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# A study of the localized bearing capacity of reinforced concrete K-segment

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**Abstract**

To control the thrust force of the shield jacks, the localized bearing capacity should be estimated when instability occurs for reinforced-concrete K-segment under eccentric compression. Then a method based on the moment–force interaction and the effect of bolt pockets is proposed. The method considers that the load corresponding to the appearance of the first crack is the load of bond cracking at $\sigma_c \doteq 0.3–0.4 f'_c$ ($f'_c$ compressive strength of concrete), and assumes that the K-segment is a column which is subjected to axial loading and biaxial bending. Analytical results were compared with experimental values obtained from four reinforced-concrete K-segments. Using the strain gauges in concrete cover during the loading process, load–strain curves can be plotted and used to describe K-segment behavior. It was found that the failure of reinforced-concrete segments is a process, and bolt pockets reduce the bearing capacity of K-segment. The starting point is the cracking load point where cracks initiated on the concrete cover of the cross-section with bolt pockets. The ultimate load point is the top of failure process, namely the stress of this point attains the compressive strength of the concrete. The experimental results are close to the analytical values. The method is rational and can be used for stability analysis of reinforced-concrete segments.


*Keywords:* Localized bearing capacity; Eccentric compression; Segment; Thrust force

## 1. Introduction

The 5 Line is a new subway line of around 27.7 km in length for 2008 Beijing Olympic Games, connecting Songjiazhuang Station of southern Fengtai District with Dongsaqi Station of north Changping District through business streets and is adjacent to the 300-year-old Yonghe Lamasery and other old, historic buildings. Anything less than tight control on surface settlement would be unacceptable. Therefore, shield tunnelling was used for the first time in Beijing, as an effective method to control on surface settlement.

The primary lining of a shield tunnel is made by segments in both the cross-sectional and longitudinal directions through the use of connecting bolts. It is necessary to study the structural behavior of shield tunnel lining, including the joints, to clarify a rational design method for the segment that suits geological condition of Beijing. Therefore, eccentric compression and pure bending of segment, combined compression and bending of joint were tested for this project. However, only eccentric compression of K-segment is described in this paper.

In general, the effect of the thrust force of the shield jacks on the segment is mostly less due to the high compressive strength of the reinforced concrete. The joint, however, must be considered because the joint cross-section is smaller, as a rule, than that of the segment and the jacking force is transferred eccentrically across the joint. Especially, the joint cross-section of K-segment is smaller than the joint cross-sections of A-segment and B-segment. Therefore, it is necessary to estimate the localized bearing capacity of the weakened K-segment with the help of bolt pockets.

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According to the dimension of the K-segment, the K-segment is classified into short column. The failure of short column is initiated by material failure, i.e. steel reinforcement yielding or concrete crushing. The column capacity is equal to the cross-sectional capacity. Previous studies on failure mechanism of reinforced-concrete segments have shown that the failure of reinforced-concrete segments is not at a certain point but is a process. The process can be described by load–strain curves.

## 2. Experimental program

### 2.1. Segment

Details of the typical test K-segments are shown in Fig. 1 and the dimensions of all K-segments are summarized in Table 1. The K-segments are 22.5° central angle, 2700 mm inside radius, 3000 mm outside radius, 50 mm outside concrete cover thickness, and 30 mm inside concrete cover thickness. Mechanical properties of reinforcement and concrete are shown in Table 2. Table 3 shows the mix composition of the applied RC mixture. Fig. 2 shows the arrangement of strain gauges in the skin of K-segments. Uniaxial compressive strength of concrete is about 73.2 N/mm$^2$ at 28 days (Yang, 2001).

### 2.2. Testing method and results

Test programs were designed to estimate the load corresponding to the first crack initiated on the concrete cover and ultimate load, and to determine the load and strain relationship of reinforced concrete K-segments. Four full-scale reinforced concrete K-segments with the section shape and reinforcing bar, which were tested under monotonically increasing eccentric load until 800 ton (defined 800 ton based on testing condition), are shown in detail in Fig. 1. The joint cross-section of segment was applied on the eccentric load with the pressure plate in 50 ton increments uniformly using an electric hydraulic compression testing machine of 1000 ton capability. The center of pressure head shown in Fig. 3 coincided with the geometric centroid of pressure plate in the tests. The segments were instrumented with strain gauges in an attempt to measure the stress profile across the segments. When the load reached the preset load, it maintained the constant load in 3–10 min in which an observation of whether the cracks

Table 2
Mechanical material properties

| | Compressive strength (N/mm$^2$) | Young's modulus (N/mm$^2$) | Poisson's ratio |
|---|---|---|---|
| Concrete | 73.2 | $3.7 \times 10^4$ | 0.2 |
| Main reinforcement | 420 | $2.0 \times 10^5$ | 0.3 |

Table 3
RC composition in kg/m$^3$

| Components | Quantity |
|---|---|
| Cement | 228 kg/m$^3$ |
| Sand | 722 kg/m$^3$ |
| Stone | 1231 kg/m$^3$ |
| Slag | 152 kg/m$^3$ |
| DFS-2 | 11.2 kg/m$^3$ |
| Main + structural reinforcements (D22/D18) | 188.70/143.95 kg/m$^3$ |

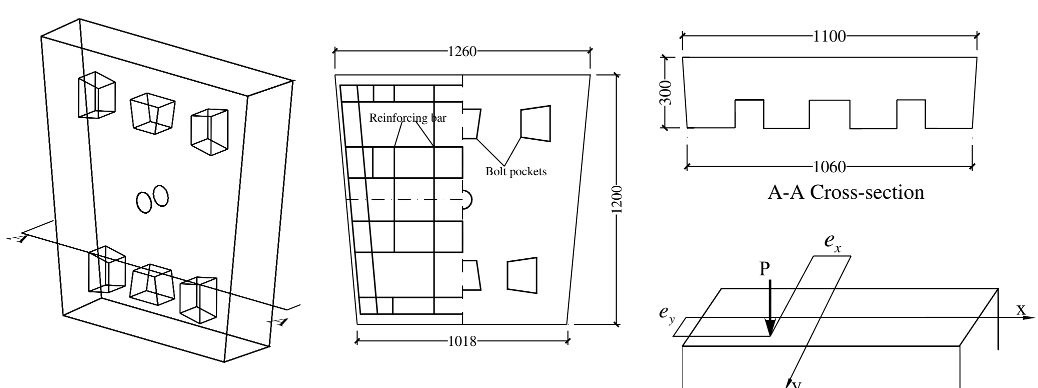


Fig. 1. Configuration and reinforcing bar and bolt pockets arrangement of segment (all dimensions are in mm).

Table 1
Details of segments

| Segment | Central angle | Inside radius (mm) | Outside radius (mm) | Longitudinal bar | Transverse bar | $e_x/e_y$ (mm) |
|---|---|---|---|---|---|---|
| D1 | 22.5° | 2700 | 3000 | 12-D22 | 16-D22 | 110/55 |
| D2 | | | | 12-D22 | 16-D22 | 100/55 |
| X1 | | | | 12-D18 | 16-D18 | 130/55 |
| X2 | | | | 12-D18 | 16-D18 | 50/55 |

$e_x$, $e_y$ are eccentricities measured parallel to $x$- and $y$-axes, respectively. The number after "D" means the diameter of reinforcing bar. $P$ represents axial load.