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DURABILITY ASSESSMENT USING INTEGRATED QUALITY MANAGEMENT FRAMEWORK IN P3 INFRASTRUCTURE PROJECTS

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Abstract: The life-cycle performance of P3 infrastructure projects is measured in terms of reduced repair and maintenance costs, as well as short duration of down-time due to the maintenance activities. As a result, durability of the infrastructure elements becomes an important performance measure of the P3 projects. In the current design codes and standards, the requirements for durability over the infrastructure life-cycle are not explicitly considered. While the life-cycle performance of the infrastructure elements, as designed, can be estimated based on the existing infrastructure, there is no research in to the life-cycle durability performance of the remedial actions due to construction deficiencies. Therefore, the planning and execution of P3 infrastructure projects requires additional contractual and construction quality management aspects to assess the durability requirements. In this paper, we propose an Integrated Quality Management framework to address the durability issues due to the remedial actions following the construction deficiencies.

1 INTRODUCTION

In Public-Private-Partnership (P3) infrastructure projects, the financial and service-life success of the project depends on the anticipated performance of infrastructure over its life-cycle. The life-cycle performance of P3 infrastructure projects is measured in terms of reduced repair and maintenance costs, as well as short duration of down-time due to the maintenance activities. Therefore, the durability of the infrastructure elements becomes an important performance measure of the P3 projects.

During the construction stage, occurrence of deficiencies is an expected part of the projects. Remedial actions for the construction deficiencies often focus on meeting the design intent while reducing the impacts to the construction costs and schedule. As the infrastructure elements are designed according to the current codes and standards, meeting the design intent would address the safety and serviceability requirements of the infrastructure elements as defined in those standards. However, the requirements for durability over the infrastructure life-cycle are not explicitly considered in the current design codes and standards. Therefore, the planning and execution of P3 infrastructure projects requires additional contractual and construction quality management aspects to assess the durability requirements in order to balance deficiency correction costs with longer term maintenance and rehabilitation requirements and costs.

Development of the construction quality management aspects that address the durability of the remedial actions due to a construction deficiency is not an easy task. While the life-cycle performance of the infrastructure elements, as designed, can be estimated based on the existing infrastructure, there is no research in to the life-cycle durability performance of the remedial actions. Furthermore, as the remedial actions often involve the use of the latest repair products and procedures, it adds to the difficulty in predicting the durability of the repaired component. In practice, not all construction deficiencies may result in the reduction of life-cycle durability. On the other hand, routine remediation actions may have significant impacts on the component durability.

In this paper, we propose an Integrated Quality Management (IQM) framework to address the durability issues due to the remedial actions following the construction deficiencies. The approach depends on identifying and categorizing the construction deficiencies that have no impact, moderate impact and significant impact on the component durability. Categorization of the remedial actions on this basis would inform the consideration of warranty, long term maintenance and rehabilitation costs, and risk transfer associated with each construction deficiency. This would improve the ability to manage the infrastructure durability either through the selection of alternative remedial actions or design changes to avoid such construction deficiencies.

2 FACTORS AFFECTING DURABILITY

As life-cycle cost performance is important in P3 projects, recognising the factors impacting the durability, and planning to either prevent or mitigate those factors is needed with the project initiation. A comparison of the common practices in design-build projects that could inadvertently impact the financial success of P3 projects by reducing the durability of the infrastructure components are as follows:

Design basis: When designed according to the existing design codes and standards, the design intent is focused on meeting the safety and serviceability requirements. Durability requirements for infrastructure elements, such as bridges and roads, focus on mitigation of degradation mechanisms, such as corrosion and fatigue that affect the long-term capacity to resist the design loads. Consequently, the focus of these requirements is to increase long-term capacity. In spite of meeting the durability requirements as set out in codes and standards, designs that limit the remediation approaches due to construction deficiencies, and reduce the ease of replacement and rehabilitation of the design elements may not address the durability requirements needed for P3 projects.

Construction methods: Construction practices to reduce the project costs, such as procurement of materials for multi-purpose use, low cement concrete mix designs, limited quality control, scant documentation of materials testing and quality control, and sparse details in as-built drawings impact durability and future maintenance and rehabilitation requirements. Methods adopted for accelerating the construction schedule, such as concurrent work by multiple teams with communication gaps, construction with modular elements that reduce the ease of repair and replacement of individual elements, on-site casting of precast concrete elements which lower the quality control, high strength concrete mix designs to reduce the requirement of formwork, use of high temperatures for accelerated concrete curing, and construction under adversarial weather conditions, may also negatively impact the durability and future maintenance and rehabilitation requirements even when they meet the design specifications and contractual requirements.

Non-Conformities: Construction deficiencies and non-conformities are addressed by recommendations of using as-is, repair and remediation, or re-work. Actions to remediate non-conformities are planned to meet the design intent and contractual obligations related to the construction component. However, remedial actions to meet the initial design conditions could introduce hidden defects that may decrease the life-cycle durability of the component and increase future maintenance and rehabilitation costs.

During the construction, decisions related to design basis and construction processes are already in-place, and the approach to mitigate the impact on durability depends mainly on the approach to address non-conformities and overall construction quality management.

3 INTEGRATED QUALITY MANAGEMENT (IQM)

3.1 Description

A Quality Management System (QMS), developed according to ISO9001:2015 (ISO9001, 2015), defines a framework for management of project quality. In an integrated implementation of QMS with IQM, all the major stakeholders in the project (such as design-build contractor, concessionaire, operations and maintenance contractor and project owner) agree to establish common quality objectives and quality system procedures. This enables transparency and coordination among all the parties involved, and quality requirements can be met with greater efficiency. The implementation and success of IQM is heavily dependent on the willingness to coordinate among all the parties involved, including the project owner who sets out the project performance requirements. A full description of the IQM and a case study with its successful implementation are presented in Vemana and Koduru (2017). A brief description of the important elements in IQM is presented in the next two sections.

3.2 Implementation

Successful implementation of the IQM is possible with the following three components, as discussed in Vemana and Koduru (2017), which are briefly summarized here:

Quality objectives: Performance measures to evaluate if quality objectives are met will be consistent between all the entities involved in the project due to common quality goals for the entire project. As the project progresses, the performance measures achieved at each phase will provide evidence for successful implementation of IQM, and allow for necessary corrections in the quality process at the earlier stages of the project. This provides additional oversight at key phases of the project.

On-site communication: The objective of the on-site communication system is to increase awareness among all the entities involved regarding the construction progress, quality records generated and any non-conformities in the construction work. The durability impact of any approach selected for schedule acceleration, documentation, and remediation of non-conformities, can be evaluated by multiple stakeholders, including the operations and maintenance contractor. This will enable the selection of remedial measure that would mitigate impact on durability and reduce overall project costs instead of solely focusing on the reduction of construction costs.

Records management: Due to the large volume of documentation needed to evaluate performance measures and its accessibility to multiple entities, a consistent approach for records management is needed for all project phases. This requires clear articulation of the type of records to be maintained, record formats, approval authority for modification or release of records, and record review and approval process. As the review and approval process is streamlined and records are accessible to all entities, evaluation of durability impact is due to any non-conformity can be performed by appropriate subject matter experts.

3.3 Process outcomes

Successful implementation of IQM with the engagement of all stakeholders can attain appropriate balance between competing demands due to design requirements, construction cost and schedule, maintenance and rehabilitation strategy and infrastructure durability, in order to meet the P3 project performance requirements over its life-cycle. Through IQM, remediation of non-conformities can be categorized to have no impact, moderate impact, and significant impact on the component durability based on the following criteria:

- Selection of repair method
- Long-term performance of repair materials
- Impact on future maintenance requirements and costs
- Requirements of records retention
- Size of construction deficiency
- Significance of the repaired component to the overall infrastructure performance

The application of these criteria is demonstrated through case studies in the next section.

4 CASE STUDIES

4.1 No or Minor Impact on component durability

Surface imperfections in concrete, such as honeycombing (shown in Figure 1), spalls (shown in Figure 2) have minor impact on the component durability and are non-conformities due to contractual obligations and technical performance requirements. Selection of appropriate repair methods that create concrete surface for proper bonding and the use high-performance repair materials with good long-term performance to repair these non-conformities would likely have no impact on the durability of the component. Improper repair methods and inadequate repair materials could lead to higher future maintenance costs and possibly a need to re-repair. However, if the size of these deficiencies is small, and if the concrete imperfections are related to non-critical structural elements, these non-conformities could be categorized to have a minor impact on component durability. In this case, record retention requirements are also minimal.

Figure 1: Honeycomb in Cast-in-place Concrete

Figure 2: Corner Spall in Concrete Road Barrier

4.2 Moderate Impact on component durability

Mechanically stabilized earth (MSE) walls are a low construction cost option for bridge abutments and reduce the volume of in-situ concrete for retaining walls by using precast concrete panels. This is an attractive option to accelerate construction schedule in cold weather regions, as the panels can be build in precast yard and are not impacted by the ambient temperatures needed for in-situ concrete. Figure 3 shows a MSE wall under construction. As shown in Figure 4, MSE walls have multiple concrete panels attached to long steel reinforcement bars that are embedded in compacted soil layers.

Figure 3: Mechanically Stabilized Earth (MSE) walls Designed as Bridge Abutments

Figure 4: MSE Wall Back Fill Reinforcement

Figure 5 shows a cracked concrete panel in a MSE wall. Panel replacement will have a moderate impact on the component durability of the MSE wall as the soil layers and the embedded reinforcement behind the panel will be disturbed. Repairing the panel in-situ through grouting the crack is a better remediation approach as it would leave the compacted soil layers undisturbed and reduces the overall impact on the durability. Figure 6 shows the differential settlement adjacent bridge barriers due to the uneven settlement of bridge approach, which in turn was caused by the improper backfill compaction for MSE walls. In both of these cases replacing the elements to be equivalent to initial design requirements would lead to greater component durability impact to the MSE wall and higher future maintenance costs than other remediation approaches. Furthermore, any remediation approach to address the non-conformities would need retention detailed records regarding the original deficiency, remediation approach and continued monitoring of the performance of remedied component.

Figure 5: Cracks in MSE Wall Panels

Figure 6: Approach Settlement Due to Deficiencies in MSE Wall Backfill Compaction

Figure 7 shows the differential settlement on the roadway due to deficiencies in the subgrade compaction. Given the size of the construction deficiency, and increased future maintenance costs, this non-conformity can be classified to have a moderate impact on the component durability of the roadway.

Figure 7: Roadway Settlement Due to Deficiencies in Subgrade Compaction

4.3 Significant Impact on component durability

Figure 8 shows a bridge deck designed to have precast and prestressed concrete panels as part of the structural system. These panels were intended to reduce the requirements of formwork and decrease overall bridge deck thickness with the prestressing of concrete in the panels. As shown in Figure 9, these panels are connected to each other through shear reinforcement and cast-in-place concrete surface that would ensure that the entire bridge deck will act as single structural element.

Figure 8: Precast and Prestressed Concrete Panels on Bridge Deck

Figure 9: Rebar Connecting Precast Panels and Cast-in-situ Concrete Deck for a Monolithic Concrete Deck

In this case, a construction deficiency in any of the precast concrete panels cannot be replaced by the removal of the panel and proceeding with the in-situ concrete pour. This removal would significantly impact the intended structural behaviour of the bridge deck. On the other hand, replacement of the panel with a similar precast prestressed panel may not be practical depending on the stage of the placement of rest of the reinforcement as well as the duration of casting and curing a replacement panel. In this case, the non-conformity impacts design intent, construction schedule and long-term durability of the structure. Due to IQM, the impact of remediation approach was communicated to all the relevant stakeholders, and an approach that balances between the design, construction and maintenance costs is selected.

5 CONCLUSION

In P3 projects, remediation approaches to address construction deficiencies and non-conformities may have significant impact on the component durability during the project life-cycle. In certain cases, the replacement of a component to address the deficiency may have greater impact on the overall component durability and may increase the maintenance costs. For any single stakeholder, it is difficult to discern the impact of each action on the rest of the project components. For example, replacement of a MSE wall panel may lead to meeting the design intent and remediation of non-conformity, but may lead to maintenance issues to disturbed backfill compaction. In such cases, through IQM, all the stakeholders are engaged to identify and assess the significance to different aspects of the project and the remediation approach is selected to minimize the project costs over its life-cycle.

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