Cracked Section Analysis for Partial Prestressing Design

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ABSTRACT

In this paper, an example of nonlinear analysis for partial prestressing design is presented. For partial prestressing design, the stress redistribution, after concrete cracking has occurred, should be accurately investigated by nonlinear analysis tools. Direct and iterative methods of nonlinear analyses were adopted for the tender design of the Incheon Bridge viaducts. Stress variations in the prestressing tendons and reinforcing bars were investigated and presented in this paper for both the in-service condition and during construction.

1. Introduction

The AASHTO LRFD Bridge Design Specification[1)] allows the use of partial prestressing design methods in the design of bridges. Partial prestress design allows limited cracking to occur in the pre-compressed tensile zone. Adoption of this method of analysis in segmentally constructed bridge structure can result in a rational and economic design. In the tender design stage of the Incheon Bridge Project, this design concept was applied to the design of the Viaduct bridges. According to Article 5.9.4.3, the design of partially prestressed members should be based on a cracked section analysis with various service limit states being satisfied. Therefore, it is essential that the effects of cracking on the structural behavior should be checked. In this paper, two types of cracked section analysis are presented; an iterative nonlinear analysis and a direct nonlinear analysis.

Both analyses are applied to the Viaduct bridge which consists of a series of 250 m long modules comprising five simply supported 50m spans made continuous for the in-service condition. The full span launching method is being adopted for the construction of the viaduct. Each 50m prestressed concrete box girder will be launched from the casting yard to its permanent position by special multi-axle carrier. During the construction period, the spans will be erected as simply supported. On completion of the in-situ stitches over the piers, the complete 5-span module will act as a continuous structure. Due to the characteristics of the construction methods, temporary loading during construction is greater than the in-service loads resulting from the permanent and live loading. Thus the partial prestressing design approach, which allows a limited amount of tensile stress in the concrete provides a more economic structure when compared with the full prestressing method.

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2. Cracked Section Analysis Methods

2.1 The Iterative Nonlinear Analysis Method

Material non-linearity can be analyzed using software that only includes linear material properties by adopting the following procedures: An M-Φ diagram can be generated under various external moments in advance. Commencing with an analysis on an un-cracked section the results can be examined and a new section stiffness can be determined from the M-Φ diagram. The analysis can be repeated until the solution converges. This procedure is shown in Figure 1. The results obtained from the final step are regarded as the iterative results and can be shown to compare well with the direct non-linear analysis. In this paper, RM-Space Frame is used for the linear analysis software because it is well-established internationally as a numerical analysis software for construction stage analysis[2].

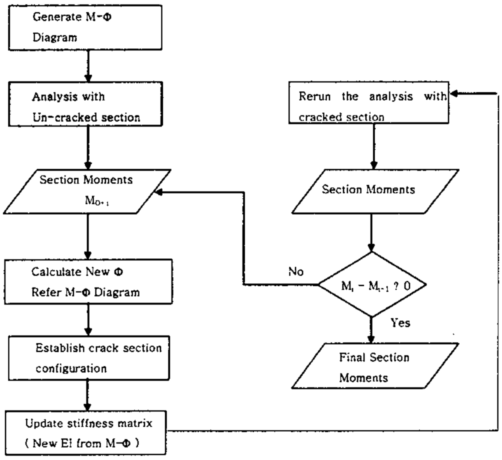


Figure 1 Flow chart for consistent method

2.2 Direct Nonlinear Analysis Method

The FESA-BRIDGE was used for the direct non-linear analysis[3]. For partial pre-stressing design, the structural behavior of force redistribution after cracking should be investigated. By utilizing a layered integration scheme, this program gives accurate results for the nonlinear behavior after cracking and/or yielding of the material.

3. Stress Redistribution after Cracking

As shown in Table 1, the results obtained by the iterative method are in good agreement with those obtained by the direct nonlinear method. The section stresses are checked for service limit state according to the AASHTO LRFD Article 5.9.4.3. Cracks were developed over an 8m length of the 50 m simply supported span during construction. Changes in the concrete stress after cracking are shown in Figure 2. During construction, cracks occur in the soffit. However, due to the prestressing force the cracks are closed at the in-service state. Final stresses after completing the construction stages converge to a value in compression.

Table 1 Stresses of cracked section during construction

Component	Iterative Method (N/mm^2)	Direct Method (N/mm^2)	Stress Limitation (N/mm^2)	Check Results
Strand	1,233	1,210	0.8 f_{py} = 1,399	O.K.
Reinforcement	105.7	180	0.6 f_y = 240	O.K.
Compression of concrete section in middle span	10.18	10.3	0.45 f'_c = 20.3	O.K.
Crack Width	0.11mm	0.13mm	0.004C = 0.2 mm PPR -> No Limit	O.K.

Table 2 Stress check for middle span in-service

Component	Iterative Method (N/mm^2)	Direct Method (N/mm^2)	Stress Limitation: (N/mm^2)	Check Results
Strand	1,210	1,102 (91%)	0.8 f_{py} = 1,399	O.K.
Reinforcements	160	120 (67%)	0.6 f_y = 240	O.K.
Compression in bottom extreme fiber of concrete section	10.3	17.6 (171%)	0.45 f'_c = 20.3	O.K.
Crack Width	0.04mm	0.04mm (100%)	0.004C = 0.2 mm	O.K.

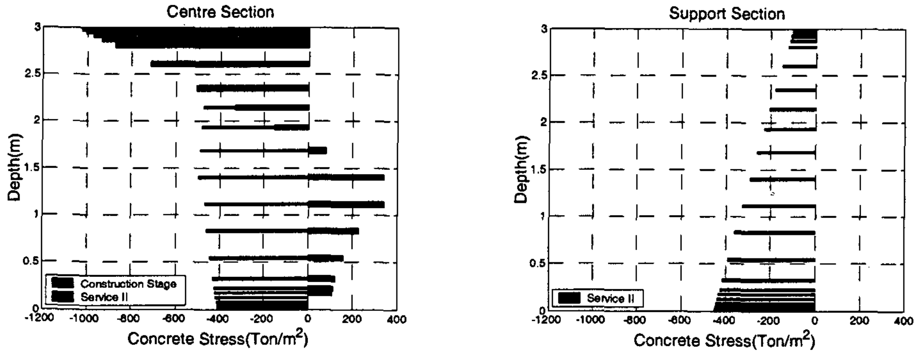
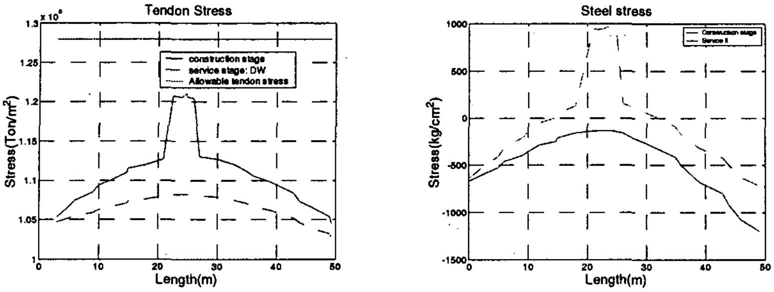


Figure 2 Concrete stress distributions at centre and support span

Figure 3 shows tendon stresses at different stages of construction. If the concrete layers crack, this causes a rapid increase of tendon stress in the cracked region. During both construction stage and in-service stages, the tendon stresses are lesser than the allowable tendon stress. Figure 4 shows top and bottom fiber stresses both during construction and in-service stages. It is interesting to note that the tensile stresses that develop in the bottom layer during construction stage change into compressive stresses in-service state. This means that the cracks close on the removal of the heavy construction loads from the structure and full sectional properties may be considered valid under normal service conditions of the bridge. Deflections due to vehicle loads have also been checked and are shown in Table 3.



(a) Tendon stress (b) Steel stress

Figure 3 Tendon stresses at different construction stages

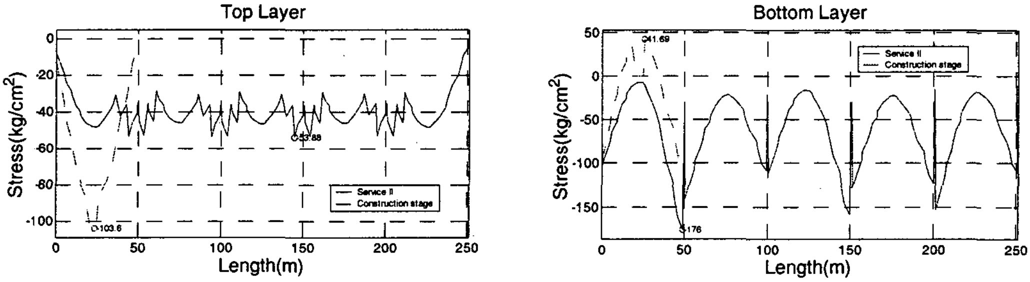


Figure 4 Top and bottom fiber stresses during construction and in-service stages

Table 3 Deflection due to LL+IM

Method	Iterative Method		Direct Method		Stress Limitation (AASHTO 5.9.4.2)
	Const-ruction	Service	Const-ruction	Service	
Deflection	44.0mm	11.6mm	39.0mm	10.2mm	800/Span Length = 62.5mm

4. Conclusions

An example of partial prestressing design approach has been presented in this paper. Partial prestressing design allows cracking in the precompressed tensile zone provided that various service limit states are satisfied. For the purpose of partial prestressing design, two types of cracked section analysis were carried out for the viaduct bridge which forms part of the Incheon Bridge crossing. Stresses of members in cracked section were checked during construction and in-service conditions. The redistribution of stresses in the cracked section was thoroughly investigated by both the iterative and the direct methods of nonlinear analysis. Both provide results which were comparable.

References

1. AASHTO, AASHTO LRFD BRIDGE DESIGN SPECIFICATIONS, 2004.

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