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The Effect of Strand Configuration on Stress Distribution and Debonding Parameters of Prestressed Girder After Detensioning

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ABSTRACT

The aim of this paper is to examine the effect of strand configuration on stress distribution and debonding parameters of precast, pretensioned concrete girders after prestressing force is transferred from strands to concrete by bond at their interface. Determination of strand configuration is important as well as determination of number of strands because it affects stress distribution and debonding parameters of girders. The debonding of strands is an application in order to control the tensile and compressive stresses at the support zone of girder. One of the typical precast girder with 90 cm height is considered in this study. To determine the effect of strand configuration, nine girders with the same cross-section, effective span length and material properties but different strand configuration are selected as an application. Equal prestressing force is applied all strands simultaneously. Three dimensional finite element models (FEM) of girder are constituted using SAP 2000 software. At the end of the study, numerically identified stress distribution and calculated debonding parameters of girders compared with each other.

Keywords: *Detensioning 1, finite element 2, prestressed girder 3, strand configuration 4, strand 5*

Öngerme Kablo Düzeninin Aktarma Dönemi Sonrası Kirişin Gerilme ve Kılıflama Parametremeleri Üzerindeki Etkisi

ÖZET

Bu çalışmada ön döküm öngerilmeli beton kirişlerde öngerilme kuvvetinin öngerme kablolarından betona aktarılmasından sonra öngerme kablo düzeninin gerilme dağılımı ve kılıflama parametreleri üzerindeki etkisinin belirlenmesi amaçlanmıştır. Öngerme kablolarının diziliminin belirlenmesi, kablo sayısının belirlenmesi kadar önemli olmaktadır. Çünkü bu durum gerilme dağılımını ve kılıflama parametrelerini etkilemektedir. Kılıflama işlemi öngerilmeli kirişin mesnet bölgelerinde meydana gelen çekme ve basınç gerilmelerini kontrol etmek için kullanılmaktadır. Bu çalışmada 90 cm yüksekliğe sahip öngerilmeli kiriş örnek olarak seçilmiştir. Öngerilme düzeninin etkisini belirlemek için, kesit alanı, efektif hesap açıklığı ve malzeme özellikleri aynı öngerme kablo düzeni birbirinden farklı dokuz adet kiriş seçilmiştir. Kirişlerin sonlu eleman modeli SAP 2000 programı

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kullanılarak oluşturulmuştur. Çalışmanın sonunda sayısal olarak elde edilen gerilme dağılımı ve hesaplanan kılıflama parametreleri birbiriyle karşılaştırılmıştır.

Anahtar Kelimeler: *Kılıflama 1, Sonlu eleman 2, Öngerilmeli kiriş 3, kablo düzeni 4, öngerilme kablosu 5*

I. INTRODUCTION

Prestressed concrete has found extensive application in the construction of medium and long span bridges since the development of prestressed concrete by Freyssinet in the early 1930s because of its better stability, serviceability, economy, aesthetic appearance, structural efficiency, ease of fabrication and low maintenance. The fundamental concept of prestressed concrete is the transfer of compressive stresses in concrete with strand, thus balancing the tensile stress that occurs under service load. Prestressed concrete girders are subject to different load types at their construction stages. At the time of strand release, i.e., detensioning, prestressed concrete girders are under the effect of dead and prestressing loads. Under these loads effects, different zone of the girder are exposed to different stresses types. Especially, the stresses in the support zone of the girders exceed the permissible stress values at detensioning. The debonding of strands is an application in order to control the maximum tensile and compressive stresses at the ends of concrete girders.

There are many studies on the design and structural behavior of the prestressed concrete in the literature during last two decades. [1] studied about the effects of deviators and strand configuration on behavior of externally prestressed girders. [2] investigated debonding strands and changing the order of strand cutting to control cracking using linear finite element analysis. [3] investigated the relation between unbonded strand stress and influential parameters such as amount of strands, amount of mild steel and loading types. [4] demonstrated the influences of structural members and strand directions on post-tension method. They evaluated the efficiency of deflection control by various strand layouts. Also, the best layouts of strands for a construction project were derived and the economic efficiency of PT method was examined considering the cost of materials and construction. [5] stated that the use of high-strength concrete and 0.6-in-diameter (15 mm) strand in the fabrication of precast, pretensioned concrete bridge girders has resulted in improved economy through the use of longer spans, increased girder spacing or fewer girder lines and created more shallow superstructures. [6] stated that horizontal web cracks and inclined cracks are generally thought to induced by the strand distribution in the girder or prestress release procedures.

The main objective of this research is to investigate effect of strand configuration on the stress distribution and debonding parameters of precast, pretensioned concrete girders after detensioning. For this purpose, simply supported nine prestressed girders with same length and cross-section area but different strand configuration is investigated. Girders are numerically modeled based on the finite element method (FEM) using finite element analysis software [7]. The effects of strand configurations on stress distribution and debonding parameters of prestressed concrete girders are identified using linear FE analysis.

II. Prestressed Concrete Girder Models

Simply supported prestressed girder with 90 cm height and 24.8 m effective span length is selected as an application (Fig.1 and Table 1). The ultimate strength of concrete (f_c) is taken as 45 MPa. The low-relaxation Grade 270 prestressing strand 15 mm (0.6 in.) in diameter is selected as a strand type. Strands layout along the girder length is assumed as linear. The distance between strands (5 cm) is selected according to [8]. The modulus of elasticity, passion ratio and density of concrete and strand are shown in Table 2. Totally nine girders with same cross-sectional area and length but different configuration is selected as an application. These girders can be classified into two groups. The Group #1 consists of five girders with different configuration of 14 strands. The maximum number strand in the bottom row is calculated as 9. The numbers of strand placed in all rows of girder are odd. Strand configurations of the Group #1 girders in bottom flange are illustrated in Fig. 2. The Group #2 consists of four girders with different configuration of 14 strands. The maximum number of strand in the bottom row is calculated as 8. The strands are placed in a row as even number. The bottom flanges of girders of Group #2 are illustrated in Fig. 3.

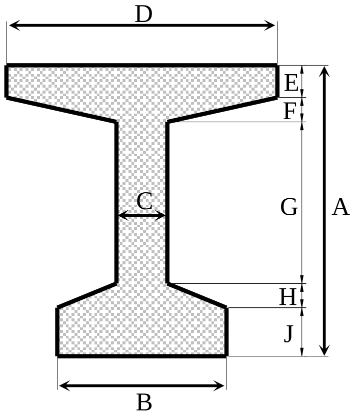


Table 1. *Parameters of girder*

Cross-Sectional Dimensions (cm)								
A	B	C	D	E	F	G	H	J
90	50	15	80	10	7.5	50	7.5	15

Table 2. *Material properties considered in the numerical analysis.*

Material	Modulus of Elasticity (MPa)	Poisson's Ratio	Density (kg/m^3)
Concrete	36057	0.2	2500
Strand	197000	0.3	7850

Figure 1. *Cross-section of the investigated girder*

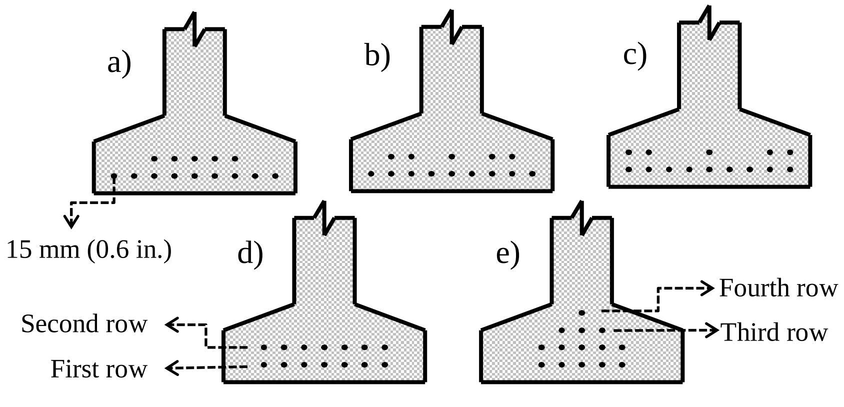


Figure 2. *Strand configurations of Group #1 girders.*

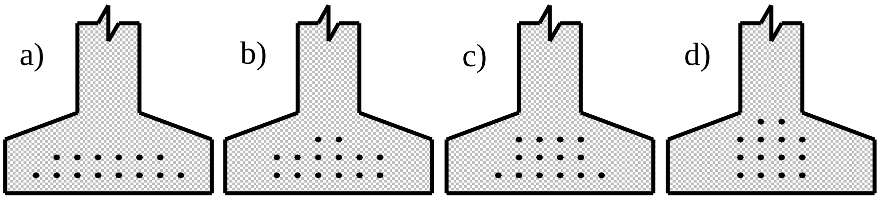


Figure 3. *Strand configurations of Group #2 girders.*

III. FINITE ELEMENT MODELING

The three dimensional (3D) FEM of the selected girders are created by using the finite element analysis software [8] and linear-static analyses are performed to obtain the stress distributions of girders. The girder models consist of 20 frame elements and 14 tendons. The girder and strands are represented with frame and tendon, respectively. Prestressing force is calculated as 195.51 kN when prestressing losses are not taken into account. As a boundary condition, the left and right hand supports are selected as pinned and roller, respectively.

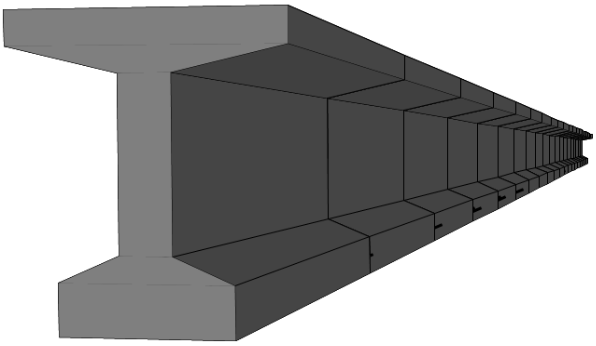
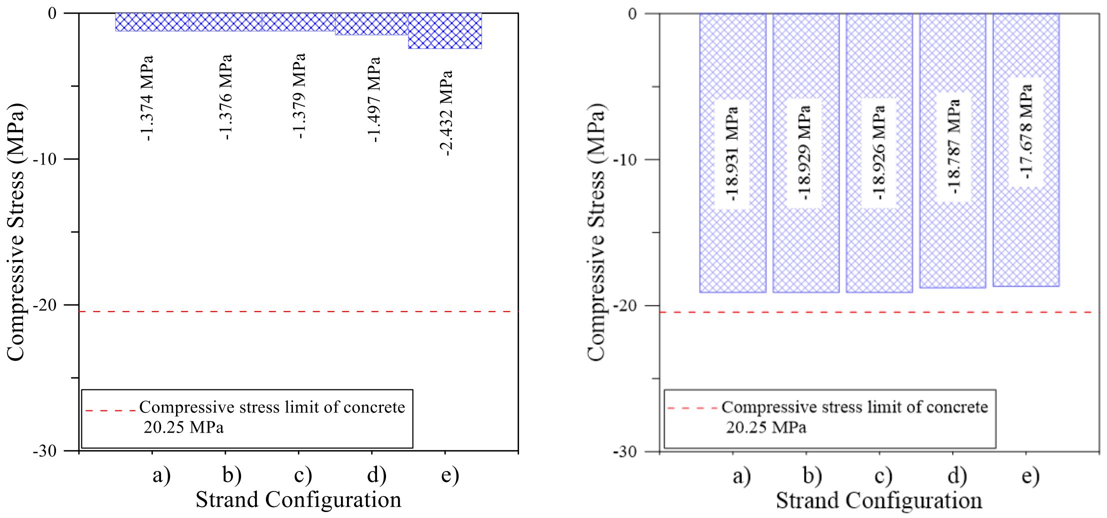


Figure 4. *Finite element model of the girder*

III. NUMERICAL RESULTS

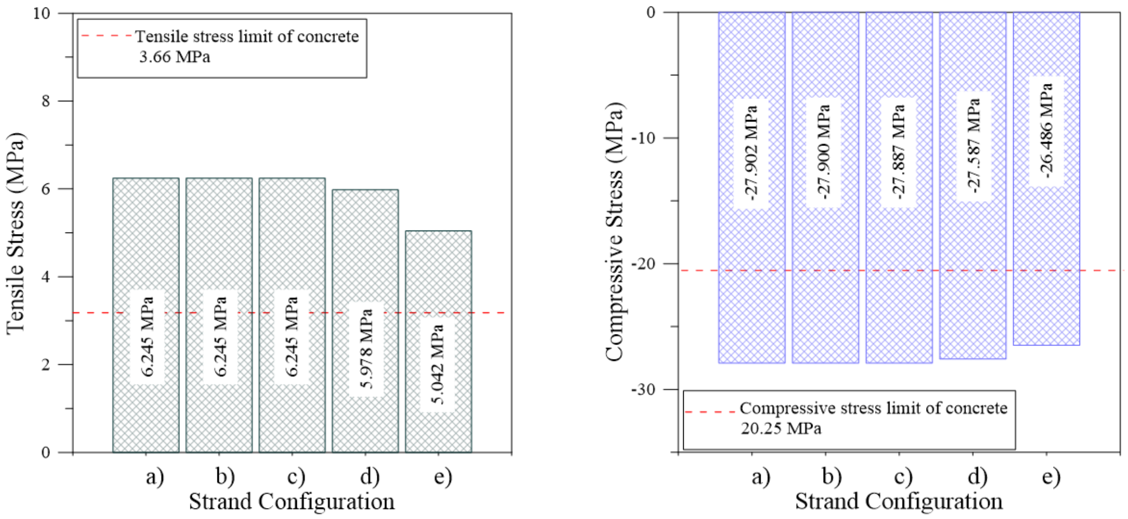
In this section, the maximum and minimum principal stresses distribution on support and midspan zone of each girder obtained under dead and prestressing load and calculated debonding parameters presented with detail. The tensile and compressive stress limit of concrete is taken from [8]. According to this provision, the allowable concrete tensile stress in MPa is $0.5\sqrt{f_c}$ for components with bonded prestressing strands or reinforcement that are subjected to not worse than moderate corrosion conditions. The compressive stress limit of concrete for girders is taken $0.45 f_c$, where f_c represents specified compressive strength of concrete. These limits of allowable concrete stress are shown with dashed line in figures.

The maximum principle stresses are obtained between -1.374 MPa and -2.432 MPa on top flange, -18.931 MPa and -17.678 MPa on bottom flange of the Group #1 girders at midspan. The maximum compressive stresses of top flange have an increasing trend from (a) to (e) girders but have a decreasing trend for bottom flange compressive stresses. It can be seen from Fig. 5 the compressive stresses obtained from midspan of Group #1 girders aren’t exceeded allowable stress limit of concrete. At the support zone of the Group #1 girders, maximum tensile stresses is obtained between 6.245 MPa and 5.042 MPa on top flange despite that compressive stresses is obtained -27.902 MPa and -26.486 MPa on bottom flange. It can be seen from Fig. 6 the tensile and compressive stress obtained from Group #1 girders at the support zone of girders exceeded allowable stress limit of concrete. An obtained excessive stress must be reduced by debonding a portion of the steel prestressing strands at the girder’s ends. The calculated number of debonded strands and debonded length used to reduce excessive stresses that occur in support zone of the Group #1 girder is shown Table 3.



(a) (b)

Figure 5. *The stresses on the top (a) and bottom (b) flange of the Group #1 girders at midspan*



(a) (b)

Figure 6. *The stresses on the top (a) and bottom (b) flange of the Group #1 girders at support zone*

Table 2. *Debonding parameters of Group #1 girders*

Group #1 Girder	Debonding Parameter			
	Number of Debonded Strand	**Debonded Lenght (m)**	**Number of Debonded Strand**	**Debonded Lenght (m)**
(a)	2	2.322	4	7.635
(b)	2	2.321	4	7.632
(c)	2	2.318	4	7.609
(d)	2	2.058	4	7.100
(e)	-	-	4	5.548

The maximum principle stresses are obtained between -1.508 MPa and -3.111 MPa on top flange, -18.774 MPa and -16.886 MPa on bottom flange of the Group #2 girders at midspan. The maximum compressive stresses of top flange have an increasing trend from (a) to (e) girders but have a decreasing trend for bottom flange compressive stresses. It can be seen from Fig. 7 the compressive stresses obtained from midspan of Group #2 girders aren't exceeded allowable stress limit of concrete. At the support zone of the Group #2 girders, maximum tensile stresses is obtained between 6.111 MPa and 4.507 MPa on top flange despite that compressive stresses is obtained -27.744 MPa and -25.856 MPa on bottom flange. It can be seen from Fig. 8 the tensile and compressive stress obtained from girders at the support zone of Group #2 girders exceeded allowable stress limit of concrete. An obtained excessive stress must be reduced by debonding a portion of the steel prestressing strands at the girder's ends. The calculated number of debonded strands and debonded length used to reduce excessive stresses that occur in support zone of the girder is shown Table 4.

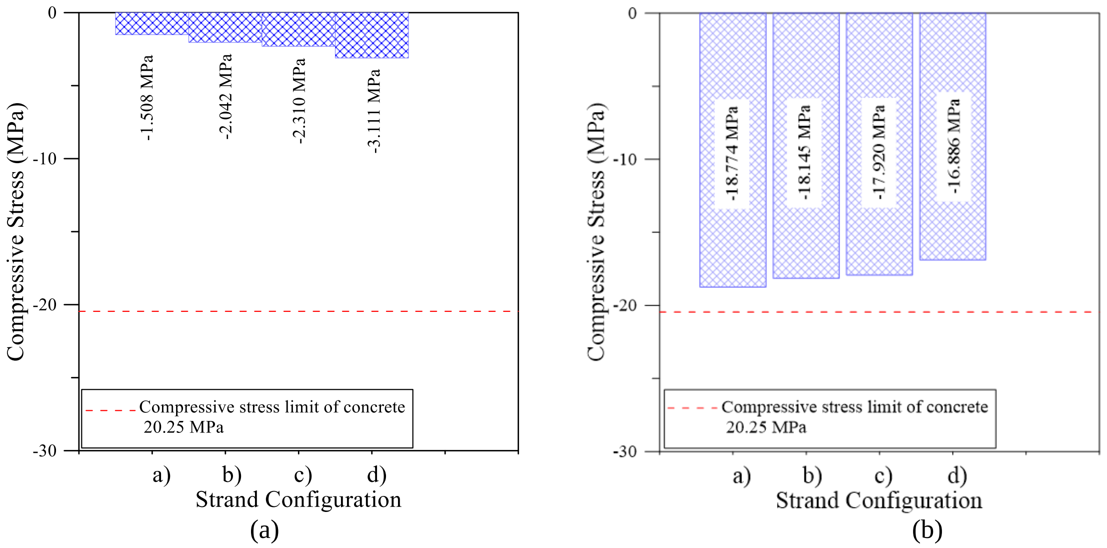
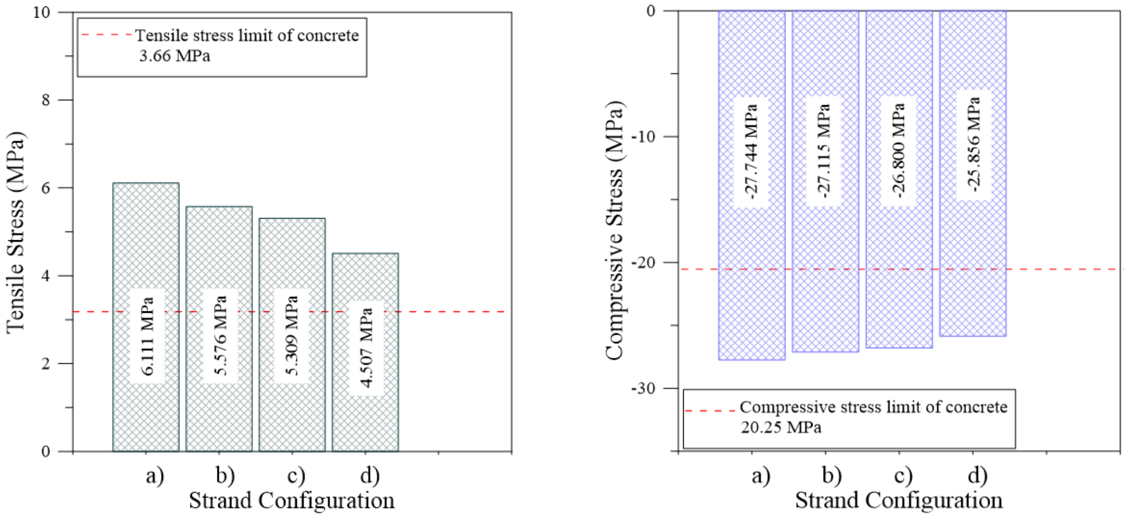


Figure 7. *The stresses on the top (a) and bottom (b) flange of the girders at midspan*



(a)

(b)

Figure 8. *The stresses on the top (a) and bottom (b) flange of the girders at support zone*

Table 3. *Debonding parameters*

Group #2 Girder	Debonding Parameter			
	Number of Debonded Strand	Debonded Lenght (m)	Number of Debonded Strand	Debonded Lenght (m)
(a)	2	2.189	4	7.360
(b)	1	1.673	4	6.385
(c)	1	1.425	4	5.952
(d)	-	-	3	4.800

IV. CONCLUSION

This study presents an investigation study about the effect of strand configuration on structural behavior of prestressed concrete girders after detensioning. Nine girders with same cross-section, effective span length and material properties but different strand configuration selected as an application. 3D FEM of girders are constituted by using SAP2000 software. Analysis of girders is performed under dead loads and prestressing loads. Stress distribution of girders under these loads and debonding parameters are compared with each other.

It is seen that strand configuration affects the structural behavior of girder such as maximum and minimum principal stresses and debonding parameters. To determine proper strand configuration of precast, pretensioned concrete bridge girders has resulted in improved economy through decreased number of strand and shallower superstructures.

V. REFERENCES

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