APPENDIX C4

SUMMARY OF ANALYSIS METHODOLOGY AND FIELD DATA COLLECTION

ANALYSIS METHODOLOGY SUMMARY

Two scenarios are possible: A) Field data is available for focused evaluation and/or improved distribution and impact factors or B) Only design drawings are available for evaluation. When field data is available, analysis can focus on the sections with diagonal cracks to assess the capacity in these regions. However, careful attention should be given to the flexural details near the crack tip to ensure adequate modeling of the section. This may require investigation of adjacent locations that may be affected by the diagonal crack.

Analysis Steps

The following methodology is recommended for evaluation of 1950's vintage RCDG bridges with diagonal cracks, and the relationships between components is illustrated in Figure 5.19.

1) Nominal material properties are used as taken from drawings unless detailed data is available from cores or steel samples removed from the bridge. Typical concrete compression strength is f'_c =3300 psi and intermediate grade reinforcing steel yield stress is f_y=40,000 ksi. No increase in concrete compressive strength is considered.
2) Nominal member dimensions and reinforcing details are used unless field data is available to supplement design drawings.
3) Lane load distribution factors are determined per the AASHTO-LRFD specification.
4) Permanent component and wearing surface moments and shears are determined along the girders and at the bent caps. Dead loads are distributed uniformly to the girders unless conditions warrant an alternative approach.
5) Moment and shear force demands from vehicles should be determined at sections of interest. These include locations of stirrup spacing changes, flexural bars cutoff, or cross-sectional changes.
    a. The following models should be considered:
        i. HL-93 (truck with lane load) with impact and load rating factors
        ii. 11 ODOT rating vehicles
        iii. WIM data if LCF is to be performed
            1. Where field data are used for load distribution factors, a modal truck should be placed in the adjacent lane to correspond with the Table value vehicles.
    b. Main girders require analysis for moving loads to find the worst load effect considering moment/shear interaction. These may be determined from elastic beam analysis using uniform beam sections. Analysis programs permit rapid evaluation of the combined moment and shear load effects for moving loads.
    c. Bent caps should be evaluated for the girder dead load and vehicle load reactions. Live load cases should consider:
        i. 0.9 HL-93 (90% of two trucks having 14 ft axle spacings and a space of 50 ft between the back axle of the lead truck and the front axle of the following truck combined with 90% of lane load)

ii. 11 ODOT rating vehicles placed in a single lane with multiple presence factor of 1.2.
iii. 11 ODOT rating vehicles placed in a single lane with the modal truck located in the adjacent lane.

d. Based on the range of impact factors measured in the field-study bridges, the AASHTO recommended factor of 1.33 for strength load combinations should be used for both capacity and service level evaluations.

e. Moment-shear interaction capacity at a section should be developed using AASHTO-LRFD modified compression field theory (MCFT) or analyzed using *RESPONSE 2000*^{TM} [Bentz, 2000].
   i. For regions with high shear and low moment, both AASHTO-MCFT and *RESPONSE 2000*^{TM} may significantly underpredict the capacity.
   ii. At locations near dead load points of inflection, it may be necessary to compute section capacity for both positive and negative moments. Where AASHTO-MCFT predicts a discontinuity in the shear capacity at zero moment, the larger value should be used, and a transition line used to connect the two capacity curves from the point of constant shear on the lower curve.
   iii. The amount of flexural steel used in the section analysis should include an equivalent area of steel that is developed. Partially developed bars should be modeled as equivalent smaller bars based on the proportion of the available length to the development length.
   iv. For cases where field inspections report wide cracks and significant crack motion under ambient traffic conditions, it may desirable to determine the section capacity by *RESPONSE 2000*^{TM} with the tensile strength of concrete reduced to approximately zero or alternatively according to compression field theory to model the impact of significant stirrup debonding.

f. Once controlling moment-shear interactions from permanent and live loads are developed at each section, they are projected along a line according to the vehicle live load moment-to-shear ratio until intersection with the capacity curve. The number of standard deviations along this line from the load effect to the capacity curve is the safety index. The larger the larger the safety index, the greater the level of safety.

g. Comparison of the safety index for different bridges permits risk ranking to assist in repair and replacement decisions.

6) LCF evaluation is performed by estimating shear and moment combinations that produce yielding of the stirrups for a section containing diagonal cracks.

   a. The yielding interaction curve can be determined using the cracked sectional analysis method described previously. It is conservative to predict the yielding interaction curve with amplified transverse strain values based on initial loading. As a first check, when rating vehicles exceed approximately 75% of V_n calculated per AASHTO-MCFT, the section may require detailed investigation.

b. When detailed LCF evaluation is required, the suite of WIM vehicles corresponding to ODOT weight classification Table 4 and 5 should be used for calculating possible load effects above yield curve at the section.
c. Where field data are used for load distribution factors, a modal truck should be placed in the adjacent lane to correspond with the Table value vehicles.
d. The number of WIM vehicles exceeding the yield threshold should counted and sorted according to the ratio of V/V_n. These can be used to estimate the life of the section.

7) Based on field measurements of in-service bridges, high-cycle fatigue is not anticipated to result in metal fatigue of the stirrups. Bond fatigue effects were not observed to diminish capacity significantly for the specimens investigated. However, for the wider diagonal cracks produced during HCF, the section capacity can be determined from *RESPONSE 2000*™ with the tensile strength of concrete reduced to approximately zero.
8) Assess flexural tension steel per AASHTO 5.8.3.5 to determine if adequate anchorage and development is available at the location of a diagonal crack. Loads effects should be from the HL-93 load model with LRFR load factors.

METHODS FOR FIELD DATA COLLECTION

The following methodology is recommended for collecting field data to assist in assessment of RCDG bridges with diagonal cracks:

1) Drawings of the as-designed bridge should be used as a reference in the field. Field collected data should be superimposed on the drawings to aid in identifying critical sections for further analysis.
2) Member dimensions shown on drawings should be field verified, such as diaphragm spacing, girder height, girder spacing, web thickness, and deck thickness.
3) The actual overlay thickness should be determined where applicable.
4) Diagonal cracks should be identified on the main girders and bent caps. Emphasis should be placed on the high-shear regions (taken approximately at the quarter span distance from supports) for main girders and the entire bent cap.
5) Diagonal crack distance relative to the supports should be determined. This can be done quickly and accurately using a laser distance meter. For cases where a diagonal crack becomes horizontal at the web-deck interface, the horizontal length should be determined.
6) Crack angle and widths should be recorded.
7) Crack motions should be observed under ambient traffic loading. Where significant crack motions are observed, and may be prudent to investigate the possibility of a fractured stirrup at the diagonal crack location.
8) Reinforcing details should be field verified at diagonal-crack locations using a nondestructive rebar detector. The number of stirrups crossing the crack and potential crack extension (assuming the crack projection remains at the dominant crack angle) should be determined.
9) Field data characterizing cracks should be transferred to the structural drawings.
10) Flexural reinforcing details should be identified at the intersection with the diagonal crack. Special attention should be given to cutoff locations and bars that are not fully developed at the section.