Effect of joint positions on flexural behaviors of box segmental specimens internally post tensioned under cyclic and static loadings

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Abstract. The goal of this paper is to get a better knowledge of effect of joint positions on flexural behavior of box segmental specimens under bending stresses. Three segmental specimens with internal tendons were produced and tested. Each segmental specimen was produced assembling three precast concrete segments and they were connected by using four post tensioning tendons. All segmental specimens were formed with dry joint type, but they different in joint positions. All specimens were tested under two types of loadings cyclic and static two point loads. The test of cyclic loading was carried out by exposure each specimen to three loading cycles. The static load test was carried out in same rate of loading that of cyclic load test and all girder specimens were tested up to failure. The loads versus deflections at specified points were recorded. Also, cracking, mode of failure and ultimate loads values were recorded as well as the concrete surface strains at the specified locations for both loadings.

1. Introduction

For construction method of concrete bridges by using segmental girders many advantages. This method can ensure concrete quality during pouring, reduction in workload on construction site, speeding in construction, and mitigation in disturbance to the environment. Moreover, the section dimensions of the girder; therefore, deadweight of internal pre-stressed bridges can be reduced. As compared with traditional monolithic bridges, many advantages can be achieved by segmental construction method such as small light segments, structure with no cracks due to opening of drying joints, recycling of damaged segments, no interruption of traffic and shorter construction time. The pre-stressed segmental box girder bridge has become the preferring construction method for many high-way projects in recent times. These beams, that have internally and externally strands, are popularly increasing due to internal strands can improve the ductility for the beam, and the external tendons are appropriate of maintenance. The present paper searches behaviors for box beams segmental concrete by internal strands and different positions for joints under bending.

A lot of investigations were carried out to study effect of joint positions of box segmental specimens. It was found that joint position has a significant effect on joint resistance when loads are located in the immediate vicinity of the joints[1]. Also, for PCSB (Precast Concrete Segmental Beams) with the same type of joints, the resistance reduces when the joint approaches to the mid-span. 12 models of segmental beams were tested with the object of clarifying the effect of span to depth ratio, number and location of joints and the distance from load to support on the shear behavior of segmental beams [2]. A study to investigate the structural behavior of segmental beams under shear considering the joint positions was done by [3]. They observed that the effects of epoxied joint position have shown the difference in the shear failure mechanism. The failure modes in the experiment are attributed to shear compression failure with cracks propagating from the bottom of the nearest joint to the loading point on the upper flange,
which indicates that load position is an important factor affecting the failure mode. A description of the construction of a post-tensioned segmental beam and a comparison between the experimental structural behaviors with the theoretical calculations were presented by [4]. Another study to evaluate the use of CFRP (Carbon Fibers Reinforcement Prestressing) tendons in replacement of traditional prestressing steel tendons for PSBs to deal with corrosion-related issues was reported by [5]. The structural behavior of Segmental Precast Post-tensioned Reinforced Concrete (SPPRC) beams largely depends on the behavior of the joints that connect between the segments [6]. In this research, series of static tests were carried out to investigate the behavior of full-scale SPPRC beams with different types of epoxied joint types; multi-key joint, single key, and plain key joint. The response of reinforced concrete precast spliced girders to static and impact loads was studied by [7]. Several experimental works were reported on the SPPRC beams [8-10]. By these studies, behaviors of segmental concrete box beams with internal and external tendons under bending were evaluated. The difference in strength between on-site cast and precast segmental concrete to accurately evaluate the deflection of precast concrete flexural members with joints within the lapped splice had been done by [11].

Experimental studies were carried out on precast concrete segmental beams with internal and external tendons [12-14]. in these studies, evaluation of flexural behavior of SPPRC beams with external tendons was reported and compared with internal tendons under combined shear and bending.

The aim of this study is to investigate the effect of the joint positions between segments with respect of the nearest support on the flexural behavior of the segmental specimens under cyclic and static loads.

2. Experimental Program

2.1 Model Cross Section

This study consists of three segmental specimens, each one of them was fabricated with three precast concrete segments by using post tensioning technique. The total length of each specimen is (2100mm) and box section with total dimensions (300mm×300mm) and hollow (140mm×140mm) was adopted for all specimens of this study. All segments are reinforced with four steel bars of Φ 10 mm for bending and with Φ 8 mm @ 120 mm c/c for stirrups. The segments was variable lengths depending on joints positions between the segments. The position of joint is defined by a ratio of (a/ h), which "a" is the distance from the joint and the nearest support, and “h” is the effective height of the specimen section as illustrated in Figure (1) and shown in Table (1).

![Figure 1. Segmental Specimens Details](image)

Table 1. General description of joint positions between segments of the segmental specimens
2.2 Materials

Ordinary type of portland cement with 53 grade according to (ASTM type I) was used in this research. The crushed granite gravel which locally available with a size of (5-12) mm was used as coarse aggregate. The clean river sand was used as a fine aggregate according to the specifications. Superplastizer type (ViscoCrete 5930-L) was added to mixing materials to improve its workability. Silica fume and Limestone powder with specified quantities were added to improve mechanical properties of concrete. Self-Compact Concrete (SCC) type was used to produce all specimens of this study by using materials above with mixing proportions as shown in Table 2.

2.3 Post-Tensioning Procedure

After curing of precast concrete segments for 28 days under outdoor atmospheric condition they were subjected to prestressing forces to form the segmental specimen by using four tendons in each specimen. P.V.C ducts with diameter 18 mm were embedded in concrete bodies to accommodate the post-tensioning strands after concrete hardening. Pre-stressing strands were seven-wire 12.7 mm in diameter, with cross-sectional area of 92.6 mm$^2$, yield strength 1570 Mpa at elongation percentage (0.1%) and ultimate strengths of 1860 MPa.

Post-tensioning operation was done in three stages to stretch each tendon to 250 bar which equivalent to 100.5 kN. Pre-stressing anchor heads and wedges were fixed to all tendons stressing ends. A (10mm) steel plate of dimensions (10×10cm) was used at each end of tendon as bearing plates.

### Table 2. Mixing proportion per cubic meter

| Cement kg/m$^3$ | Fine Agg. kg/m$^3$ | Coarse Agg. kg/m$^3$ | Silica Fume % of wt. of Cement | Powder kg/m$^3$ | ViscoCrete % | w/c |
|-----------------|-------------------|-----------------------|--------------------------------|-----------------|--------------|-----|
| 470             | 750               | 900                   | 23                             | 130             | 2.45         | 0.39|

2.4 Testing Procedure

2.4.1 Testing Setup

All the tests were done in the Structures Laboratory in Civil Engineering of Mustansiriya University. All specimens were tested under two loadings with the shown setup of test in Figure 2. The loads applied over the beams were provided by two jacks which were placed on a frame supported to strong floor. Two steel rods with diameter 50 mm were used to transfer the vertical loads as two point loads to the specimen.
2.4.2 Instrumentation
The test measurements included recordings of applied loads, beam deflections and strains.
1. Two strain gages were placed on the lower and upper sides of mid span position of specimens to measure maximum tensile and compressive strains for concrete.
2. Dial gauge with (0.01mm) accuracy dial gauge and of (30mm) range was installed at mid span underneath the bottom face of the test specimens to measure the vertical deflections.

2.5 Testing procedure
2.5.1 Cyclic loading test
This test was carried out by exposure each beam to three loading cycles. Each cycle has been implemented by loading each beam up to (70 kN) and release the loads returning to non-loading case. The deflection and strain versus each (5 kN) load were measured at mid span position.

2.5.2 Static loading test
The loading was applied slowly at small increments of about (5 kN) intervals. The deflections and strains were recorded. Once cracking of concrete was observed (first crack), the load was recorded. The tests were continued up to failure where the ultimate load was recorded.

3. Test Results and Discussions
3.1 Results of Cyclic Load Tests
3.1.1 Deflection results
The test results of deflection versus peak load (70 kN), which represent the maximum deflection of each load cycle for control specimen (SB1), (SB9) and (SB10) are shown in Table (3) and load-deflection relationships are illustrated in Figure (3).
Table (3) Test results of deflections for three loading cycles

| specimen | No. of loading cycle | $\Delta_{70}^a$ (mm) | $\Delta_{a}^b$ (mm) | $\Delta_{70}/(\Delta_{a})^c$ | a/h |
|----------|----------------------|----------------------|---------------------|--------------------------|-----|
| SB1      | 1                    | 1.10                 | 1.42                | 1.00                     | 2   |
|          | 2                    | 1.55                 |                     |                          |     |
|          | 3                    | 1.52                 |                     |                          |     |
| SB9      | 1                    | 2.79                 | 2.87                | 2.02                     | 1.5 |
|          | 2                    | 2.81                 |                     |                          |     |
|          | 3                    | 2.83                 |                     |                          |     |
| SB10     | 1                    | 5.78                 | 5.92                | 4.17                     | 2.5 |
|          | 2                    | 5.81                 |                     |                          |     |
|          | 3                    | 5.81                 |                     |                          |     |

a: Maximum deflection at peak load (70 kN) of each load cycle
b: Average of deflections for three load cycles
c: $(\Delta_{a}) = $Average of deflections for three load cycles of control specimen

From the results, specimen (SB9) which was formed with ratio (a/h=1.5) measured deflection about 102% more than that of reference specimen SB1, while specimen (SB10) with ratio (a/h=2.5) had deflection more than of reference specimen by about 317%.

The behavior of specimen SB9 can be attributed to that approaching the joint position from the support led to increase the shear force effect on the interfaces of joint and reduce its strength under bending stresses. On the other hand, changing the ratio (a/h) from 2 to 1.5 required increase the span length of middle segment from 700mm to 1000mm, this change increase effect of bending moment on the specimen.

In situation of specimen SB10, the joint approaches to the maximum moment zone, therefore; the joint section subjected to high tensile and compressive bending stresses. Because of low resistance of the dry joint section to the bending tensile stress so the high bending stress led to decrease stiffness (increase deflection), this can be attributed to the low resistance of lower concrete parts of the tension side of the dry joint to the bending tensile stress and tendency these parts to the spread of some led to reduce resistance of the tension side of joint position under bending tensile stress resulting an increasing in deflection.
3.1.2 Strain results
The results of maximum of tension and compression strains for three loads cycles of mid-span position were listed in Table (4), in addition to the average value of these loads.

Table (4): Strains of mid-span for tested specimens

| Specimens | $\varepsilon^t_a \times 10^{-6}$ | $(\varepsilon^t_a/\varepsilon^c)_a \times 10^{-6}$ | $(\varepsilon^c_a/\varepsilon^t_a)_a \times 10^{-6}$ | $(\varepsilon^c_a/\varepsilon^t_a)_c \times 10^{-6}$ | $(\varepsilon^c_a/\varepsilon^t_a)_c \times 10^{-6}$ | $a/h$ |
|-----------|-------------------------------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|------|
| SB1       | 214                           | 1.00                             | -302                             | -314                             | 1.00                             | 2    |
|           | 237                           |                                  | -315                             |                                  |                                  |      |
|           | 253                           |                                  | -324                             |                                  |                                  |      |
| SB9       | 1739                          | 8.06                             | -441                             | -442                             | 1.41                             | 1.5  |
|           | 1847                          |                                  | -436                             |                                  |                                  |      |
|           | 2100                          |                                  | -448                             |                                  |                                  |      |
| SB10      | 374                           | 1.66                             | -487                             | -505                             | 1.61                             | 2.5  |
|           | 382                           |                                  | -497                             |                                  |                                  |      |
|           | 416                           |                                  | -532                             |                                  |                                  |      |

a,d: Tensile and Compressive strains for each loading cycle, respectively
b,e: Averages of Tensile and Compressive strains for three loading cycles, respectively
c,f Tensile and Compressive strains of control specimen, respectively
g: $a=Distance\ between\ joint\ and\ nearest\ support, \ h=Height\ of\ specimen\ section$

From Table (4), it was found that the joint position, for the segmental specimens with the same characteristics, had a significant effect on the strain behavior of the segmental specimen under bending stresses.
The ratio ($a/h= 2$), which was for specimen SB1, was adopted as a reference ratio to study the effect of the joint position for this group.
Decreasing ratio ($a/h$) from 2 to 1.5, it was applied for specimen SB10. The distance from the joint and the nearest support was decreased from 600mm to 450mm thus the middle segment of this specimen was in length (1000mm) and each end segment with length (550mm).
The relationship between loads and the corresponding tension and compression strains of three loading cycles of specimen SB9 were illustrated in Figure (4).
Figure (4): Load-Tensile (a) and Compressive (b) Strains Relationships of SB9

From the results, it was observed that specimen SB9 behaved in large interval in tension strains comparison with strains in compression, where it reached to (0.0018) in tension as an average value, while it recorded an average compression strain about (0.0004). This behavior can be attributed to that approaching the joint to the shear zone led to decrease resistance of the joint and then reduce stiffness of the specimen (more deflection), therefore; it exposure more strain comparison with specimen SB1. In comparison with corresponding results of specimen SB1, can be observed that specimen SB9 recorded increase in tension and compression about 706% and 41% more than that of specimen SB1. A larger (a/h= 2.5), it was applied for specimen SB10. The distance between the joint and the nearer support increased from 600mm to 750mm. According to the obtained results, specimen SB10 recorded increase in both tensile and compression strains more than that of SB1 by about 66% and 61%, respectively, Figure (5).
Specimen SB10 recorded maximum strain in tension lower than that of specimen SB9 by about 79% although the joint position of specimen SB10 approached to mid span position (maximum bending moment), this can be attributed to that low resistance of lower concrete parts in tension side of the dry joint to the bending tensile stress and tendency these parts to the spread of some led to reduce effect of tensile stress at the tension side of the joint for the middle segment resulting in a reducing in tension strain.

This behavior of the joint led to increase the convergence of upper parts of concrete at the compression side of the joint which led to generate a compressive stress additional to that of bending, therefore; more strain in compression was recorded in comparison with strain in tension.

3.2 Results of Static Load Tests
3.2.1 Deflection results
The test results have represented in Table (5) and Figure (6).

| Specimens | Pcr (kN) | Pu (kN) | Pcr/(Pcr)c | Δc/Δc (mm) | Δcr/(Δc)c | Δc | Mode of Failure |
|-----------|---------|---------|------------|------------|------------|----|----------------|
| SB1       | 90      | 205     | 1.00       | 3.00       | 1.00       | 15.1 | Joint Crushing |
| SB9       | 81      | 101     | 0.90       | 4.00       | 1.33       | 7.6  | Joint Crushing |
| SB10      | 85      | 172     | 0.96       | 6.81       | 2.27       | 21   | Joint Crushing |

From Table (5), it can be observed that specimens SB9 and SB10 behaved with very low stiffness (high deflection) comparison with specimen SB1.

Decreasing ratio (a/h) from 2 to 1.5, which was applied in specimen SB9, this ratio led to approach joint position to the shear force zone at the nearest support. For dry joint, the shear force was resisted, only, by internal tendons, therefore; when shear force increased the joint strength will be decreased.

The ratio (a/h=1.5) required increase middle segment length, this length let to increase had a clear effect in reducing opening of joint and reducing concentration compressive stress on the upper parts of concrete at the joint position, therefore; the failure mode occurred with less crushing of concrete, Figure (7).
For specimen SB10, increasing ratio \((a/h)\) up to 2.5 required reducing length of middle segment to 400mm and approaching joint position within maximum bending moment zone, therefore; joint position subjected to high bending tensile stress. Because of shortening of middle segment length and low resistance of dry joint to bending moment, the joint opened generating more compressive stress on the upper concrete resulting in more crushing of the side of joint, Figure (7).

![Image](image.png)

**Figure (7): Mode of Failure of SB9, SB10 and SB1**

### 3.2.2 Strain results
The results of tensile and compressive strains of first loading are listed in Table (6).

| Sp.  | \(P_{cr}^a\) kN | \(\varepsilon_{cr}^b\times10^6\) | \(\varepsilon_{cr}^c\times10^6\) | \(P_u^d\) kN | \(\varepsilon_{tu}^e\times10^6\) | \(\varepsilon_{tu}^f\times10^6\) | \(P_{cr}/(\varepsilon_{cr})^g\) | \(\varepsilon_{ccr}/(\varepsilon_{cr})^h\) % | \(\varepsilon_{ccr}/(\varepsilon_{ccr})^i\) % |
|------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| SB1  | 90              | -511            | 205             | 1067            | -2033           | 100             | 100             | 100             | 100             |
| SB9  | 81              | -547            | 101             | 2766            | -2435           | 90              | 518             | 107             |                 |
| SB10 | 85              | -654            | 172             | 1101            | -2756           | 96              | 115             | 128             |                 |

- \(a\) First crack load
- \(b,c\) Tensile and compressive strains at first crack loading, respectively
- \(d\) Ultimate load
- \(e,f\) Tensile and compressive strains at ultimate load, respectively
- \(g\) First crack load of control specimen
- \(h,f\) Tensile and compressive strains at first crack loading of control specimen, respectively

From the Table, it was found that when the joint position approached to the support by ratio \((a/h)=1.5\), which was applied in specimen SB9, led to reduce the resistance of joint, especially, against the bending tensile stress where the specimen reached to strain in tension zone more than five times that of specimen SB1, while it recorded approximated response of strain at compression zone. This behavior can be explained because of reducing the resistance of joint to the shear force as a result of approach the joint position to the shear zone.

The loads-strain relationship for tension and compression zones at mid-span location of the specimens SB1, SB9 and SB10 are illustrated by Figure (8).
In contrast, with respect to specimen SB1, specimen SB10 recorded strain about 115% at tension zone, while it had about 128% as a compressive strain. On the other hand, although the joint position of specimen SB10 approached to mid-span position (maximum bending moment), but specimen SB10 had strain at tension zone lower than that at compression zone, where it reached to compressive strain about 66% more than that of tensile strain. This behavior, can be attributed to that low resistance of lower concrete parts in tension side of the dry joint to the bending tensile stress and tendency these parts to the spread of some led to reduce effect of tensile stress at the tension side of the joint for the middle segment resulting in a reducing in tension strain. This behavior of the joint led to increase the convergence of upper parts of concrete at the compression side of the joint which led to generate a compressive stress additional to that of bending, therefore; more strain in compression was recorded in comparison with strain in tension.

For joint position, comparison between the results of joint position with respect to mid-span position are listed in Table (7) and clarified by Figure (9).

**Table (7): Test results at joint position of the tested specimens**

| Specimens | Mid-span | Joint position | ($\varepsilon_{\text{dp}}/\varepsilon_{\text{ad}}$)$_{cr}$ | ($\varepsilon_{\text{dp}}/\varepsilon_{\text{ad}}$)$_{b}$ |
|-----------|----------|----------------|---------------------------------|---------------------------------|
|           | $\varepsilon_{\text{ccr}}$ | $\varepsilon_{\text{cut}}$ | $\varepsilon_{\text{ccr}}$ | $\varepsilon_{\text{cut}}$ |                      |                      |
| SB1       | -511     | -2033          | -501                          | -3105                          | 0.82                  | 1.53                  |
| SB9       | -547     | -2435          | -260                          | -291                           | 0.40                  | 0.12                  |
| SB10      | -654     | -2756          | -695                          | -2933                          | 0.89                  | 1.06                  |

$\varepsilon_{\text{dp}}, \varepsilon_{\text{ad}}$ Compressive strain at joint position and mid span location, respectively.

Generally, specimens SB9 and SB10 behaved in same manner that of specimen SB1, but with different percentages in strain readings at compression zone of joint position due to different distances between the joint position and the maximum bending stresses zone. Based on these results, can be concluded that joint position in one third of span ($a/h=2$) had a butter behavior comparison with other positions.
4. Summery and Conclusions

All specimens were tested under cyclic and static bending loadings. The obtained results provided quantities of data and understanding of behavior on deflections, failure modes, joint strength, and strains. Depending on these results the following conclusions can be drawn:

1. Approaching joint positions to the nearest support (decreasing ratio a/h) leads to decrease the strength of the joint and increase concentration tensile stress on the lower part of the middle segment.

2. Approaching joint positions to the mid-span location of the specimen (increasing ratio a/h) leads to decrease strength of joint in effect more than the case of decreasing ratio (a/h), and decrease concentration tensile stress on the lower part of the middle segment.

3. The case of specimen SB1 in which joints locate in one third of span can be considered better manner of the joints positions.

4. All specimens failed in same mode that was crushing of the upper part of the joint positions and more intensity of crushing was observed when joint approaching to the mid-span location.

5. With further loading, the opening width of the lower side of the dry joint increase with increasing the ratio (a/h) and increasing compressive stress on the upper side of the joint positions.

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