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AVOIDING MISTAKES DURING ASSESSMENT, DESIGN AND CONSTRUCTION OF STRUCTURAL REPAIRS

The process of structural repairs or retrofit generally includes evaluation of an existing structure and its design or as-built capacity, design of the required repairs, and the construction of designed repairs. If the evaluation was not done properly, the design may not address the causes of the structural deficiencies and the repair will not be adequate. After proper evaluation of the existing conditions and design of appropriate repairs, it is important that the construction of the repairs be performed properly. Failure of any of these steps may result in inadequate or faulty repairs. This paper discusses, in more detail, the specific projects and the mistakes made in the repair process.

Keywords: structural repairs, mistakes, assessment, repair design

1. INTRODUCTION

Over the years, more existing structures are being repaired or structurally retrofitted. In times of the economic slowdowns, as the construction of new structures slows down, more and more existing structures are being reused and upgraded. The main reasons for the repairs and retrofits are deterioration of structures over time, material failures, deficient design, faulty original construction or change of use which requires increased load-carrying capacity.

The process of structural repairs or retrofit generally includes evaluation of an existing structure and its design or as-built capacity, design of the required repairs, and the construction of designed repairs. In order to complete the appropriate and necessary repair, all these three steps in the repair process need to be done properly. It is obvious that if the evaluation was not done properly, the design may not address the causes of the structural deficiencies and the repair will not be adequate. After proper evaluation of the existing conditions and design of appropriate repairs, it is important that the construction of the repairs be performed properly. Failure of any of these steps may result in inadequate or faulty repairs.

Over the years, the author's firm has designed repairs or investigated the design of repairs performed by others for hundreds of structures and has encountered instances where there were mistakes made which resulted in ineffective repairs. The following sections will discuss, in more detail, the specific projects and the mistakes made in the repair process.

2. MISTAKES DURING ASSESSMENT OF EXISTING STRUCTURES

It is taken for granted that the dimensions of the existing structural members should be measured properly and that the location and size of steel reinforcing in concrete structures will be determined by non-destructive testing methods and verified by limited exploratory openings. Mistakes are more likely to be made in interpretation of observed conditions and test data during the load testing of structures.

As part of the evaluation process, exploratory openings are made in concrete structures to evaluate the condition of underlying concrete or the buried membrane, or to inspect post-tensioning tendons and then the observed conditions are extrapolated to the rest of the structure and projections are made of anticipated repair quantities. This methodology could lead to wrong results. For example, there have been instances where the actual quantities of post-tensioning tendon repairs exceeded the projected quantities by a factor of 5 to 10. It is almost impossible to apply this methodology to this type of repairs. The knowledge gained by examining exploratory openings needs to be supplemented by engineering judgment and past experience with similar projects.

Sometimes we overact when we observe significant cracking in concrete structures like the one shown in Figure 1. Before we declare an emergency and start installing temporary shoring, we should perform a simplified quick evaluation of the remaining structural capacity. In some instances, we will find that even though structural capacity is reduced and strengthening is required, there may be enough capacity remaining. This condition need not be treated as an emergency.

Figure 1. Severely cracked concrete slab

Figure 2. Cracking due to restrained volume change

It is not uncommon to misinterpret the structural distress caused by the restrained volume changes in concrete structures as shown in Figure 2. We should be aware that long pieces of concrete, when restrained at both ends, will crack because there will be large tensile stresses due to shrinkage and creep that can overcome the strength of the structural member. It is important to properly assess the cause of this distress in order to design appropriate repairs.

Figure 3. Arching of the test load

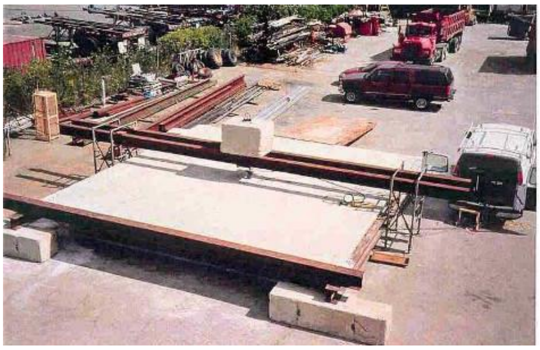

Figure 4. Test slab exposed to temperature effects

During the load testing of the structures, we have to recognize the effects of the possible arching of the test loads (Figure 3), the temperature effects on the structure during the testing (Figure 4) and the deflection of the loaded structure member under constant hydraulic load (Figure 5). We also need to design the test load application so it does not fail during the load application and that we provide adequate shoring under the structure in case of its unexpected failure under the test load (Figure 6).

Figure 5. Hydraulic test loading

Figure 6. Failure of structure during the load test

3. MISTAKES DURING DESIGN OF STRUCTURAL REPAIRS

Most common mistakes include inadequate attention to design of the temporary shoring required for construction of the structural repairs. This shoring needs to be strong enough to carry all vertical and lateral loads on the structure in addition to its self-weight. The footing elements of the shoring have to have adequate stiffness (Figure 7) to distribute the loads to the soil and to be properly designed for the expected soil reactions (Figure 8). Also, not taking into account temporary longitudinal loads may result in failure of the temporary shoring structure (Figure 9).

Figure 7. Deflection of shoring mudsill

Figure 8. Cracked concrete bearing pad

Figure 9. Collapsed construction gantry

During a demolition of an old steel bridge, the fascia girder was being removed by picking it up with two cranes on barges, one on each end (Figures 10 and 11). When the existing floor beams were cut to free the fascia girder from the rest of the bridge, the weight of the girder was transferred at each end to a crane (Figure 12). However, since the girder was not adequately laterally braced, it buckled under its own weight and collapsed. The two cranes also collapsed and an operator of one crane was killed (Fig. 13).

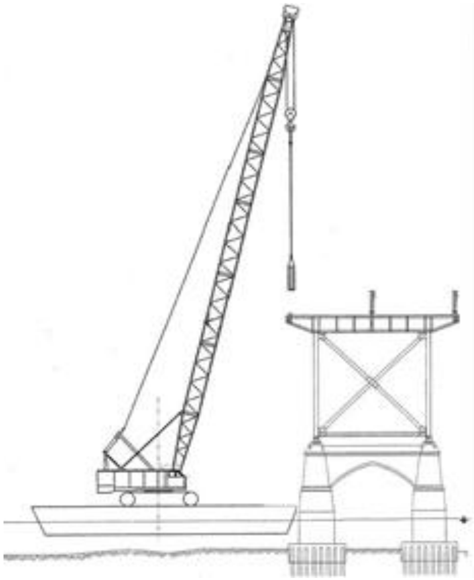

Figure 10. Removal of fascia girder from the bridge

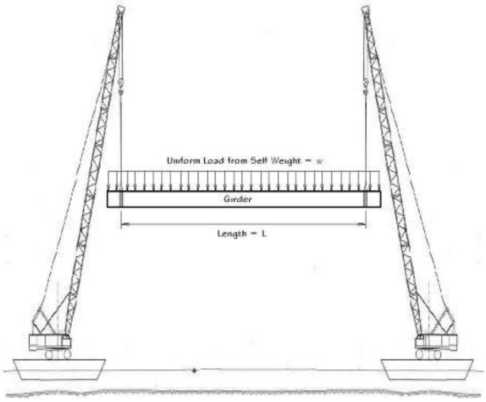

Figure 11. Pick-up points for the fascia girder

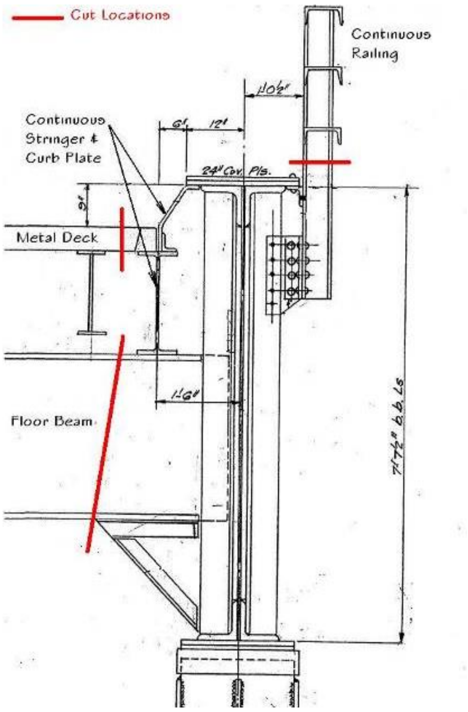

Figure 12. Cutting the connections of fascia girders

Figure 13. Collapsed girder and barges

When our repair designs include removing the concrete floor around a column, we need to recognize that this may double the unsupported length of the column which may reduce the column capacity by a factor of four (Figure 14). Our designs need to provide for adequate lateral bracing during that phase of construction or specify the proper sequencing of concrete removal.

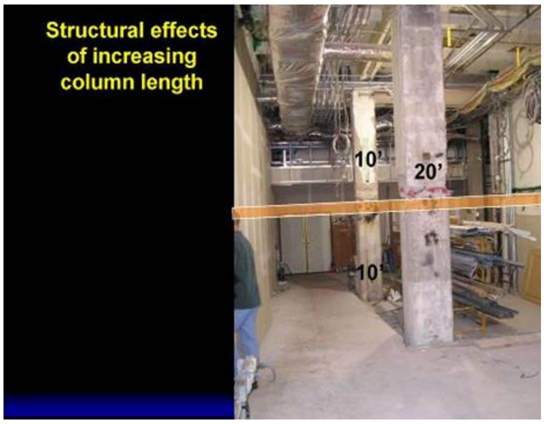

Figure 14. Increasing column length

Figure 15. Compression struts in post-tensioning repairs

Similar conditions may occur in sequencing of repairs of post-tensioning tendons. If we do not provide for leaving concrete compression struts along the line of tendon repairs, parts of the structure may move when the tensioning loads are applied to the tendon (Figure 15).

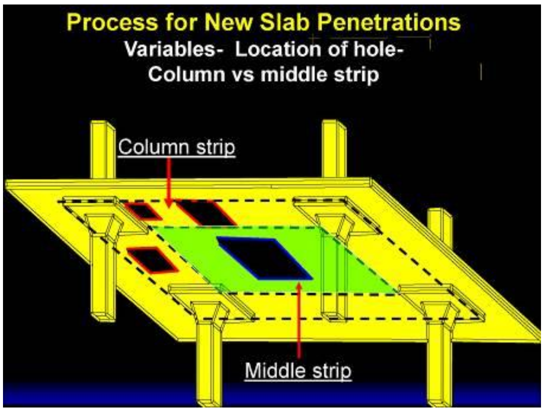

Figure 16. Cutting large openings in slab

When we need to design penetrations in the existing floor slabs, we need to make sure that they do not reduce the capacity of the slab beyond what is required. If we cut large openings in the slab (Figure 16) which interrupt the flow of tensile forces in a two-way slab system without additional reinforcing, the structure will not be able to carry even its self-weight. A similar condition may occur if we design too many penetrations in the floor close to each other (Figure 17).

Figure 17. Closely spaced slab penetrations

4. MISTAKES DURING CONSTRUCTION OF STRUCTURAL REPAIRS

As in the previous sections, one of the common mistakes during the construction of structural repairs includes improper bracing and shoring of structures during the repair process. We have to be alert to the fact that when we remove a connection between a wall and slab during the repair process (Figure 18), we need to provide additional supports for both the slab and the wall.

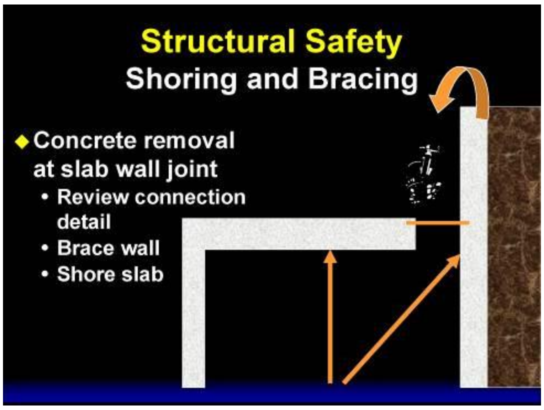

Figure 18. Removal of slab wall connection

Also, when we chip deteriorated concrete in slab around a column, the unbraced length of column doubles and it needs to be laterally supported (Figure 19).

We have to provide for additional supports to accommodate the weight of construction loads, including heavy equipment and removed debris to prevent overloading of the structure during repair (Figure 20).

Figure 19. Removing concrete around column

Figure 20. Excessive construction loads

During the strengthening of the structures we oftentimes use steel anchors into the existing concrete to attach supplemental supports. It is very difficult to predict the exact as-built location of embedded steel reinforcing and we can have great difficulties placing the anchors in the intended locations (Figure 21). It is important to allow for this condition by placing the anchors where possible and then drilling the holes in the attachments to match the locations of the already placed anchors.

Figure 21. Irregular spacing of anchors

Figure 22. Cutting post-tensioning tendons

Special care is required during the repairs of post-tensioned concrete structures. Sometimes during the chipping of deteriorated concrete, the contractor may not be aware of the presence or location of post-tensioning cables and will cut them by mistake (Figure 22). It is important that the sequence of concrete removal does not result in undermining of the post-tensioning cable anchorages.

The contractor should be aware how the structure is constructed and how its load-bearing elements function prior to beginning the repair. The main steel reinforcing is usually at the bottom of the concrete slab but it is the opposite in cantilevered balcony slabs. If that is not recognized in advance, concrete removal may result in collapse of the balcony (Figure 23).

When repairing a loaded concrete column, we need to be aware that chipping inside the reinforced column core, we will be removing loaded concrete and overstressing the column (Figure 24). It is also important that personnel in the field do not over excavate the concrete in loaded columns (Figure 25).

Figure 23. Balcony slab failure

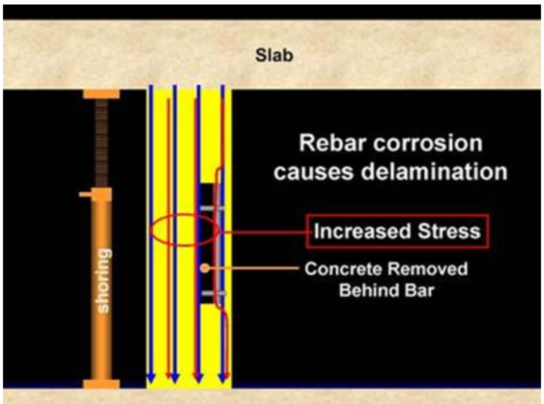

Figure 24. Overstressing column during repair

During concrete repairs, it is important that supplemental reinforcing steel be placed within required tolerances because even small variations may reduce the effectiveness of the repair. All repair materials are not always suitable for all repair applications. The repair material has to have similar characteristics to the base material including strength, modulus of elasticity and shrinkage. Otherwise, the repair will fail. It is common that concrete patches made with very high strength material with a lot of cement will crack because of large shrinkage. An example of improper material used for replacement of an expansion joint seal is shown in Figure 26.

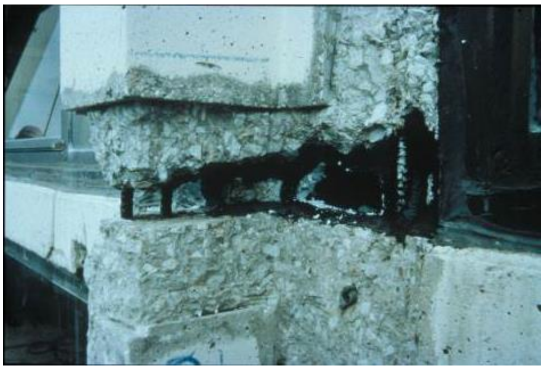

Figure 25. Excessive concrete excavation

Figure 26. Failed joint seal

When using an epoxy to inject cracks, it is necessary to confirm with tests that the epoxy has penetrated the full depth and length of the crack or an area to be epoxied (Figure 27). In concrete repair, proper surface preparation will ensure intimate bond between the patch material and the substrate. When the repair project includes installation of a protective waterproofing membrane over the repaired area, the ambient temperature and the temperature of the substrate have to be within the limits specified by the manufacturer to avoid failures of the membrane (Figure 28).

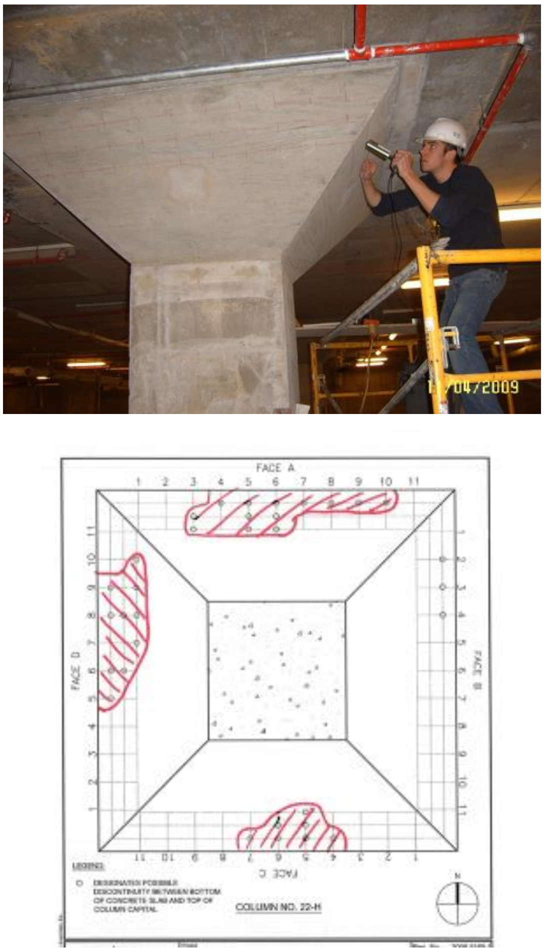

Figure 27. Testing for voids

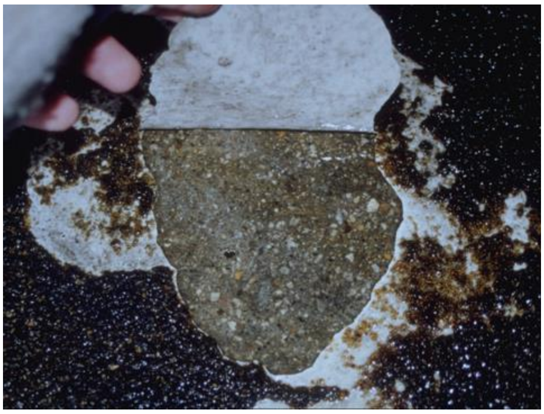

Figure 28. Failed waterproofing membrane

5. SUMMARY AND ACKNOWLEDGEMENTS

The above mentioned examples do not provide all possible mistakes that we encountered over the years but point out to commonly made mistakes in evaluation, of structures and design and construction of structural repairs. The examples listed in this article were, in addition to the author, investigated by engineers from author's firm and their contribution is gratefully acknowledged.