abutment had to be made safe.

To retain abutment stability during excavation to install permanent support, the following temporary measures were included:

- Installation of percussion anchors (300 millimeters wide head, 20 kilo Newton lock-off load) via slots cut into existing shotcrete (urgent works) at 1 meter vertical and horizontal spacing in a staggered pattern.
- Staged excavation at 1.2 meters lifts, followed by installation of percussion anchors, mesh and shotcrete, a row at a time until the toe of excavation was reached for formation of foundation for gabion.
- Installation of percussion drainage (three meters long by two rows at two meters staggered spacing).

It is worth noting that percussion anchors were chosen as they are quick to install, do not need specialized equipment, suit the application in a small space, and can be loaded soon after installation. Figure 4 shows the final design adopted to remediate the bridge abutment.

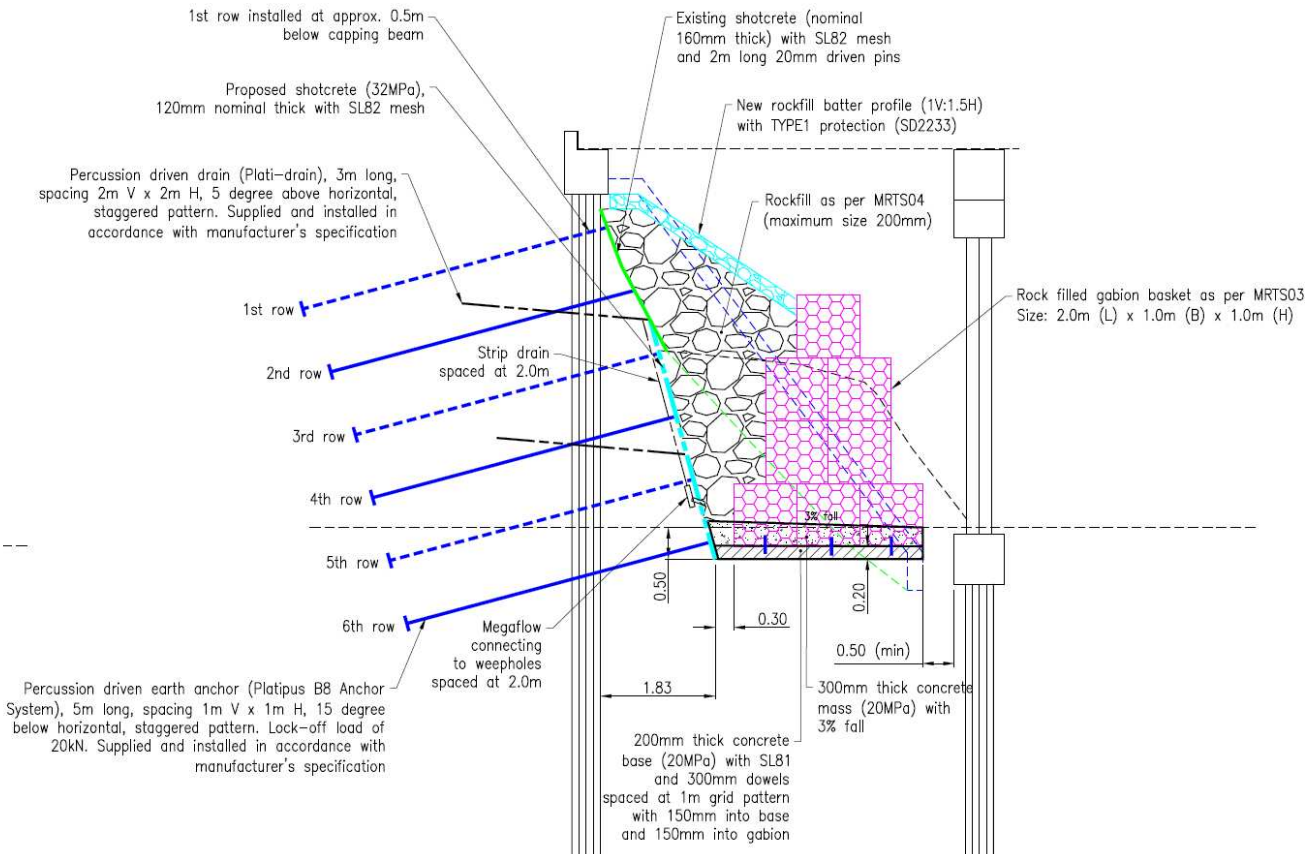


Figure 4. Permanent remediation of the bridge abutment.

CONSTRUCTION

The construction of the remediation works commenced in May 2022. The appointed contractor proposed an alternative anchor head size to the size proposed in the design. This was mainly to accommodate a smaller machine to drive the percussion anchors. The proposal was accepted provided that the working load of 80 kilo Newton could be achieved. Three test anchors (180 millimeters head size) were tested prior to the commencement of production anchors. Two of the anchors achieved >25 kilo Newton and the test had to be terminated due to soft material around the collar (Figure 5). One anchor was tested to 100 kilo Newton (at 850 millimeters extension) and the test was terminated as the load reached 80 per cent of ultimate breaking load of the steel tendon, 120 kilo Newton. On that basis, the proposed 180 millimeters anchor head was accepted as the minimum size that could be used. However, during construction, a mixture of 180-millimeter and 300-millimeter head sizes were used since there was a supply issue with the smaller heads. No issues were encountered during installation of the anchors.

Figure 5. Percussion anchor (180-millimeter head) and load testing.

As the highway had to be kept open and safe during the temporary excavation and support installation, site monitoring was required. The site monitoring was composed of daily observation of any tell-tale signs of weakness on the wall, visible changes on the road above and measurement of displacement on the shotcreted wall. The contractor was required to keep a monitoring register on site.

The excavation, anchor installation, and shotcrete application progressed well for the first three rows of anchors, after which, the contractor inadvertently excavated to full depth not following the support sequences specified in the design drawings. This resulted in the exposure of the slope face between 2-4 meters high without full protection. Consequently, approximately, 0.5 meter thick soil movement occurred behind the highest exposed face (Figure 6) with displacement of 250 millimeters in shotcrete below the headstock. On the same day, 13 millimeters of rainfall exacerbated the movement. Additional rows of anchors and steel mesh were installed to stabilize the movement. As a precautionary measure, the highway speed was also reduced to 60 kilometers per hour to minimize any vibration-induced movements. Surveillance was also increased to ensure safety was not compromised. The rate of the movement reduced after the installation of additional support measures and ceased two days after shotcrete application was completed (Figure 7).

Figure 6. Excavation completed to formation level. The abutment is supported with percussion anchors and reinforced shotcrete. Note larger unsupported span on the far right.

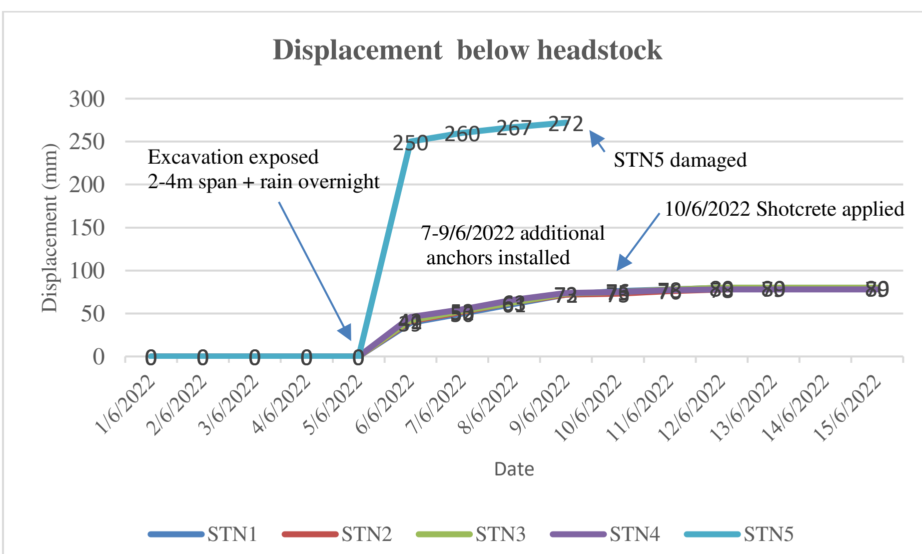


Figure 7. Displacement (mm) in shotcrete below headstock. Station 5 (STN5) located on far right. Displacement ceased two days after shotcrete application.

DESIGN MODIFICATION

As the construction progressed, the dimension of pile cap at pier was found to be wider than what was anticipated. This causes space constraints, and the gabion baskets could not be installed at the base according to the original design. Therefore, it was deemed necessary to modify the design of the last row of the baskets. The modifications included reducing the base width of the baskets to two meters and providing additional restraint (tie down anchors) at one-by-one-meter spacing (staggered) to prevent sliding and overturning.

CONCLUSION

The remediation work undertaken on the bridge abutment was predominantly due to a significant level of rainfall occurring over an extended period. The learnings from this failure include:

- Selection of a remediation method is important to accommodate various constraints, especially in brown field sites (i.e., space, material availability, availability of resources, and flexibility to make changes as required).

- Design-specified control measures and monitoring requirements should be followed to ensure optimal performance of the slope during construction.

- Robust design is important in future works to prevent such failures in changing climatic conditions.

- The deep scouring of bridge abutments/foundations as well as creek bank scours/erosions could become more frequent as extreme weather events in Queensland, Australia are expected to continue.

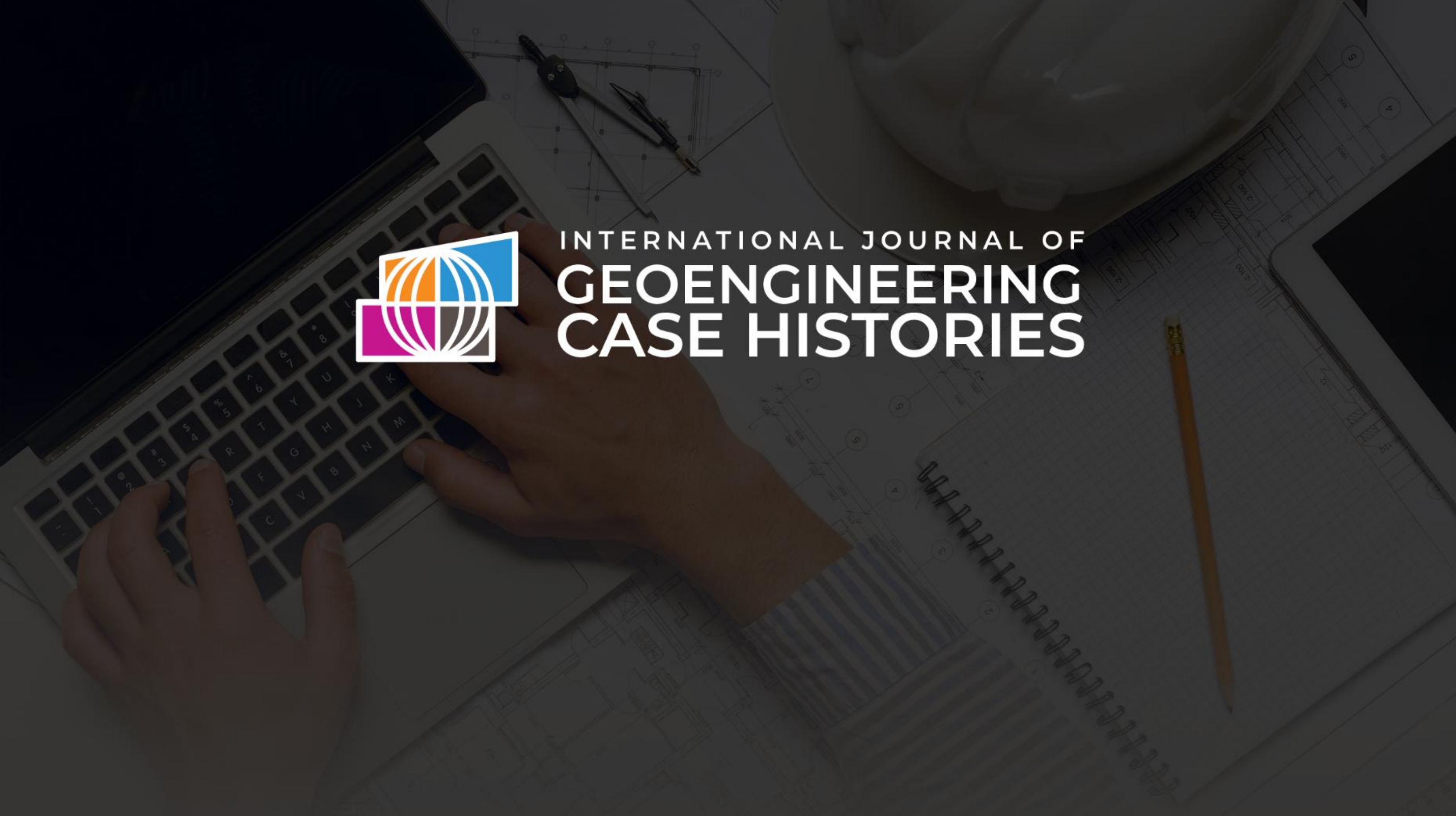
ACKNOWLEDGMENTS

The authors wish to thank the Department of Transport and Main Roads, Darling Downs District, and RoadTek Darling Downs District for granting permission to publish the paper. The views herein are exclusively those of the authors, and this paper does not constitute a standard, specification, or regulation.

REFERENCES

Lester, J., Welikala, D.L., and Creagh, M. (2015). "Slope Instability Risk Management for State Roads Queensland Australia." *International Conference on Geotechnical Engineering,* (ICGE Colombo, 2015), 565-568.

Australian Rainfall Update. <bom.gov.au>


INTERNATIONAL JOURNAL OF
GEOENGINEERING
CASE HISTORIES