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Investigation into Discrepancies in Alignment and Levelling of Precast Segmental Box Girders (SBGs) During Launching for LRT 3, from Bandar Utama to Johan Setia (Package GS10)

Nurul Afiqah Mohd Idris[1], Reventheran Ganasan[1,2]*, Akmal Hakim Ismail[3], Mustapha Kamil Omran[1], Zuraidah Ngadiron[1], Ramesh Nayaka[4], Akter Hosen[5]

[1] *Department of Transportation Engineering Technology, Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, Pagoh, 84600, MALAYSIA*
[2] *Sustainable Engineering Technology Research Centre (SETechRC), Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, Pagoh, 84600, MALAYSIA*
[3] *AlKauthar Kinematics Sdn Bhd, Cyberjaya, 63000, MALAYSIA*
[4] *Department of Civil and Infrastructure Engineering, Indian Institute of Technology (IIT) Dharwad, Karnataka, 580011, INDIA*
[5] *Department of Civil and Environmental Engineering, Dhofar University, Salalah, 211, OMAN*

*Corresponding Author: reven@uthm.edu.my
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Abstract

In recent decades, there has been a notable global increase in the utilization of precast concrete segmental bridges within construction projects. However, discrepancies have been observed in the height of precast Segmental Box Girders (SBGs) installed alongside PS1 (monolithic), deviating from project specifications. This discrepancy impacts the deck level and consequently influences the Top of Rail (TOR). Consequently, a study was undertaken at AlKauthar Kinematics Sdn Bhd, a company involved in the LRT3 project's construction, with a specific focus on the casting and installation of Segmental Box Girders. The study's objectives include identifying the factors contributing to precast SBG misalignment during the LRT3 project's launch at P25-08, analyzing data for realignment purposes, and proposing design methodologies for manufacturing SBGs. The methodology employed in this study entails the analysis of data sourced from the industry, utilizing As-Built Surveys conducted by surveyors. Findings indicate that precast SBG misalignment during launching at P25-08 is primarily attributed to on-site errors, particularly casting errors during the construction of the cast-in-situ monolithic segment P25-08. This insight is invaluable for both governmental bodies and private construction organizations in mitigating project setbacks.

1. Introduction

In recent decades, there has been a significant global surge in construction projects employing precast concrete segmental bridges, particularly in highway infrastructure [1][2]. This surge is attributed to the cost-effectiveness of segmental structures compared to traditional monolithic bridges, which are composed of a single large piece. Unlike monolithic bridges, segmental bridges consist of smaller prefabricated elements held together by exterior tendons, allowing for greater flexibility and efficiency in construction processes [3][4]. To accommodate the width of roadways, segmental bridges utilize mild steel reinforcement and high-strength post-tensioning tendons, combined in a trapezoidal box form with cantilevered top flange extensions [5][6]. Both segmental and monolithic box girders are prevalent in modern construction practices, with segmental box girders favored for projects like the KVLRT3, where long-span decks are necessary to cross active traffic routes like the KESAS lane. Precast methods involve off-site construction of bridge components, which are then transported and installed at the construction site. Yet, the cost-effectiveness of precast segment bridges is limited to spans of approximately 150 meters due to the expenses associated with specialized installation equipment [7][8][9][10]. Despite this limitation, precast segmental bridge construction offers advantages over cast-in-place segmental bridge building, including controlled casting conditions in pre-casting yards and reduced costs. In the LRT3 project, Prasarana Malaysia Berhad took over as the project owner, with MRCB George Kent Sdn Bhd (MRCBGK) selected as the primary contractor after their nomination as the Project Delivery Partner (PDP) on September 4, 2015. Subsequently, the project transitioned to a fixed-price contract regime on October 17, 2018, with MRCB as the primary contractor [11].

AlKauthar Kinematics Sdn Bhd is involved in the LRT3 project as a deck specialist subcontractor, alongside MMSB Consult Sdn Bhd as the lead consultant and S.N. AKMIDA Holdings Sdn Bhd as a subcontractor. MMSB Consult Sdn Bhd specializes in the construction of segmental box girder (SBG) bridges, utilizing industrialized methods that reduce costs and allow for quality monitoring of segments before installation. These methods have facilitated long-span constructions over challenging terrain with minimal disruption to traffic flow, demonstrating adaptability to various settings. This study primarily focuses on the ongoing industry project, the Construction and Completion of LRT3 from Bandar Utama to Johan Setia. Due to limitations of the Cantilever Line below 72m, SBG segmental precast was employed in the LRT3 (Package GS10) project. The line comprises 81 segments, consisting of two PS1 (monolithic) segments and 79 precast segments. However, during the installation of precast SBG alongside the PS1 (monolithic), it was observed that the height did not adhere to the project specifications. This discrepancy led to a difference in the deck level, consequently affecting the Top of Rail (TOR) requirement in the railway system. When such a level mismatch occurs between the in-situ segment and the precast, it necessitates redoing the samples, thereby delaying the completion process. Consequently, the study aims to investigate the causes of the design mismatch between precast SBG and in-situ PS1 from both standard and manufacturing perspectives. Additionally, comparisons have been conducted to determine the appropriate method for addressing the current situation in this line.

2. Pre-cast Segmental Box Girder (SBG)

Segmental post-tensioned concrete box girder bridges offer a multitude of advantages, including their unparalleled versatility in accommodating various curvatures, whether in the horizontal or vertical plane. Alongside their cost-effectiveness, adaptability, and aesthetic appeal, these bridges can be erected with minimal disruption to ground level surroundings, making them particularly suitable for urban and environmentally sensitive areas. The ability to construct segmental bridges swiftly, especially with the utilization of prefabricated segments, underscores their efficiency. Despite being a relatively recent innovation, segmental bridges represent the culmination of centuries-old technological and construction techniques, with key advancements such as Segmental Construction, Box-Shaped Cross Sections, Pre-stressing, and Post-Tensioning Segmental Box Girders [5][12][13].

In Malaysia, the adoption of the Precast Segmental Box Girder system signifies a significant leap forward in highway construction technology. Post-tensioning was first introduced to the metropolitan area in 1997 during the construction of the viaduct for the Light Rail Transit (LRT), marking a milestone in urban infrastructure development. The precast segmental box girder has emerged as one of the most favored types of box girder, owing to its cost-effectiveness compared to suspension or cable-stayed bridges. Not only does its construction process entail less environmental impact, but it also enables quicker completion times [14]. While the concept of segmental construction may not be overly complex, the level of technological expertise required for the design and construction of precast segmental bridges far exceeds that of other bridge types. A comprehensive understanding of the technology is imperative to mitigate past construction challenges, minimize delays, and alleviate concerns related to non-essential issues or insufficient understanding of critical aspects. These considerations apply equally to in-situ span-by-span casting and incremental launching methods, both of which are executed on-site [15].

The fundamental measurements of primary segments include segment length (L), web spacing (I's), bottom slab width (B), and top slab width (W), as outlined in Fig 1 [16]. In its simplest form, the width "W" corresponds to the bridge's width. However, when the bridge width exceeds 40 ft. (12m), or when there is a need to minimize the segment weight or size, the structure width may be subdivided into multiples of the segment width [17].

Transverse post-tensioning across all the boxes and the cast-in-place joint can connect the top slabs (s). Single box sections with multiple webs have been employed for widths up to 70 ft (12 m) instead of using multiple boxes. Additionally, single box sections with integral transverse floor beams, such as the St-Andre de Cubzac Viaducts, or boxed cantilevers, as seen in the Chillon Viaduct, are utilized for intermediate widths.

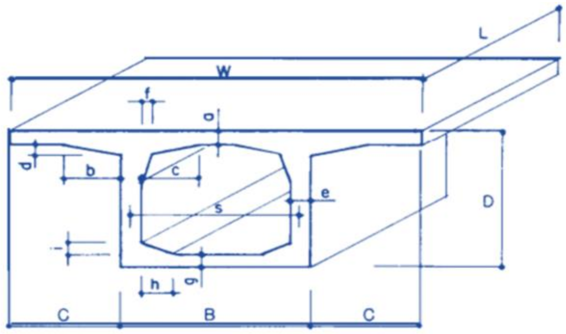

Fig. 1 *Segment dimensions*

2.1 Segmental Box Girder (SBG) Launching at LRT3

The present section mandates the delineation of specifications and properties of materials, equipment, and other resources employed in the ongoing study. If warranted, a bulleted list should be provided, resembling the following example: The LRT3 development project encompasses elevated stations and depots, in addition to viaducts. Each viaduct necessitates the construction of both foundation and superstructure components. The foundation comprises piles and pile caps, while the superstructure is erected using Segmental Box Girder (SBG) construction. Furthermore, the construction of pile caps, columns, and crossheads is requisite for the elevated stations featured in this project.

Moreover, the project entails the establishment of a depot in Johan Setia, along with the installation of various utilities, including internal roads, drainage systems, wastewater facilities, telecommunications lines, and electrical cables Light Rail Transit Line 3 [18]. The positioning of the GS10 package within the LRT3 construction project, adjacent to the KESAS highway, serves as the primary impetus for its implementation. The GS10 package focuses on SBG installation due to its involvement in large-span crossings, with SBG installation at the GS10 package spanning 250 meters.

AlKauthar Kinematics Sdn Bhd's pivotal role in the LRT3 construction project revolves around the precasting and subsequent installation (launching) of segmental box girders (SBGs). Out of a total of 81 units, 79 were precast, while 2 were fabricated on-site. Fig 2 illustrates a segment of the Segmental Box Girder (SBG) slated for use in the construction of the LRT3 [19]. Monolithic piers are assembled from two sections joined together utilizing the cast-in-situ technique. For large spans exceeding 100 meters, box girders emerge as the prevailing and dependable choice for bridge superstructures. In such cases, the utilization of precast segmental bridges becomes imperative to ensure structural integrity and stability over long distances. Box girders offer notable advantages, particularly in the context of 11-plan curved bridges, owing to their exceptional torsional stiffness. Moreover, due to the substantial bending moment exerted on the supports of extended continuous box girder bridges, variations in girder depth along the span may occur, as highlighted by Elmahadi [14].

Fig. 2 *Segmented box girder*

2.2 Considerations for Segment Design

The trajectory of segmental construction's technological advancement has been characterized by periods of intense development, punctuated by significant leaps forward, as well as periods of relative stability. Economic and competitive pressures have been instrumental in driving innovation, leading to incremental improvements across various aspects of construction, including structural forms, analysis and design methods, material properties, pre-stressing techniques, construction methodologies, and contracting practices.

However, it's crucial to recognize that not all incremental improvements necessarily represent progress. Engineers seeking to enhance structural performance must subject their innovative ideas to rigorous investigation and testing to ensure their feasibility, reliability, and practicality. Despite the numerous advantages offered by precast construction, such as expedited construction schedules, enhanced quality control, and reduced labor costs, it also presents unique challenges and issues that require careful consideration and resolution. Table 1 outlines the factors influencing the decision-making process between segmental pre-casting and associated construction methods within the context of the LRT3 project Package GS10.

Table 1 *Factors influencing the decision-making process between segmental pre-casting and associated construction methods*

Factors	Description
Fabrication tolerances	Precast segments adhere strictly to specified design tolerances, deviations from which may result in misalignments during the launching phase.
Construction method	The choice of construction method for launching precast segments significantly impacts alignment accuracy. Variables such as launching equipment, alignment systems, and the sequence of segment installation all contribute to the final alignment outcome.
Segment handling and transportation	Mishandling or improper transportation of precast segments can cause damage or misalignment, leading to discrepancies during launching. Ensuring appropriate lifting, securing, and transportation procedures are followed is essential to preserve segment integrity.
Ground conditions	The condition of the ground or supporting structure where launching occurs can impact segment alignment.
Environmental factors	External environmental factors, including temperature, humidity, wind, and seismic activity, can influence segment behavior during launching, potentially resulting in misalignments.
Quality control and inspection	Inadequate quality control measures during manufacturing and construction phases may contribute to misalignment issues. Regular inspections and quality checks are necessary to identify and address any concerns prior to launching.
Design considerations	The design characteristics of precast segments, such as geometry, connection details, and support conditions, can affect alignment accuracy during launching. Thoughtful consideration of these factors during the design phase is essential to mitigate misalignment risks.
Error on-Site	Casting errors observed during the cast-in-situ monolithic segment P25-08.

Standardization is paramount in precast segmental construction, aiming to minimize variations among segments while allowing contractors some flexibility. This approach facilitates cost savings through standardized and industrialized production processes. When daily tasks align with the design, a small team can fabricate one segment daily from each mold. To achieve this efficiency, consistency in shape, standardization of mild steel reinforcing cages, and a consistent pattern of post-tensioning tendons are imperative. Furthermore, the bottom slab of the segment adjacent to the pier must consistently be thickened. However, even minor deviations from segment specifications can significantly disrupt the regular manufacturing schedule.

3. Methodology

In structuring this section, careful consideration has been given to aligning it with the stated objectives, employing various organizational frameworks such as chronological timelines, case groupings, or configurations of experiments to ensure logical coherence. When embarking on projects involving segmental bridges, the selection of construction methods and materials assumes paramount importance, as these factors exert a significant influence on the design process, particularly in terms of tendon arrangement and accommodating construction loads. Notably, the Balanced Cantilever Method, Incremental Launching, and Span-by-Span Construction represent three primary approaches to constructing segmental box girders, each with its unique characteristics and considerations [20]. The methodology adopted plays a pivotal role in guiding researchers through a systematic progression towards achieving the project objectives. It serves as a structured framework, facilitating step-by-step advancement until informed decisions are reached. Moreover, the methodology underscores the importance of employing appropriate tools for data analysis, particularly statistical methods, to derive meaningful insights and conclusions throughout the project's duration.

A critical aspect of the methodology involves the implementation of the As-Built Survey method, which assumes significance both before and after the launching phase of the project. During the survey process, meticulous attention is paid to detail, with initial readings being captured immediately post-launch. Subsequent steps involve the application of stress to the instrumentation, followed by the acquisition of post-stress As-Built readings. These readings serve as crucial reference points, allowing for the precise determination of the section's position following stress application. However, it is important to acknowledge that deviations may occur post-stressing, necessitating a reassessment of the surveyed data to ensure compliance with specified tolerance levels, which are typically set at less than 15mm. In essence, the methodology serves as a structured roadmap, guiding researchers through the intricacies of the project, from data collection and analysis to the implementation of specific techniques and methodologies. It embodies a meticulous and systematic approach, aimed at facilitating rigorous inquiry and the generation of robust findings in line with the project's overarching objectives. Fig 3 depicts the arrangement of Piers P25-06 to P25-12, facilitating the erection of a Long Span Crossing employing mobile cranes. This installation encompasses five piers and 79 segments, totaling 250 meters in length, with the longest span measuring 78 meters [19].

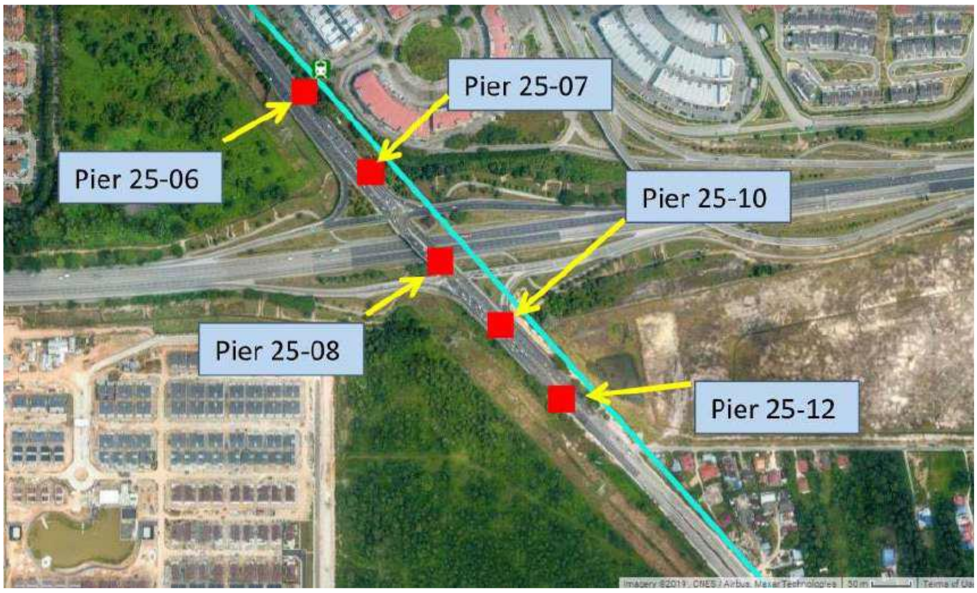

Fig. 3 *Layout of pier P25-06 to P25-12*

The reading will commence, followed by the initial As-Built reading before the stressing process post-launching. During launching, Surveyors initially take the As-Built, then repeat it during the stressing phase. The objective is to identify nearing deviations, allowing adjustments for subsequent segments to realign and restore acceptable levels. Failure to readjust deviations may prevent proper realignment, necessitating minimization efforts or resizing for alignment restoration. However, the LRT3 case presents another issue. In this segment, casting aligns with the old level, raising questions about matching it with the new IFC. Proposals for level adjustment will address this concern. The statistical data configuration analysis is detailed in the subsequent section, with the data analysis conclusion utilized for research closure.

4. Result and Findings

Data was gathered from an industrial project involving the Construction and Completion of LRT3 from Bandar Utama to Johan Setia. The collected data encompasses details including the As-Built Survey Report and the Segment Erection Using Hanger Beam. Each dataset obtained will be depicted in tables to discern the factors influencing precast Segmental Box Girder (SBG) mismatches during launching at (P25-08) and analyze the data for realignment efforts concerning the mismatch issue during Segmental Box Girder (SBG) launching.

4.1 Result Analysis

Surveyors are tasked with conducting detailed surveys, contour surveys, and various scans to scrutinize expansive areas for obstacles. They are responsible for utilizing instruments or procedures to investigate factors affecting SBG mismatch, including horizontal alignment and levels. Regrettably, it was determined post-completion of the overall SBG casting that the SBG level exceeded the level specified in the IFC, resulting in non-compliance with level and alignment requirements. Thus, this document will primarily outline the method of level adjustment for the construction of the long span P25-08 to meet the IFC requirement. For instance, AlKauthar Kinematics Sdn Bhd employed the balanced cantilever method in the SBG installation for the LRT3 construction project. Segment delivery is carried out in pairs, such as P25-08-U01 with P25-08-D01. For a building segment like this, the segment is determined based on its segment ID, upper chainage, and down chainage. Therefore, two key aspects need to be emphasized: vertical alignments (level) and horizontal alignment. The process flow of the As-Built Report Survey can be delineated and summarized as depicted in the Table 2 to Table 9 below.

Table 2 *Before stressing (vertical levels) for P25-08-U01-1*

Point	Theoretical Level (m)	As built (m)	Deviation (mm)
1	20.309	20.300	-9
2	20.307	20.296	-11
3	20.294	20.289	-5
4	20.298	20.297	-1

Table 3 *Before stressing (horizontal alignment) for P25-08-U01-1*

Point	Northing (N1)	Easting (E1)	Northing (N2)	Easting (E2)	Avg. N	Avg. E
DC	-21018.409	-27775.637	-21018.389	-27775.667	-8	-35
UC	-21020.398	-27773.805	-21020.378	-27773.838	-11	-35

Table 4 *Before stressing (vertical levels) for P25-08-U01-2*

Point	Theoretical Level (m)	As built (m)	Deviation (mm)
1	20.309	20.306	-3
2	20.307	20.298	-9
3	20.294	20.294	0
4	20.298	20.302	+4

Table 5 *Before stressing (horizontal alignment) for P25-08-U01-2*

Point	Northing (N1)	Easting (E1)	Northing (N2)	Easting (E2)	Avg. N	Avg. E
DC	-21018.409	-27775.637	-21018.387	-27775.658	0	-30
UC	-21020.398	-27773.805	-21020.377	-27773.830	+5	-30

Table 6 *Before stressing (vertical levels) for P25-08-D01-1*

Point	Theoretical Level (m)	As built (m)	Deviation (mm)
1	20.306	20.306	0
2	20.308	20.307	-1
3	20.313	20.308	-5
4	20.311	20.311	0

Table 7 *Before stressing (horizontal alignment) for P25-08-D01-1*

Point	Northing (N1)	Easting (E1)	Northing (N2)	Easting (E2)	Avg. N	Avg. E
DC	-21013.705	-27779.970	-21013.724	-27779.951	+1	+27
UC	-21015.691	-27778.140	-21015.715	-27778.129	-9	+27

Table 8 *Before stressing (vertical levels) for P25-08-D01-2*

Point	Theoretical Level (m)	As built (m)	Deviation (mm)
1	20.306	20.309	+3
2	20.308	20.309	+1
3	20.313	20.310	-3
4	20.311	20.312	+1

Table 9 *Before stressing (horizontal alignment) for P25-08-D01-2*

Point	Northing (N1)	Easting (E1)	Northing (N2)	Easting (E2)	Avg. N	Avg. E
DC	-21013.705	-27779.970	-21013.720	-27779.940	-12	+32
UC	-21015.691	-27778.140	-21015.708	-27778.121	-1	+32

**Note: Theoretical = Expected, Northing = Offset, Easting = Chainage*

4.2 Findings

The simulation conducted for both the IFC drawing and the casting line (see Appendix 1) revealed that the casting line is situated at a higher elevation compared to the IFC drawing. These simulations were generated using AutoCAD software to prepare for the launch of the SBG. AutoCAD was selected for its capability to produce precise 2D and 3D drawings and models, including construction drawings. It is worth noting that this research study primarily concentrates on the launching of segmental box girders. Further evidently found when the installation of precast PS1 for the P25-08 monolithic segment exhibits an overcast of 22mm. To achieve alignment, a comprehensive simulation of the entire alignment from P25-07 to P25-10 is necessary. Upon comparison, it was determined that the segment impacts the long span, particularly evident at Pier P25-08, where the overcast for the P25-08 monolithic segment measures 22mm. As Pier P2-08 represents the highest alignment of the Top of Rail (TOR) at 22m, adjustments are imperative to meet the level and alignment requirements. Consequently, lowering the span and augmenting it to the original design level becomes essential. Following the adjustment of level and alignment, an analysis revealed a mismatch in span orientation, primarily in the shimming area. Consequently, AlKauthar Kinematics Sdn Bhd (AKKSB) proposed a realignment of the span, as delineated in Table 10.

Table 10 *Recommendation of rectification method for realign the level and alignment*

ID Segment	Proposed Rectification Method
P25-08-U01	Apply a 5mm shim at the top and bottom of the Right-Hand Side (RHS) to achieve alignment. This adjustment is applicable to the next segment, P25-08-U01.
P25-08-D01	Apply an 8mm shim at both the top and bottom of the Left-Hand Side (LFS) to achieve alignment. This adjustment applies to the next segment, P25-08-D01.

5. Conclusion

From this investigation, the primary aim was to ascertain the factors influencing precast Segmental Box Girder (SBG) mismatch during the launch at (P25-08). Factors influencing the precast Segmental Box Girder (SBG) mismatch during the launch at (P25-08) within the LRT3 project's GS10 package have been effectively identified. Extensive literature review revealed eight key factors, including fabrication tolerances, construction methods, segment handling and transportation, ground conditions, environmental factors, quality control and inspection, and design considerations. Specific factors pertinent to Segmental Box Girder (SBG) during launching, such as errors on site, were also identified. Following the identification of these factors, data analysis was conducted. The analysis of data, centered on realignment efforts to address mismatch issues during the launch of Segmental Box Girder (SBG), has also been successfully accomplished. Differences in alignment and levels in relation to the LRT3 project at GS10 package, specifically involving precast SBG during launching, were scrutinized using As-Built Survey data. To realign the alignment and level of monolithic segments in the LRT3 project's GS10 package, an industry-proposed method involving shimming was considered. Shimming, involving the use of metal or other materials to fill gaps between parts, was proposed for vertical and horizontal alignment/level adjustments.

In addition, a recommendation can be provided where Segmental construction technology, versatile as it is, can be effectively and economically used where the volume of the work involved is huge, especially for fast-track construction. The technology has subtle differences from that of non-segmental construction, which has considerable structural implications. The aspect of permanent structure design being complemented, supplemented by temporary structure design and construction technology, and vice versa makes it imperative that 'design & build' organizations who have well-defined and proven technical departments are entrusted with the execution of such construction. The technology has already appeared as a front-runner in India for long span and urban transport structures. If this can be used in judicious combination with other technologies such as external pre-stressing, partial pre-stressing, high performance and high-grade concrete, society can benefit much more.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *N.A.M.I., R.G. R.N.;* ***data collection:*** *N.A.M.I., A.H.I., M.K.O.;* ***analysis and interpretation of results:*** *N.A.M.I., R.G., Z.N.;* ***draft manuscript preparation:*** *N.A.M.I., R.G., A.H. All authors reviewed the results and approved the final version of the manuscript.*

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Appendix 1: Level comparison as-built vs expected level vs ifc drawing of pier p25-08