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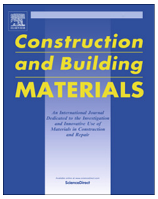

Investigation and improvement of strut-and-tie model for design of end anchorage zone in post-tensioned concrete structure

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HIGHLIGHTS

- Reinforcements and spiral resulted in a redistribution of stresses in anchorage zone.
- The Mörsch's STM for centric end anchorage zone was modified.
- FIP suggested STM for large eccentric end anchorage zone was improved.
- Simplified but accurate equations for design of end anchorage zone were proposed.

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ABSTRACT

The strut-and-tie model (STM) is commonly used for the design of the end anchorage zone in post-tensioned concrete structures. In present work, the most accepted STMs in practice design for either centric or eccentric anchorage zone were inspected comprehensively based on experimental investigations and FEM simulations, to improve the models in accuracy, economy and efficiency. FEM was first employed to obtain the stress distribution in the anchorage zone, to reveal the influence of the anchor size and tension eccentricity on the compressive force, bursting force, spalling force and flexural tensile force. Based on FEM findings, the Mörsch STM for the design of centric end anchorage zone was configured and modified by taking into account the counteractive effect of the spiral circle and reinforcement on the distribution of stress in the anchorage zone. The adjusted Mörsch STM was employed for small eccentric end anchorage zone with the simplified equations from the FEM simulations. For the large eccentric end anchorage zone, a completely design procedure based on Schlaich model was offered by improving the determination method of the spalling force and bursting force in both values and locations. In above improvements on STMs, simplified equations were proposed for engineers to design the end anchorage zone more conveniently.

1. Introduction

Pre-stressing structures, especially post-tensioned concrete structures, are widely used in civil engineering [1–3], such as in bridge beams [4,5], high-rise buildings [1] and underground structures [6–8], due to the advantages of a low risk of cracking of the concrete matrix and the high tensile capacity of steel reinforcement [9–12]. In pre-stressed structures, the performance of the anchorage zone is critical for the safety and stability of the whole concrete structure [9–10]. The end anchorage has been the most commonly used both historically and in current practice [13,14]. For the end anchorage zone, including either centric or eccentric end anchorage zone, a local failure may occur in the immediate vicinity of the anchorage device if the local compression induced by the preload of the anchorage tendon exceeds the compressive capacity of the concrete matrix. To enhance the local strength, spiral reinforcement or steel twist wire mesh is usually employed in front of the bearing plate. Furthermore, cracks may also occur in the direction parallel to the axis of the pre-stressed tendon due to the lateral spreading of post-tension force. To prevent these cracks, transverse reinforcement is usually applied to resist the transverse tensile force in the concrete. Especially, for a large eccentric end anchorage zone additional reinforcement should be placed in the side away from the tendon path to resist the flexural-tensile force induced by the eccentric post-tension load.

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Nomenclature

a	dimension of anchor plate	σ_y	stress in y direction
a_2	distance of tendon path from near boundary	σ_1, σ_2	stress in the side of anchorage zone
A	area of lateral cross-section of member	σ_{burst}	bursting stress
b	thickness of member	T_{burst}	bursting force
C_i	compression force in struts, ($i = 1,2,3,4.$)	σ_{spall}	spalling stress
d	distance of bursting force center from anchor plate	T_{spall}	spalling force
d_i	distance of Steel Bar No. i from Anchor Plate ($i = 1,2,3.$)	T_i	tension force in ties, ($i = 1,2,3.$)
e	eccentric distance	M	additional bending moment, $M = P \times e$
h	lateral dimension of anchorage zone	W	section moment of anchorage zone
P	preload	σ_{FT}	flexural-tensile stress
P_1, P_2	decomposition load of P	T_{FT}	flexural-tensile force
σ_0	uniform stress, P/A	β	disperse angle
σ_x	stress in x direction		

In the past, the no-linear stress distribution within the anchorage zone has been investigated by elastic analysis [9–11], equilibrium methods of analysis [15–18], finite element method (FEM) [19–22], experimental investigations and Strut-and-Tie modeling [23,24]. Guyon et al. [9–11] proposed a simplified design method based on an elastic analytic solution for pre-stressing distribution within the anchorage zone under a 2-dimensional stress state, where spalling stress and bursting stress controlled the anchorage zone. The FEM offered a powerful tool to analyze the stress distribution in the anchorage zone. Generally, linear finite element analysis is used for the determination of un-cracked state stress, while nonlinear finite element studies can model the anchorage zone in a cracked state. To date, the most advanced method for the design of the anchorage zone in pre-stressed structures is the strut-and-tie model (STM) [19,20], in which approximate stress fields are used to formulate an equilibrium model consisting of compression struts and tension ties connected at discrete nodes. For the centric end-anchorage zone of steel reinforced structures, the most accepted STM is that proposed by Mörsch [25]. For an eccentric end-anchorage zone, an adjusted Mörsch STM is usually used to adapt the small eccentric post-tension condition. For the large eccentric end anchorage zone, a design method proposed by Schlaich [23,24] and suggested by the International Federation for Pre-stressing (FIP), is most applied. Although some new methods to generate an optimal STM [26,27], and combined method of experimental investigations and non-linear FEM simulations to study shear and bending performances of complex concrete components [28,29], have been developed in recent years, the traditional STMs are still the most convenience and effective method in practical design for pre-stressing structures [30–32]. Today, a typical STM method, usually combined with the linear FEM analysis on the stress distribution in a sound and unreinforced end-anchorage zone, is usually conducted as shown in a flow-chart format in Fig. 1.

In present work, the most accepted STMs in practice for the design of end anchorage zone were inspect comprehensively based on FEM simulations and experimental investigations, to refine the models in accuracy, economy and efficiency. FEM was first

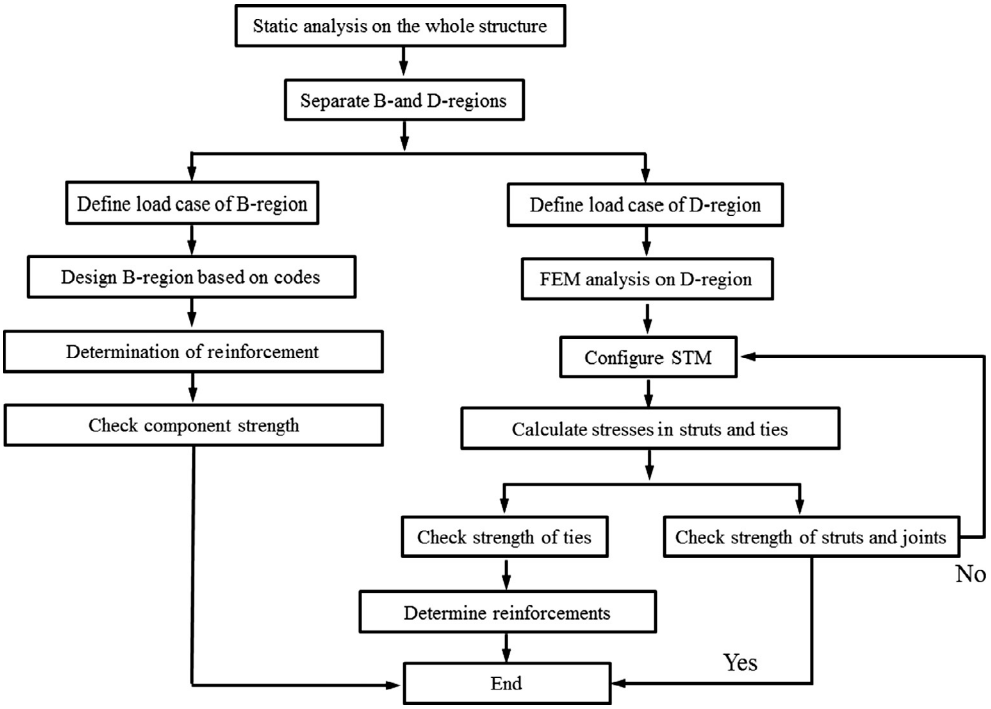

Fig. 1. Design procedure for end anchorage zone with STM.