INDUSTRIAL CATEGORY

# Strengthening of Grinding Building Slab at Batu Hijau Copper-Gold Mine

Nusa Tenggara Barat, Indonesia

Submitted by Vector Corrosion Technologies

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On the island of Sumbawa, in remote 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.

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 caused by steel mill liners being piled on them. In addition to the steel liners, heavy equipment is often carried by the structural concrete slab.

Original design drawings indicated that 0.63 in. (16 mm) diameter reinforcing steel should be installed in the 8.6 in. (220 mm) thick slab in the structural direction at 5.9 in. (150 mm) on center, and in the nonstructural direction at 17.8 in. (450 mm) on center. The slab is supported by W610 steel beams at varying spacing, which are in turn supported by larger W1000 steel beams. The spacing of the supports cause the slab to act as a one-way slab on multiple supports. Only positive moment reinforcement was specified in the original design drawings, which is unusual for any concrete member designed to be continuous.

## EXISTING CONDITION OF SLAB

The condition of the 14-year-old slab clearly showed signs of a lack of tensile reinforcement, 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 reinforcement being installed in the structural direction, leading to a significant strength reduction versus the original design.

Several cores were taken in cracked areas and revealed that most of the cracks extended the full depth of the concrete slab.

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 reinforcement provided, and there was no negative moment reinforcement 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. Because the design live load in this case is significantly more than the dead load, 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 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 to the intended design live load.

## NEAR-SURFACE-MOUNTED CFRP

The repair method used involves cutting slots into the concrete surface, installing prefabricated CFRP strips (carbon fiber encased in epoxy binding resin) into the slots and bonding them to the concrete using appropriate epoxy resin. These strips are generally allowed to be stressed to 135 ksi (934 N/mm²) 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 reinforcement of 49 ksi (340 N/mm²).

If the CFRP reinforcement is installed while the structural member is free from live loads (that is, 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.

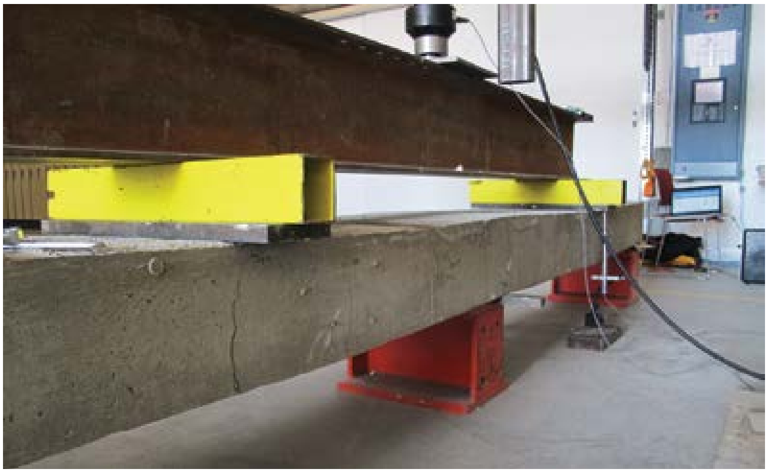
## MODELING AND VERIFICATION TESTING

To enable the slab to safely carry the intended design loads, it was obvious that additional reinforcement and epoxy injection of the cracks would be required to restore the slabs shear strength.

By enabling the slab to carry negative moment over the supports, the positive moment on the mid-span sections identified to be insufficiently reinforced could be reduced to be within acceptable limits for the as-built reinforcement condition.

*The Batu Hijau mine was the world's largest greenfield mining project when it was developed by PT Newmont Nusa Tenggara*

*Typical negative moment crack over beams*



*Slab modeled after existing condition*

To confirm the effectiveness of the CFRP strengthening concept, laboratory tests were carried out on representative samples modeled 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.

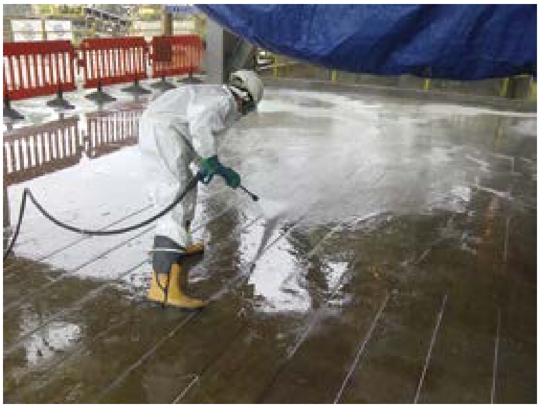
The results of the tests indicated that this method was highly effective in providing the additional negative moment resistance to allow the slab to carry the original design live loads. On average, the repair method provided a 57% increase in overall failure load, which was caused by overall shear failure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

An advanced calculation model was used, which resulted in a predicted load-versus-displacement relationship. Basic assumptions were used involving strain compatibility and a perfect bond between the CFRP and the concrete. The predicted load-versus-displacement behavior very closely matched the actual behavior 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.

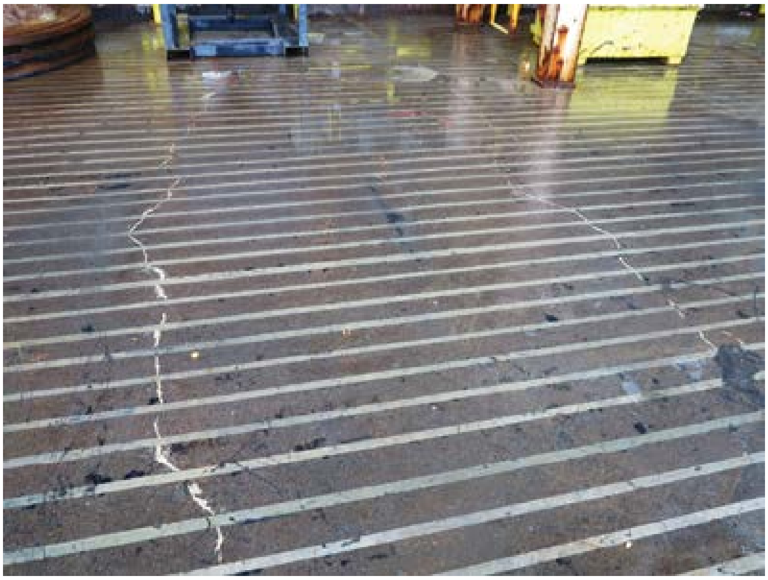
## REPAIR IMPLEMENTATION

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

- Saw-cut slots for the CFRP reinforcement in the top of the slab at spacing as per calculations;



*Water blasting CFRP slots*



*Slab strengthening and repairs completed*

- 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; and
- After the bonding epoxy is cured, install a 0.12 x 1.97 in. (3 x 50 mm) wide epoxy seal on the top surface of the slot to prevent process water seeping in and disturbing the bond over time.

The epoxy injection repairs were more difficult 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 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 acid or residue;
- Inject the cracks using epoxy resin; and
- Confirm proper crack penetration through core sampling.

## REPAIR SUCCESS

After the slab was repaired and strengthened, it was successfully placed in service. A total of 19,685 ft (6000 m) of CRFP was installed, in conjunction with approximately 9843 ft (300 m) of crack injection. Since then, the slab has been visually inspected several times and no additional cracking or distress has been noted.

### Batu Hijau Copper-Gold Mine

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