Figure 1: Crack Movement Reading at Pier 1-33

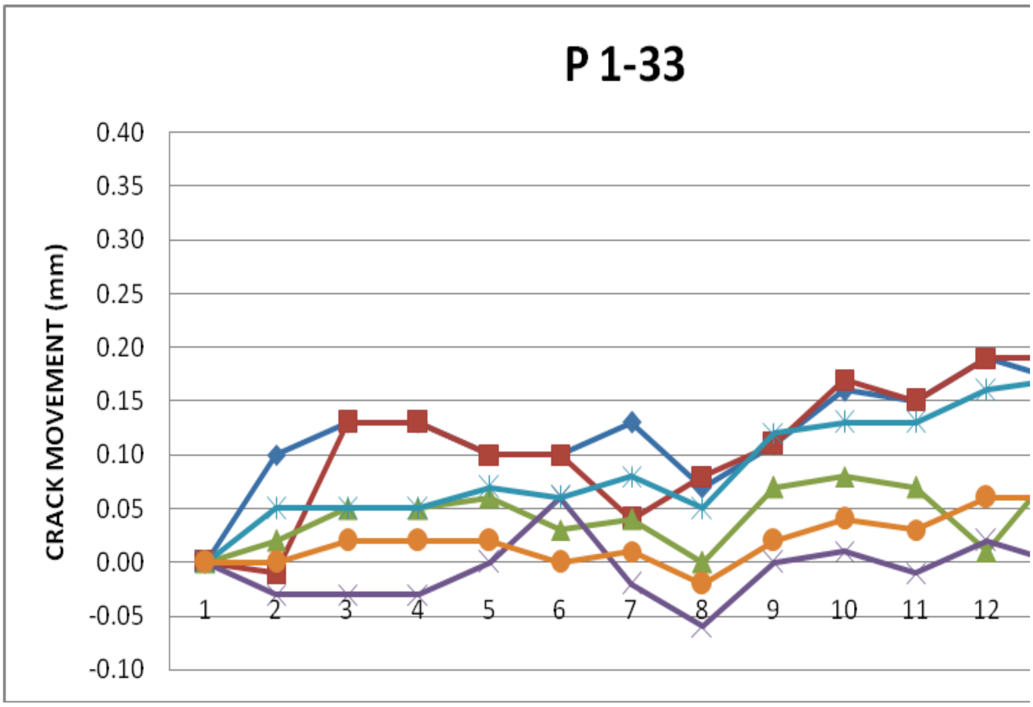


Figure 2: Crack Movement Reading at Pier 1-25

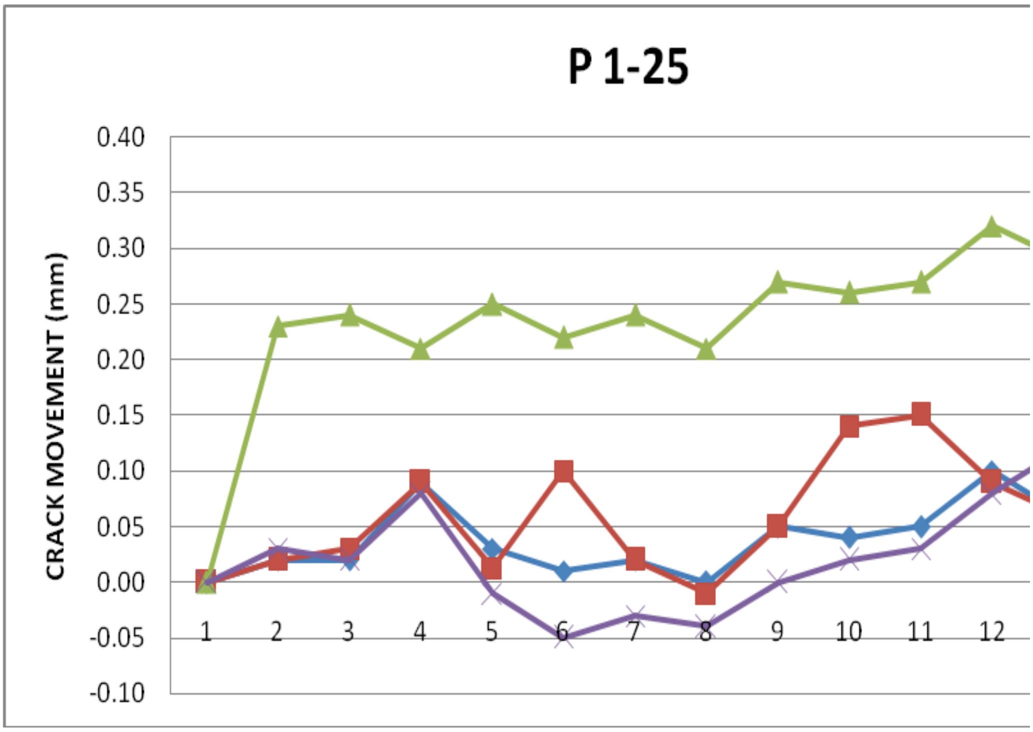


Figure 3: Crack Movement Reading at Pier 1-15B

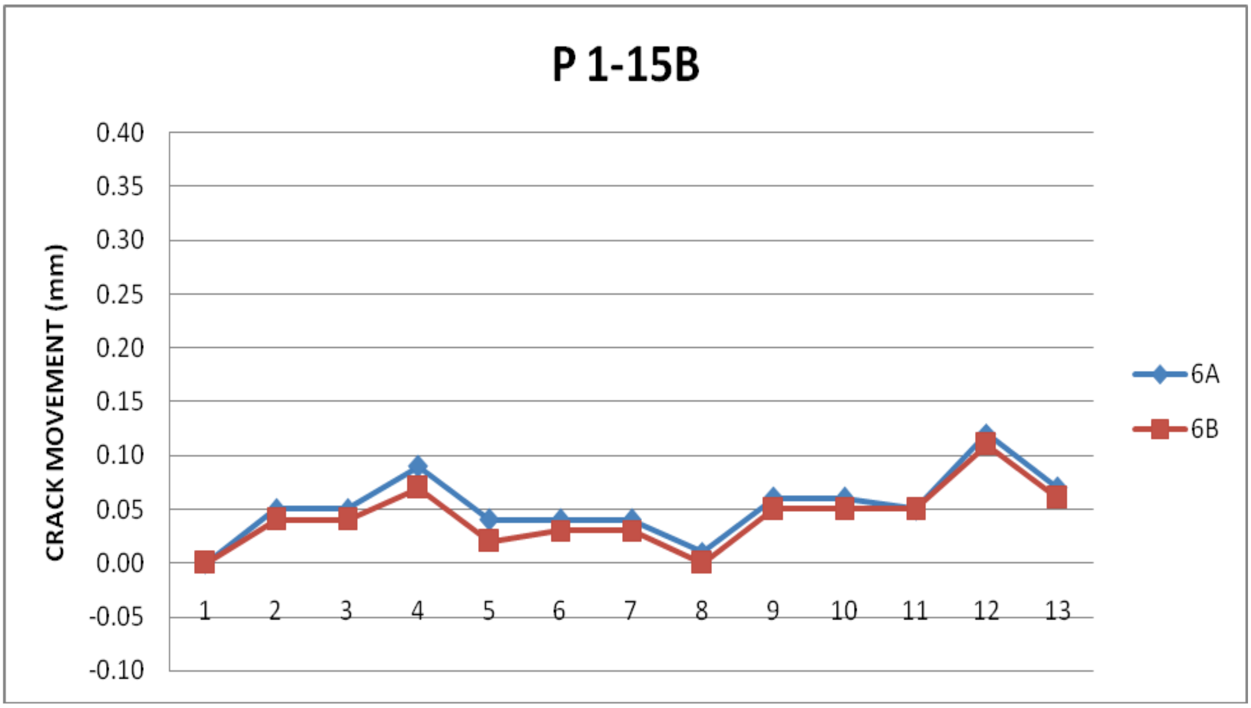


Figure 4: Crack Movement Reading at Pier 1-14B

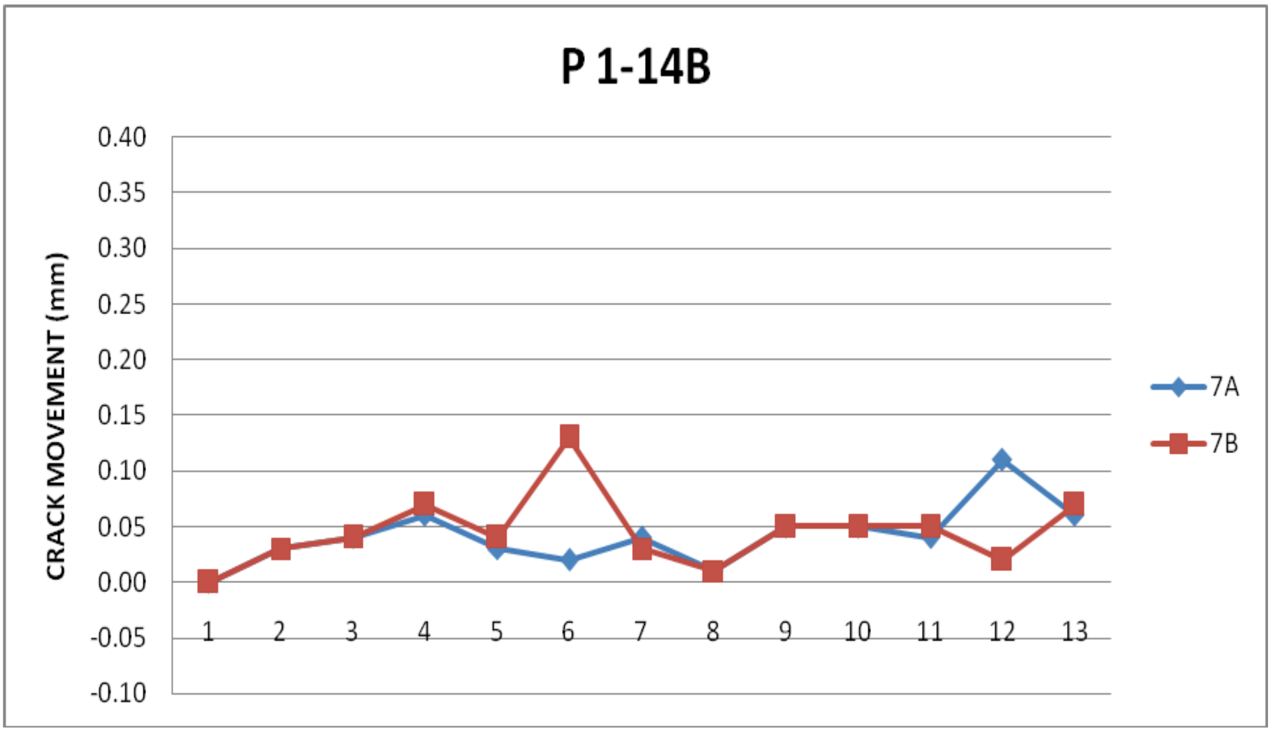


Figure 5: Crack Movement Reading at Pier 1-13B

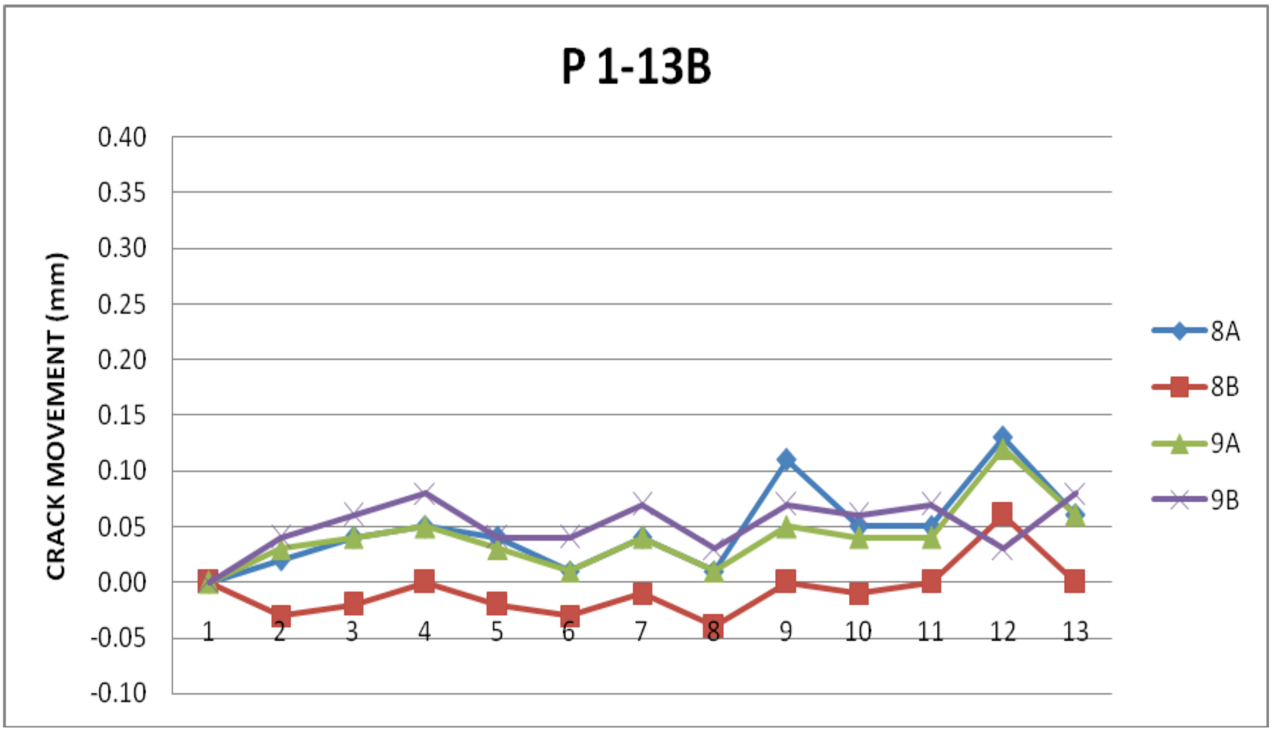


Figure 6: Crack Movement Reading at Pier 1-10A

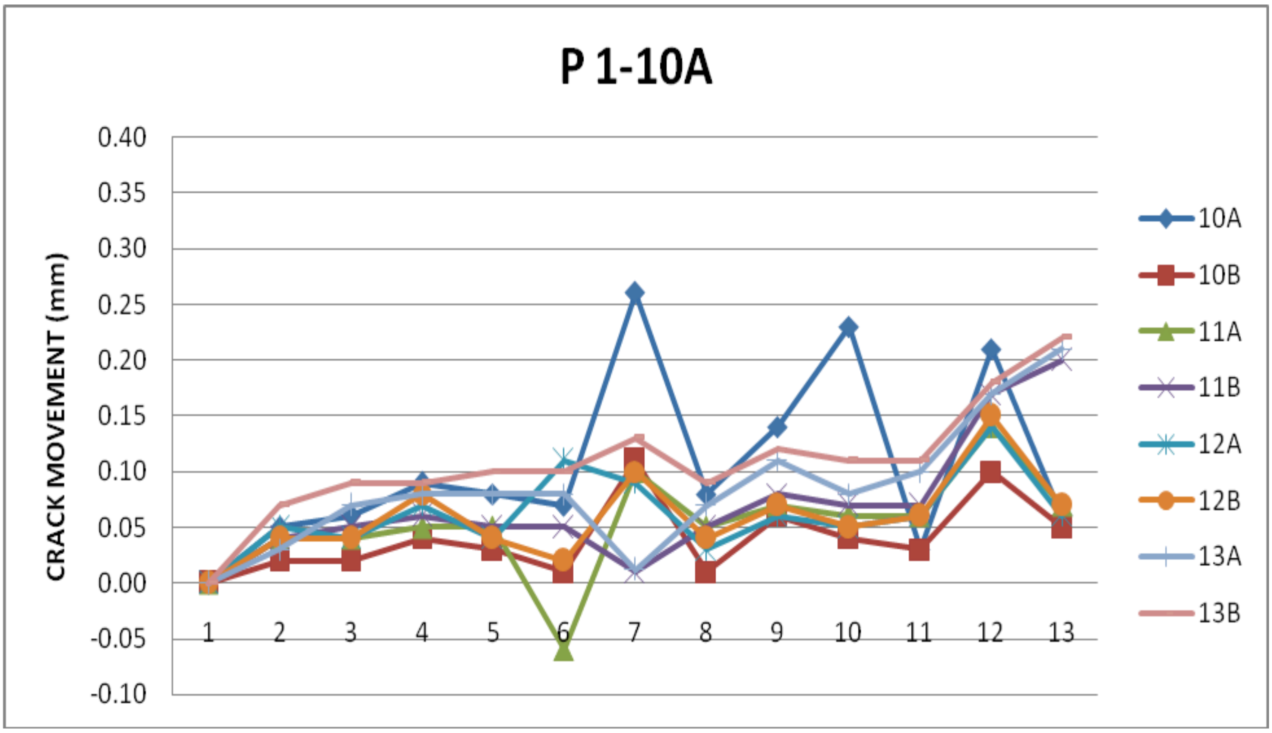


Figure 7: Crack Movement Reading at Pier 1-11A

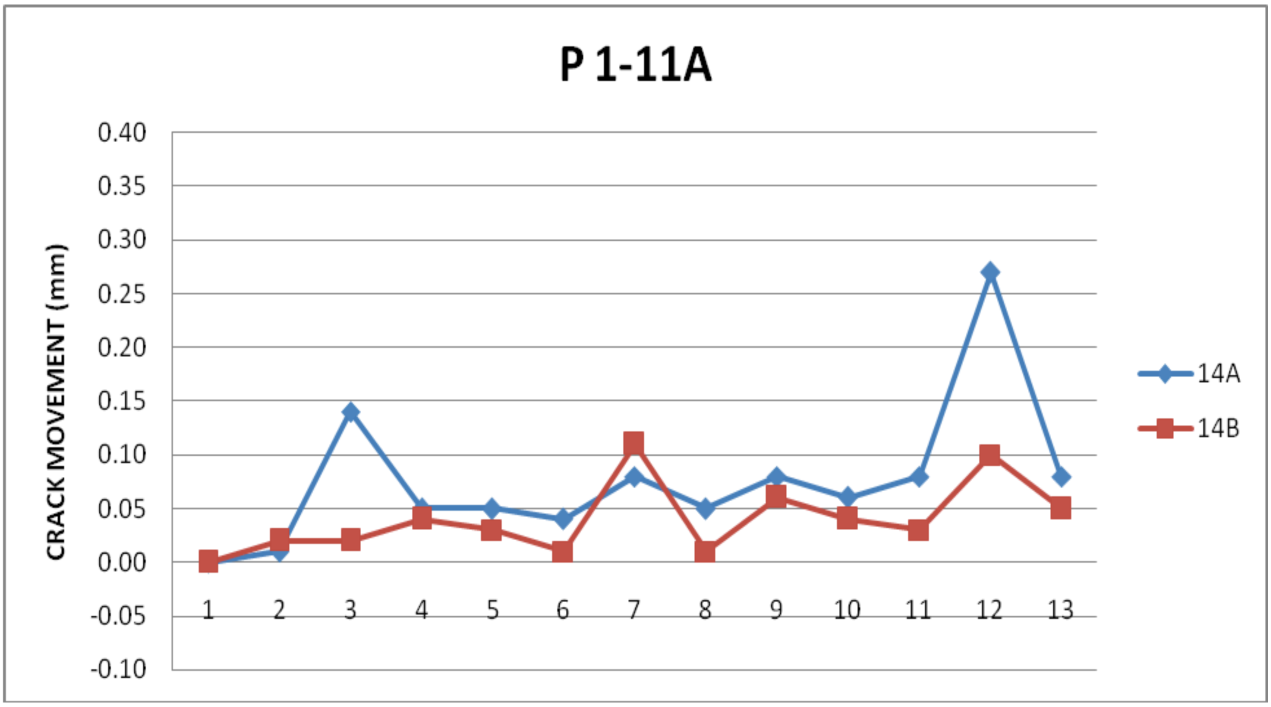
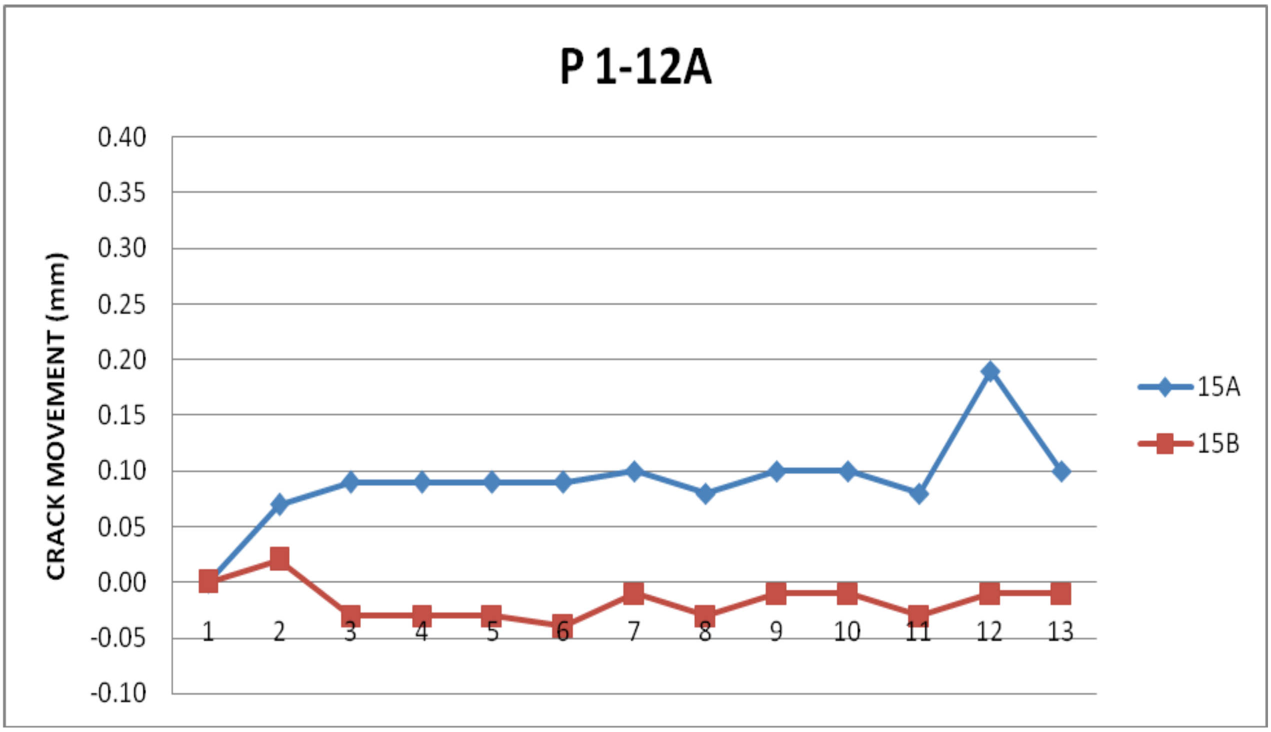


Figure 8: Crack Movement Reading at Pier 1-12A



5.4 Figure 1 and Figure 2 show the graphical plots of crack movement at 'T'-shape pier during the monitoring period. It can be seen that the movement of crack for 5A is consistently much higher with maximum reading up 0.32 mm compared to other readings at less than 0.20mm.

5.5 Figure 3 until Figure 8 show the graphical plots of crack movement at 'L'-shape pier. From the graph, it can be seen that the maximum reading at Pier 1-10A and P1-11A approach 0.30mm. The other points have movement at less than 0.25 mm.

6.0 Conclusion

Based on the findings of design check, crack mapping, material testing and structural analysis, the following conclusions are made:

6.1 Pier Column

6.1.1 The sectional axial and bending capacities are computed and checked against the maximum forces from the analysis under ULS condition. The crack widths are computed based on the maximum force from the analysis under SLS condition.

6.1.2 For SLS check, the crack width of the pier column is checked against the maximum allowable serviceability crack width of 0.25mm. It is found that P-25 and P-33 columns meet the allowable limit. However, the crack widths for P-11A (inverted "L" pier) under three (3) different traffic load conditions are found to be more than 0.25mm with a maximum value of 0.416mm. Hence, the existing column design for P-11A does not fulfil the SLS requirement.

6.1.3 The ultimate axial and moment capacity of the pier columns are checked against the maximum induced force from the analysis and it is found that the existing design of the pier columns satisfies the ULS criteria.

6.2 Crosshead

6.2.1 The affected pier crossheads are checked for its' ultimate moment and shear capacity, and the crack width for SLS.

6.2.2 The design of crosshead for P-25 and P-33 ("T" shape Pier") is found to be adequate for their bending moment capacities at ULS. However, ultimate moment capacity of P-11A crosshead is found to be marginally less than the induced moments; about 6% less.

6.2.3 The existing shear design for P-11A and P-33 crosshead is found adequate.

6.2.4 It is found that the existing shear capacity for P25 is marginally insufficient to resist the maximum induced shear force at the existing section with depth of 2.0m. .

6.2.5 Crack widths calculated for P-25 and P-33 crosshead are within the allowable limit of 0.25mm, which satisfies the SLS criteria. Whereas, the crack width for P-11A is found to marginally exceed the allowable limit of 0.25mm.

6.2.6 Strut and Tie Analysis (STM) was carried out to determine the compression strut and tie force of the crosshead. P-11A and P-33 STM indicates that sufficient top reinforcement has been provided to resist the crosshead ULS tensile force. The vertical tensile force of P-11A is found to exceed the shear capacity calculated from the existing shear link provided using STM approach.

6.2.7 The STM analysis shows that vertical reinforcement with sufficient anchorage length into the nodal zone has to be provided. However, the as-built drawings indicate that the pier main reinforcement did not extend up to the top tension fibre of the crosshead.

6.2.8 Finite Element Analysis (FEM) was performed to investigate the localized stress in the pier columns and crossheads. The FEM for both P-11A and P-33 show a common trend of tensile stress extends beyond the mid height of the crosshead measured from the top of pier column. It is recommended that all main reinforcement for pier column shall extend up to top of crosshead and provided with sufficient anchorage length.

6.3 Crack Mapping & Material Testing

6.3.1 Based on crack mapping, L-shape pier and crosshead were found with crack within 0.1mm to 0.4mm width. T-shape pier also were found with crack within 0.1mm to 0.4mm width. However, crack at crosshead of the T-shape pier has maximum width of 4.0mm at Pier No.33.

6.3.2 Out of ninety five (95) locations tested for concrete cover provision, only one (1) element was found with concrete cover marginally below 20mm. The overall concrete cover measured was generally acceptable and ranged from 19mm to 59mm;

6.3.3 The estimated in-situ cube strength obtained from the compressive strength test on concrete core samples was generally inconsistent and ranged between 26.0N/mm^2 to 52.5N/mm^2 with mean value of 42.0/mm^2 and standard deviation of 7.8.

6.3.4 The concrete density tested revealed that all elements tested are within the acceptable limit of 2,200kg/m^3. This reflected satisfactory concrete compaction for most of the elements tested during the construction;

6.3.5 Based on the petrographic examination test results, two (2) numbers of concrete core samples was no likely of any major Alkali Silica Reaction (ASR) and Alkali Carbonation Reaction (ACR). These two (2) samples also were no Ettringite crystal were observed, hence there was unlikely any DEF were found.

6.3.6 It was noted that three (3) numbers of core samples at Column has minimum a crack depth of 25mm and the maximum a crack depth of 110mm deep. While the minimum value of crack depth at Crosshead is 12mm and the maximum is 160mm deep.

6.3.7 From the data obtained, Ground Penetration Radar results showed the size of reinforcement for pier P25 and P33 are 32mm with concrete cover ranging from 35mm to 60mm. It is also noted that lap length of the reinforcement at the crosshead ranged from 1300mm to 1500mm and at the circular column ranged from 1300mm to 1550mm.

6.3.8 Based on the monitoring results, there are some minor movement of less than 0.35mm recorded and no obvious crack movement was noticed at thirty (30) locations. However, the crack movement is shown to be active. Generally, the readings at selected bridge pier showed very minimal movement occurred during the monitoring periods

6.3.9 In conclusion, some of the cracks developed had affected the structural integrity of the pier. However, appropriate rectification measures should be taken immediately to prevent the structure from further distress.

7.0 Recommendations for Rehabilitation and Strengthening

The following rehabilitation and strengthening proposals are recommended:

(a) Inverted "L" shape pier column

All cracks to be sealed and applied with two coats of polymer-modified cementitious waterproofing coating (SIKA Top Seal 109 MY) which has crack bridging capacity up to 1.0mm.

(b) Inverted "L" shape crosshead

Use Epoxy-bonded CFRP at both sides of crosshead to enhance anchorage capacity of the existing main column rebars. Upper portion of the existing column shall be enlarged to provide sufficient anchorage for the bonded CFRP. All cracks shall be sealed beforehand and applied later with the protective coatings. All surfaces with CFRP shall be applied with a 25mm thick wet sprayed fire protection mortar (SIKACRETE 213F). The remaining surfaces to be applied with two coats of polymer-modified cementitious waterproofing coating (SIKA Top Seal 109 MY) which has crack bridging capacity up to 1.0mm.

(c) "T" shape pier column

All cracks to be sealed and surfaces shall be applied with two coats of polymer-modified cementitious waterproofing coating (SIKA Top Seal 109 MY) which has crack bridging capacity up to 1.0mm.

(d) "T" shape crosshead

Use Epoxy-bonded CFRP at both sides of crosshead to enhance the anchorage capacity of the existing main column rebars. Upper portion of the existing column shall be enlarged to provide sufficient anchorage for the bonded CFRP. All cracks shall be sealed before applying the protective coatings. All surfaces with CFRP shall be applied with 25mm thick wet sprayed fire protection mortar (SIKACRETE 213F), the remaining surface to be applied with two coats of polymer-modified cementitious waterproofing coating (SIKA Top Seal 109 MY) which has crack bridging capacity up to 1.0mm.

8.0 Reference Photographs

The following photographs were taken on site to show the affected pier structures.

Figure 9: Pier P-10A

Figure 10: Pier Column P-10A (Rear View)

Figure 11: Pier Crosshead P-10A

Figure 12: Pier Crosshead P-10A (Close up)

Figure 13: Pier P-11A

Figure 14: Pier Column P-11A (Rear view)

Figure 15: Pier Column P-11A (Close up)

Figure 16: Pier Column P-12A (Close up)

Figure 17: Pier P-13B

Figure 18: Pier Column P-13B (Close up)

Figure 19: Pier Column P-14B (Close up)

Figure 20: Pier Column P-15B

Figure 21: Pier P-25

Figure 22: Pier Column P-25 (Close up)

Figure 23: Pier Crosshead P-25 (Close up)

Figure 24: Pier Crosshead P-25 (Underside)

Figure 25: Pier P-33

Figure 26: Pier Column P-33 (Close up)

Figure 27: Pier Crosshead P-33 (Close up)

APPENDIX A

TERM OF REFERENCE