CONCRETE SLAB EDGE REPAIRS WITH POST-TENSIONING ANCHORS

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At the building owner's request, we reviewed repair procedures during balcony slab edge spall repairs on their high rise residential building that was built in 1986 in West Palm Beach, FL. This is a structure with waterfront exposure. A separate engineer and contractor had been hired for the concrete spall repairs. The engineer reported that in addition to the slab edge spalls, exposed post-tensioning (PT) anchors at the slab edge were significantly deteriorated, causing a structural integrity issue. During the repairs, seven PT anchors were replaced. The PT replacements required interior slab excavations to install temporary load lock offs. The purpose of our review was to provide a second opinion regarding the need for PT repairs. We observed the work during the repairs and took the removed PT anchors away with us.

OBSERVATIONS:

1. The spall repairs excavations exposed rust on slab-edge reinforcing bar and the exterior side of PT anchors. The reinforcing bar was not significantly thinned. The PT anchors were replaced. Some of the reinforcing bar behind the PT anchors showed very little rust. The repair process required interior lock offs. New concrete was placed and the new PT anchors were tensioned.
2. We reviewed the seven PT anchors with cut cables that were removed. All the specimens show varying degrees of surface rust. The results are summarized in Table 1.

CONCRETE REPAIR STANDARDS

The current standards for reinforcing bar corrosion-caused spall repairs are provided by the American Concrete Institute (ACI)[1,2] and International Concrete Repair Institute (ICRI).[3,4] The standard is excavation of concrete behind and along the reinforcing bar, then replacement of concrete. On a nonprestressed steel reinforced concrete structure, the standard is easy to follow. Sometimes thinning of reinforcing bar is minimal. Adding new reinforcing bar occurs only if the thinning of the original rebar was significant. Sometimes, the extent of concrete excavations will require removal of other structures, including PT anchors.

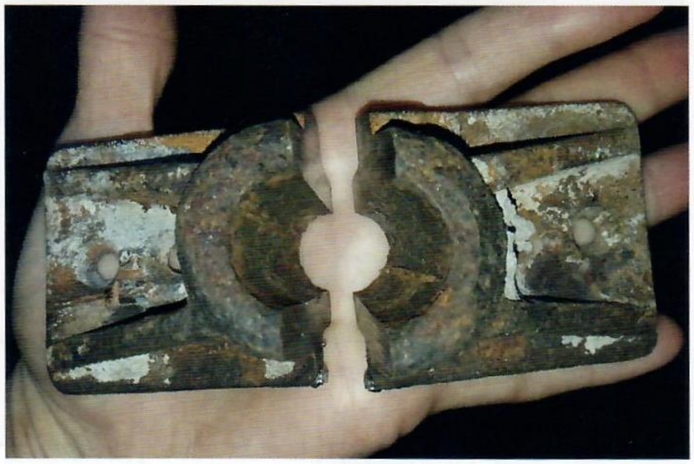

Fig. 1—Specimen No. 1: anchor, nonbearing front side.

Fig. 2—Specimen No. 1: anchor, nonbearing front side.

Table 1—Summary of observations from removed PT anchorages.

Specimen No.	1	2	3	4	5	6	7
General	The anchor, wedge, and strand were saw-cut in half (Fig. 1)	The wedges and strand were machine pressed out of the anchor (Fig. 9 and 10). The wedges stayed attached to the strand (Fig. 11, and 12	The anchor, wedge, and strand were left intact	The anchor, wedge, and strand were left intact	The anchor, wedge, and strand were left intact	The anchor, wedge, and strand were left intact	The anchor, wedge, and strand were left intact[2]
Strand in tendon		Lightly oxidized with no loss of cross-sectional area	No loss of cross-sectional area	No loss of cross-sectional area	No signs of rust or deterioration	No signs of rust or deterioration	
Bearing side of anchor	Minor pitting approximately 0.005 in. deep (Fig. 3)	Very minor pitting approximately 0.005 in. deep	Surface rust and outer edges with pitted areas approximately 0.06 in. deep (Fig. 15)	Surface rust at the edges only and pitted areas of 0.06 in. in some areas (Fig. 17)	Surface rust at the edges only (Fig. 19)	Surface rust with minor pitting around the edges only approximately 0.005 in. deep (Fig. 21)	
Wedge cavity	Minor pitting <0.005 in. deep (Fig. 4)	Very minor pitting <0.005 in. deep (Fig. 13)					
Nonbearing front side of anchor	Minor pitting approximately 0.005 in. deep (Fig. 2)	Minor pitting approximately 0.005 in. deep	Rust scale mostly at the outermost surface at the barrel	Minor pitting and scaling, mostly at the outer edges with pitting approximately 0.005 in. deep	Minor pitting and scaling; the pitting is approximately 0.005 in. deep	Minor pitting approximately 0.005 in. deep	
Wedge outside surface	Minor pitting <0.005 in. deep	Very minor pitting <0.005 in. deep					
Wedge inside surface	Clean serrated teeth intact along the cut (Fig. 5-7)[1]						
Strand tail in front of anchor	Significantly deteriorated	No loss of cross-sectional area	Significantly deteriorated (Fig. 14)	No loss of cross-sectional area (Fig. 16)	Deteriorated with approximately 30% loss of cross-sectional area (Fig. 18).	No loss of cross-sectional area (Fig. 20)	

1. The serrated teeth that did not contact the stranded are covered in scale the same height as the teeth. The cable strands on the load side of the anchor show clea[r] bite marks from the wedge teeth with no rust and no loss of cross-sectional area. (Fig. 8)
2. The anchor, wedge, and strand were installed into a bench vice intact. The strand was cut square with a cut-off wheel close to the anchor. The strand on th[e] bearing side of the anchor was pounded with a 5 lb hammer in an effort to unseat the wedges. The strand and wedges could not be knocked out.

Fig. 3—Specimen No. 1: anchor, bearing side.

Fig. 4—Specimen No. 1: anchor cross section.

Fig. 5—Specimen No. 1: wedge cross section.

Fig. 6—Specimen No. 1: wedge serrated teeth.

Fig. 7—Specimen No. 1: wedge serrated teeth

Fig. 8—Specimen No. 1: strand bite marks from wedge.

The cause of spalling is water intrusion over time, resulting in loss of concrete alkalinity and loss of reinforcing bar protection. Then, the reinforcing bar begins rusting. Over time, the extent of the rust grows, causing a volume increase of the iron in the reinforcing bar. The iron converts to rust scale. The rust scale is approximately 10 times higher in volume, which then creates pressure in the concrete. The concrete splits from within, resulting in a spall. The concrete breaks because it cannot resist the interior pressure of expanding rust.

In the early days of spall repairs, excavations were only slightly larger than the damaged concrete. This did restore structural integrity. Over time, it was discovered that adjacent areas would develop new spalls because of the presence of low-PH, non-alkaline concrete in adjacent areas. The standard changed to increase the extent of excavations along reinforcing bar to areas of alkaline concrete. The new concrete is alkaline.

The common practice for doing spall repairs is after spalls occur. This means that before a spall occurs, rein-

Fig. 9—Specimen No. 2: anchor, nonbearing side.

Fig. 10—Specimen No. 2: anchor, bearing side.

Fig. 12—Specimen No. 2: wedge and strand.

Fig. 11—Specimen No. 2: wedge and strand.

Fig. 13—Specimen No. 2: anchor, inside surface of wedge cavity.

forcing bar rust may be occurring but there is no structural integrity concern. Repairs are not needed until after spalls occur.

STEEL FRAMING REPAIR STANDARDS

There are no industry standards for repair of rusted steel framing, columns, column base plates, etc. The common practice for steel components during repairs is that rust surfaces are cleaned and replaced if rust has thinned the sections significantly.

PT REPAIR STANDARDS

The current standard for repairs of PT structures is provided by the Post-Tensioning Institute (PTI), PTI DC80.3-12: Guide for Evaluation & Repair of Unbonded Post-Tensioned Concrete Structures.[5] This document addresses the assessment, evaluation, and detailed repair procedures for different levels of deterioration of PT structures.

DISCUSSION

A careful evaluation is necessary of deterioration of PT anchors in combination with reinforcing bar corrosion or steel column base plates caused spall repairs. Concrete repairs with PT structures do not need to always follow normal concrete repair standards.

If the tensile capacity of the original concrete was significantly higher, then the concrete might be able to resist the rust caused internal pressure for a much longer time. The tensile capacity could have been increased with carbon fiber or polymer additives.

When concrete is pre-loaded in compression, the effect is an increase in tensile resistance. The concrete

Fig. 14—Specimen No. 3: anchor, nonbearing side.

Fig. 16—Specimen No. 4: anchor, nonbearing side.

Fig. 15—Specimen No. 3: anchor, bearing side.

Fig. 17—Specimen No. 4: anchor, bearing side.

might be more capable of resisting internal pressure due to rust. Concrete under the base plate of a steel column is in compression. Concrete on the bearing side of a PT anchor is in compression. Concrete is less likely to spall in a compression zone.

If a steel column base plate showed rust, the concrete around it could be excavated without excavating concrete under it. The steel column base plate could be cleaned of rust, but not replaced unless the steel was significantly thinned. Excavating concrete under a steel column base plate would be considered only if the base plate needed to be replaced and would require 100% shoring.

If a PT anchor showed rust, the concrete around it could be excavated without excavating concrete behind it. The nonbearing front side of the PT anchor could be cleaned of rust, but not replaced unless the steel was significantly thinned. Excavating concrete behind a PT anchor would be considered only if it needed to be replaced and would require a temporary lock off. Concrete excavation on the bearing side of the anchor cannot be done without careful consideration as very high forces exist in that area. Excavation should not be performed in the anchorage zone of a life anchor without the case-by-case evaluation by a licensed design professional; this zone extends 45 degrees from the edges of the anchor and approximately 4 ft (1200 mm) into the concrete.

Rust on PT anchors or strand does not cause a loss of the ability to carry load unless there is a failure. A PT anchor or strand will hold the full design load until it fails. It will not release its load slowly. If a PT anchor or strand fails, then PT repairs are needed. This means that before a PT failure occurs, there is no structural integrity concern,

Fig. 18—Specimen No. 5: anchor, nonbearing front side.

Fig. 19—Specimen No. 5: anchor, bearing side.

Fig. 20—Specimen No. 6: anchor, nonbearing front side.

Fig. 21—Specimen No. 6: anchor, bearing side.

however, a potential of failure in the near future may necessitate repairs when deterioration is discovered. We have never seen spalling concrete on the bearing side of a PT anchor without movement of the PT anchor. Movement of the PT anchor would be considered failure.

Engineers generally decide on the extent of repairs needed based on their judgment of structural integrity. Because there are no mandatory standards, each engineer can decide differently. The logic can be that if it might be a problem in the future, include it now in the current repairs. The other logic can be that if it's not a problem now, it can be repaired in the future if needed. Replacing PT anchors or PT cables earlier than needed is a judgment call.

CONCLUSIONS

1. The concrete spalls were caused by rust expansion from the reinforcing bar. The rust created pressure within the concrete sufficient enough to fracture the concrete.
2. The spalls were not caused by rust on the nonbearing front side of the PT anchors.
3. There were no spalls on the bearing side of the PT anchors.
4. The PT anchors were not causing a structural integrity issue.
5. Steel surfaces loaded in high compression against other steel surfaces will not rust. The steel loaded in compression in the wedges serrated teeth showed no rust. The rust on the PT parts only propagated between void spaces between cable strands or wedge spaces. If the void spaces were reduced or eliminated, the rust would be eliminated.
6. The rust on steel can propagate into void areas in porous concrete. If concrete porosity could be reduced or eliminated, rust on steel would be reduced or eliminated.
7. Concrete loaded in compression has increased tensile capacity and is less likely to spall.

RECOMMENDATIONS

1. During some slab edge concrete spall repairs, some PT anchors can be left intact. The slab edge concrete repairs can proceed carefully around the PT anchor except in the bearing area of PT anchors; engineering judgement is required to determine the extent of concrete excavation around the PT anchors. Small hairpin reinforcing bar can be doweled in around PT anchors to reinforce edge repairs. Rust can be cleaned on the outside of the nonbearing front side of PT anchors. Corrosion inhibitors can be added before placement of new concrete.
2. Sometimes, because of the extent of concrete excavations, PT anchors will need to be removed. Removal of PT anchors will need temporary lock offs and installation of new PT anchors.
3. PT anchors and/or PT strand should always be repaired whenever failures occur.

REFERENCES

1. ACI Committee 562, "Code Requirements for Assessment, Repair, and Rehabilitation of Existing Concrete Structures and Commentary (ACI 562-16)," American Concrete Institute, Farmington Hills, MI, 2016, 88 pp.

2. ACI Committee 546, "Guide to Concrete Repair (ACI 546R-14)," American Concrete Institute, Farmington Hills, MI 2014, 70 pp.

3. International Concrete Repair Institute (ICRI), "Nondestructive Evaluation Methods for Concrete Structures (Guideline No. 210.4-2009)," ICRI, Des Plaines, IL, 2009, 28 pp.

4. International Concrete Repair Institute (ICRI), "Guide for Surface Preparation for the Repair of Deteriorated Concrete Resulting from Reinforcing Steel Corrosion (Guideline No. 301.1R-2008)," ICRI, Des Plaines, IL, 2008, 16 pp.

5. PTI Committee DC-80, "Guide for Evaluation and Repair of Unbonded Post-Tensioned Concrete Structures (PTI DC80.3-12)," Post-Tensioning Institute, Farmington Hills, MI, 2012, 54 pp.

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