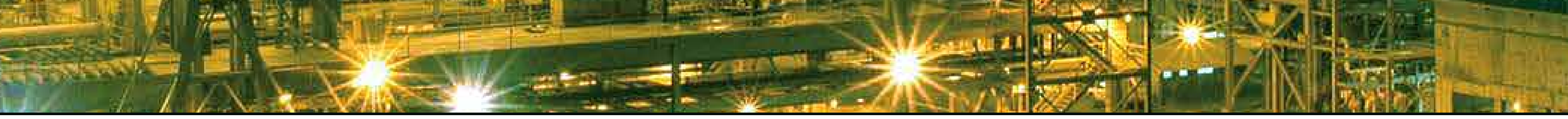
Strengthening of Grinding Building Slab

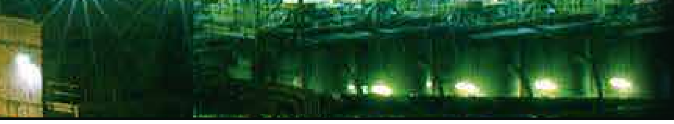
Batu Hijau Copper-Gold Mine



Introduction

On the tropical island of Sumbawa, located in a remote section of Indonesia, is the Batu Hijau gold-rich porphyry copper deposit. The Batu Hijau mine was the world's largest greenfield mining project when it was developed by PT Newmont Nusa Tenggara.

At Batu Hijau, ore containing copper and gold is extracted from an open-pit mine, crushed, then conveyed to the concentrator facility, where it is further ground and processed by stages of flotation to a copper/gold concentrated slurry.



Grinding Building Mill Deck Level Slab

The Grinding Building mill deck level slab is required to carry relatively heavy live loads (2.5 metric ton/m^2) caused by steel mill liners being piled on them which are used to reline the Ball and SAG Mills during bi-annual shutdowns. In addition to the steel liners, heavy equipment is often carried by the structural concrete slab.

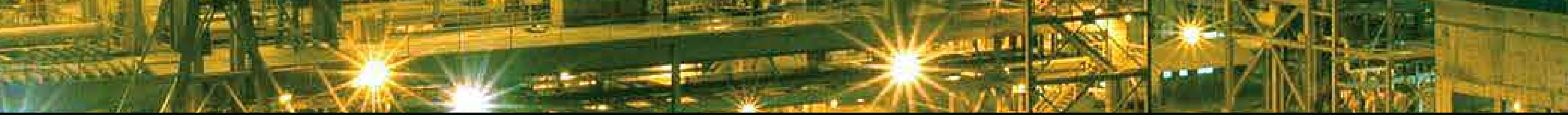
Original design drawings indicated that 16 mm diameter rebar should be installed in the 220 mm thick slab in the structural direction at 150 mm o/c, and in the non-structural direction at 450 mm o/c. The slab is supported by W610 steel beams at varying spacing. The W610 steel beams are in turn supported by larger W1000 steel beams. The spacing of the supports for all intents and purposes cause the slab to act as a one way slab on multiple supports. Only positive moment reinforcing was specified in the original design drawings, which is unusual for any concrete member designed to be continuous.

Corrosive process water used in the grinding process has caused the stay-in-place steel form pan on the bottom of the slab to corrode to the point that it was assumed to not provide any tensile restraint when the structure was analyzed.

Existing Condition of Slab

The condition of the 14 year old slab clearly showed signs of a lack of tensile reinforcing whereby large structural cracks could be seen over the top of many of the steel support beams. However, prior to designing the repair, a field investigation was completed to confirm the existing condition of the slab.

A ground penetrating radar survey revealed that the reinforcing bars intended to restrain shrinkage were installed in the structural direction and vice versa. This resulted in only 33% of the specified reinforcing being installed in the structural direction leading to a significant strength reduction versus the original design.



Typical Negative Moment Crack Over Beams

Ground Penetrating Radar (GPR) Survey

Several cores were taken in cracked areas and revealed that most of the cracks extended the full depth of the concrete slab and could be broken in two by hand.

The strength reduction was confirmed through a structural analysis comparing the factored loads felt by the slab to its factored strength. The two main problems were that there was insufficient positive moment reinforcing provided, and there was no negative moment reinforcing called for in the design.

Repair Methodology

The proposed repair procedure would be to epoxy inject the cracks and upgrade the slab using advanced composites.

Pressurized epoxy injection is a method which fills voids in cracked concrete by providing a medium stronger than the concrete where it has become weakened by a crack. In the case of a negative moment crack located on top of a support, repairing such cracks becomes particularly important due to the felt shear stresses in this region, which under a uniform load are higher than any other location along the structural member.

Because the design live load in this case is significantly more than the dead load (approximately 5 times), it was possible to remove all live load and provide negative moment carbon fiber reinforced polymer (CFRP) reinforcing strips in the top of the slab. By removing all except the dead load and waiting for proper bonding time, the newly installed CFRP repair is able to contribute to the slab's ability to carry additional live loads. The intent of the repair was to shift the bending moment diagram from that

Core Sample Showing Full-depth Cracking

of a series of adjacent simple spans to one continuous span, carrying both positive and negative moment and by doing so increase the live load capacity to conform with the intended design live load.

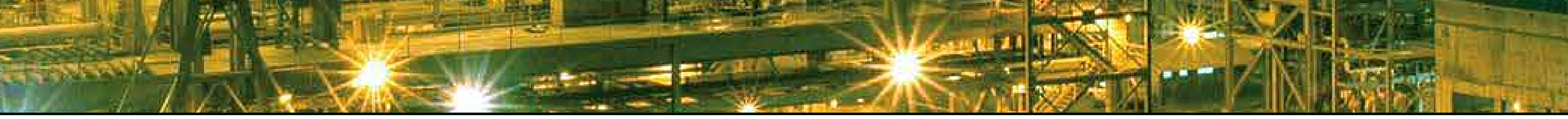
CFRP reinforcing of concrete structures is an excellent method for increasing the load capacity of a concrete structure, either on account of a construction / design error, or a need to carry loads in excess of the original design loads.

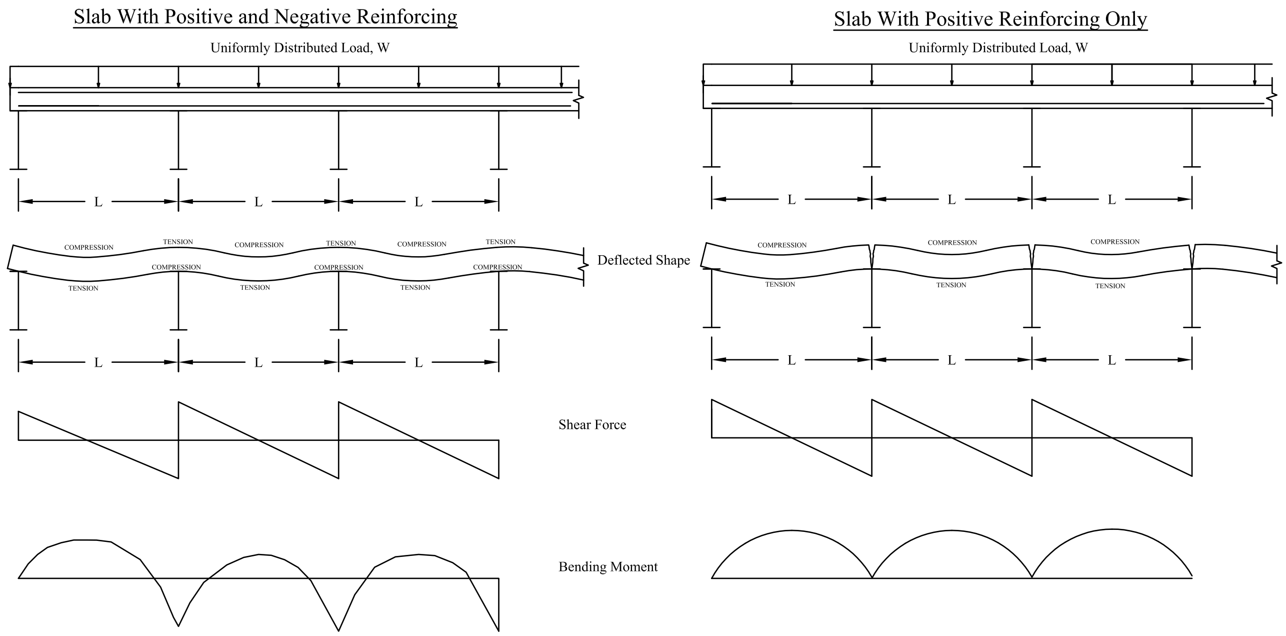
Near Surface Mounted CFRP

Carbon fiber is available generally in two forms. The first being carbon fiber sheets which are bonded to the surface of a concrete member using a primer and epoxy. This method it is not practical to use on the top surface of an industrial slab exposed to heavy traffic.

The second method, which was used on this project, involves cutting slots into the concrete surface, and installing prefabricated CFRP strips (carbon fiber encased in epoxy binding resin) into the slots and bonding them to the concrete using appropriate epoxy resin, referred to as the Near Surface Mounted Method. From a factored design perspective, these strips are generally allowed to be stressed to 934 N/mm² (135 KSI), which depending on the cross section of the CFRP used, can add a significant amount of tensile contribution to the section's ability to resist bending moment. This is compared to generally allowable tensile stress in steel rebar of 340 N/mm² (49 KSI)

If the CFRP reinforcing is installed while the structural member is free from live loads (i.e. under dead load only), the CFRP can actively strengthen the structure under further live loads placed on the structure after installation of the CFRP and adequate curing time.





Qualitative BMD, SFD for Continuous Slab (LHS) and Adjacent Simple Spans (RHS)

Modeling & Verification Testing

To enable the slab to safely carry the intended design loads, based on the visible condition and structural calculations accounting for the actual quantity and orientation of the reinforcing steel, it was obvious that additional reinforcing and epoxy injection of the cracks would be required to restore the slabs shear strength.

The approximate bending moment and shear force diagrams (Figure 4) show the difference between a slab or beam reinforced for positive and negative bending moments (post-repair condition), compared to a slab or beam reinforced only for positive moment (pre-existing condition). The result is a reduction in positive moment on account of negative moment resistance being provided.

By enabling the slab to carry negative moment over the supports, the positive moment on the midspan sections identified to be insufficiently reinforced could be reduced to a magnitude which was calculated to be within acceptable limits for the as-built reinforcing condition.

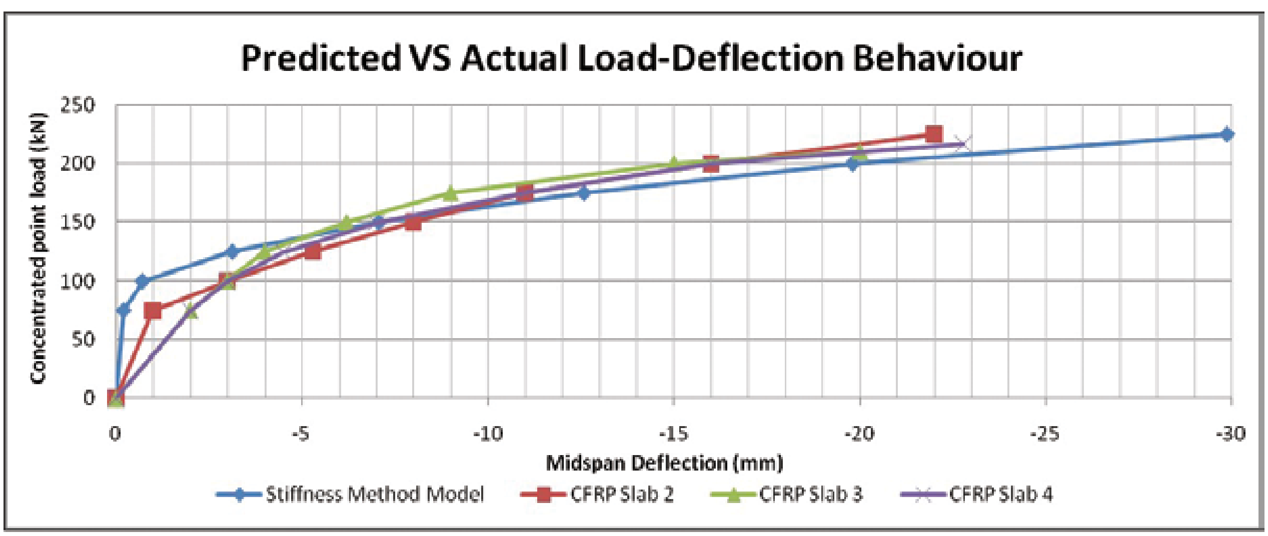
To confirm the effectiveness of the CFRP strengthening concept, laboratory tests were carried out at an engineering research university on representative samples modelled to mimic the pre-and post-strengthened conditions of the slab. The intent of the tests was to measure the strength increase provided by the repair, and to verify that the epoxy flooding method using crack injection resin provided sufficient strength to adequately bond the CFRP in accordance with accepted FRP strengthening guideline standards.

Slab Modelled after Existing Condition

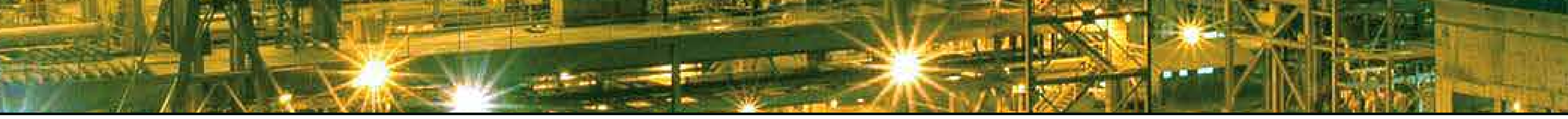
Slab Modelled after Strengthened Condition

The results of the tests indicated that this method was highly effective in providing the additional negative moment resistance to allow the slab to carry the original design live loads. On average, the repair method provided a 57% increase in overall failure load, which was caused by overall shear failure of the concrete.

An advanced calculation model was used which resulted in a predicted load vs displacement relationship. Basic assumptions were used involving strain compatibility and a perfect bond between the CFRP and the concrete. The predicted load vs displacement behaviour very closely matched the actual behaviour of the specimens, and on that basis, back calculating from the model, the strain at which the CFRP debonded was determined and the design strain used in the section strength calculations was confirmed to be appropriate and included a sufficient factor of safety.



Predicted vs Actual Load-Deflection Results



Cutting CFRP Slots

Water Blasting CFRP Slots

Repair Implementation

Having verified the repair design, the slab strengthening project would proceed. The repair steps for installation of the CFRP were as follows:

- Saw cut slots for the CFRP reinforcing in the top of the slab at spacing as per calculations
- Blast slots with high pressure water and degreaser solution
- Vacuum standing water and blow the slots dry with compressed air
- Wipe clean the CFRP strips with acetone
- Place the CFRP strips in the slots using spacers as required to ensure the correct position
- Flood the slots using low viscosity resin mixed by an epoxy injection pump
- After the bonding epoxy is cured, install a 3 mm thick by 50 mm wide epoxy seal on the top surface of the slot to prevent the possibility of process water seeping in and disturbing the bond over time

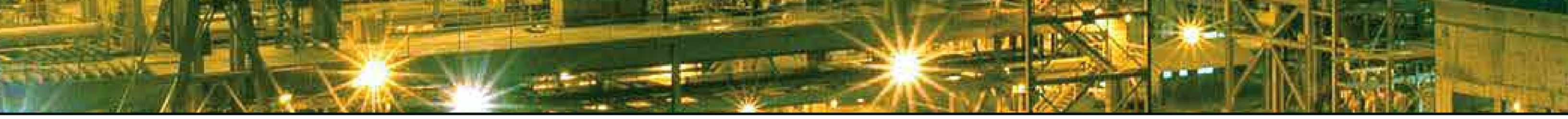
Installing CFRP with Epoxy Injection Pump

Sealing Top of Slots with Epoxy

The epoxy injection repairs were more difficult at this project than usual, mainly due to mineralization of process water blocking the cracks and preventing epoxy from flowing from one port to the next.

The repair steps to inject the structural cracks were as follows:

- Install injection ports intersecting the cracks at approximately 45 degrees
- Seal the top surface of the cracks with appropriate epoxy adhesive
- Inject under high pressure a diluted phosphoric acid solution to clean the crack of any mineralization or other blockages
- Inject clean water under high pressure to remove any remaining phosphoric acid or residue from the cracks
- Inject the cracks using appropriate epoxy resin
- Confirm proper crack penetration through core sampling



Ports Installed for Cleaning / Injection

Slab Strengthening and Repairs Completed

Project Challenges

This project presented several challenges which the contractor had to address to achieve the project objectives.

Ongoing activity on the slab required staging the repairs in zones in order to restrict live loads on the structure and prevent process water from flooding the work area. This required close coordination between the contractor and the owner.

The local labor force had to be technically trained to install these materials as this type of repair work was not familiar to them. This was accomplished through training on use of the specialty equipment, and education about the repair methods, both through theoretical and practical training.

The cracks which were to be injected were blocked by years of process water and residue from sandblasting particles entering them and hardening, making it nearly impossible to pass injection resin through them. Several methods were attempted prior to succeeding with the steps indicated in the repair procedure section of this report. Since additional materials needed to be used to accomplish a successful result, it was necessary to procure them from North America, requiring significant lead and transport time met with several logistical challenges.

Heavy Steel Mill Liners in Place on Strengthened Floor

Conclusion

After a comprehensive field investigation, it was determined that reinforcing in the Batu Hijau Grinding Building Slab was misplaced or missing, leaving a significantly under-performing slab unable to safely handle heavy loads from steel mill liners. A practical and cost-effective repair method consisting of epoxy injection and Near Surface Mounted CFRP strips was modelled and university lab verified to meet the project criteria. A total of 6,000 lineal meters of CRFP was installed, in conjunction with approximately 300 lineal meters of crack injection. After the repairs, the slab was placed back into service. Since then, it has been visually inspected several times and no additional cracking or distress has been noted.