

Load Transfer Test of Post-Tensioned Anchorage Zones in High Strength Concrete

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Abstract: *The post-tensioning methods use a large amounts of strands to introduce a prestressing force into concrete. When the strands are strained, a considerable load is imposed on the concrete in the anchorage zone. Therefore, the cross section becomes larger and more reinforcements are used to prevent cracking. To decrease the inefficiency such as the increase of cross section and the use of a large amount of reinforcements, various studies are under way. In this study, the behaviors were evaluated by load transfer test of a post tensioned anchorage zones using high strength concrete. A total of 8 specimens were prepared for various amounts of spiral reinforcement and the reinforcing degree of lateral reinforcements. Compared those specified with the Korean Highway Bridge Design Code, the spiral reinforcement was found to be removable, but stronger lateral reinforcing is required rather than those specified in the design code. It may be possible to simplify lateral reinforcements when using spiral reinforcement.*

Keywords: *Post-tension, Lateral reinforcement, Spiral, Reinforcements, Crack.*

1. Introduction

In the post tension method, a considerable load is imposed on the concrete due to a large amounts of strands tensioning, so that the cross section of anchorage zone becomes larger and more reinforcements are used more than necessary to prevent usual cracks. The dimensions of anchorage zone increase and the materials used also increase, resulting in environmentally and economically ineffective results. To reduce such inefficiency, high strength or high performance concrete were applied, which is being actively researched recently, or pretension method and post-tension method are applied at the same time. A research on UHPC post-tensioned anchorage zone [1] revealed that the reduction of reinforcement may be possible. In the case of using a single unbounded strand in post tensioned anchorage zones the additional reinforcement is unnecessary. Another research on experiment and finite element analysis of the post tensioned anchorage zones using Ultra-High Performance Concrete under active research in Korea [2]. It showed that sufficient strength and performance were obtained without reinforcing.

In this study, the performance of the post-tensioned anchorage zones using 100MPa high strength concrete was examined by the load transfer test and crack pattern, crack width, the stresses reinforcements were measured.

2. Specimens

The characteristics of the test specimens used in this experiment were designed according the exist specifications [3], [4]. Following the regulations of ETAG013, the sections must satisfy the conditions shown in (1), (2) and TABLE I, and the result is summarized in TABLE II and Fig. 1

$$A_c = x \cdot y = a \cdot b \quad (1)$$

$$x \geq 0.85a, y \leq 1.15b \quad (2)$$

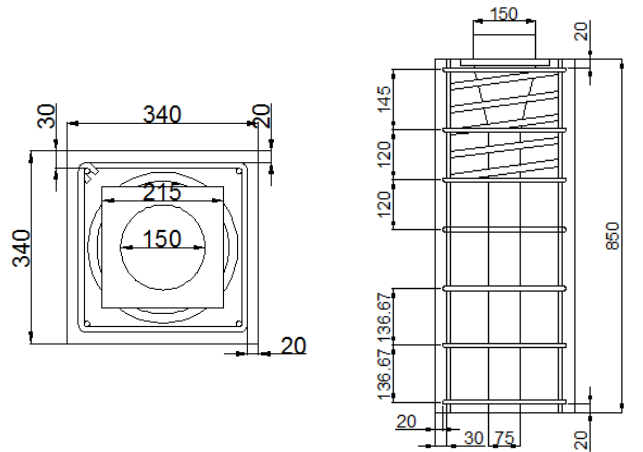
TABLE I: Requirements for Specimens

	Requirements
Vertical Reinforcement	$A_s \leq 0.003A_c$
Specimen Height	More than two times the long dimension of section side dimension

TABLE II: Specimen Dimensions

	Dimension (mm)
Width	340
Length	340
Height	850

Where, A_c is the cross-section area of the concrete(mm^2), a is width or length(mm), b is length or width(mm), and A_s is the total area of the vertical reinforcements(mm^2). To meet the requirements for vertical reinforcements and area of ETAG013, four D10 reinforcements were used for vertical reinforcement and the dimensions were determined as those specified in TABLE I, which are given by the restriction in the experimental site and equipment's capacity.



(a) Section dimension (b) Side surface dimension

Fig. 1 Specimen dimension

Following the specifications of ETAG013, there is requirement that the lateral reinforcements should not exceed 50Kg per 1m³ of concrete volume, and they should be evenly distributed along the specimen's height. Although the condition of not exceeding 50Kg was followed, the spacings of reinforcements is arranged to meet the requirements of [4]. This condition is summarized in TABLE III and Fig. 2 [3], [5]. In Fig. 2, the names given to the specimens were classified to US by using spiral reinforcement and NS by non-using spiral reinforcement respectively, and numbered as the number of tensile resistance reinforcements except for three lateral reinforcements to prevent fracture failure at the bottom.

TABLE III: Lateral Reinforcements Design Condition For 2010 Korea Highway Bridge Design Code [4]

Case	Condition
Condition 1	Reinforcements have to settle close to the surface of member, and extend in the entire width, as long as cover thickness allows
Condition 2	Reinforcements should be distributed in accordance section with the distance of $2.5d_{burst}$, but not exceeding 1.5 times the corresponding lateral dimension of the section, and distributed in front of loading surface along the both axis, and the bursting reinforcements centre should coincide with the d_{burst} .
Condition 3	The reinforcements spacing should not exceed 24 times the diameter of rebar or 300mm.

Where, d_{burst} is the location of the maximum bursting force specified in the 2010 Korea Highway Bridge Design Code [4], as shown in (3).

$$d_{burst} = 0.5(h - 2e) + 5e \sin \alpha \quad (3)$$

Where, h is the width or length dimension of the side of specimen(mm), e is the eccentric distance between the centre of the anchorage equipment and the centre of specimen(mm), and α is the angle between anchorage and specimen during loading(degree). The lateral reinforcements are D10, and the spiral reinforcements are D16. To meet the condition 3 of TABLE III, the spacing of lateral reinforcements was 240mm at maximum, so it was adjusted according to the number of lateral reinforcements and dimensions of reinforcing area. The anchorage equipment is VSL TYPE EC 5-12 from VSL Korea Co. [6]. The load base of specimen was 7 twisted twelve 12.7mm strand of SWPC-7B 1860MPa, with $F_{pk}=2073.53\text{KN}$, where, F_{pk} is characteristic ultimate resisting force of tensile elements of tendon. The thickness of concrete cover between lateral reinforcements was 20mm [4], [7], [8], [9].

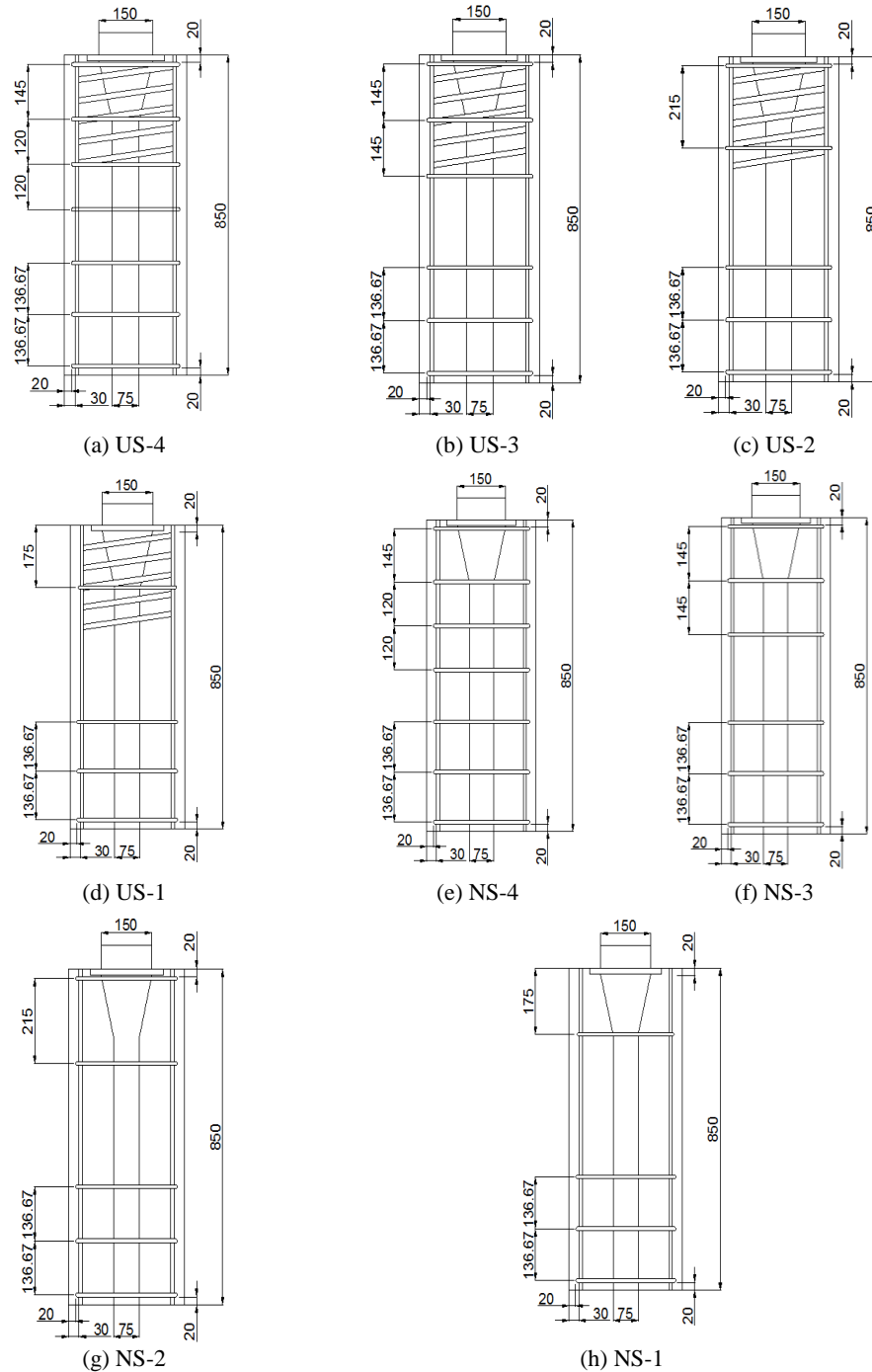


Fig. 2 Specimen details

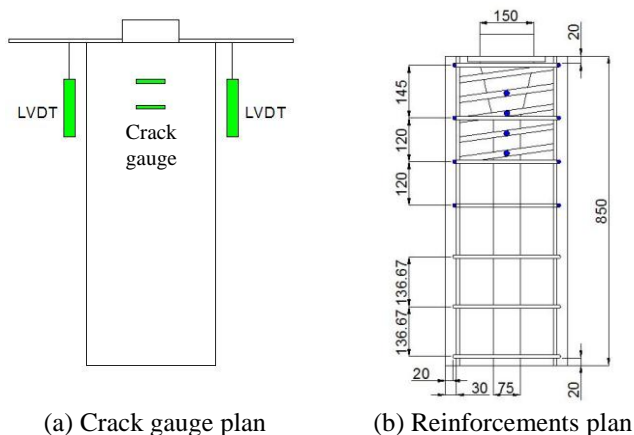
The specimens were fabricated using 100MPa high strength concrete. They were de-molded after one day air curing and steam-cured for 3days. Concrete characteristics such as compressive strength, split strength, flexural tensile strengths are summarized in TABLE IV.

TABLE IV: Characteristic of Concrete

Characteristics	Value
Compressive Strength (MPa)	105.1
Splitting Strength (MPa)	4.84
Flexural Strength (MPa)	7.01

3. Measurement and Loadings

In this study, cracks and reinforcements stress were measured and analyzed. For the crack measurement, four PI gauges were installed on the left and right sides of the specimens and the reinforcements strain gauges were installed on the left and right sides of the spiral reinforcement and lateral reinforcements as shown in Fig. 3 (b).



(a) Crack gauge plan (b) Reinforcements plan
Fig. 3 Crack and reinforcements measurement plan

The 3000KN capacity UTM was used and loaded to 2551KN to meet the 1.1F_{pk} specified in ETAG013 and considered UTM’s capacity. The judgement criteria of specimen failure were based on the yield strength of lateral reinforcements. Load plan and operation procedures were followed by the experimental method of ETAG013, and the application conditions are shown in TABLE V and Fig. 4. If all the condition of TALBE V are satisfied, the strain stabilization is conducted as shown in Fig. 3 [2], [5].

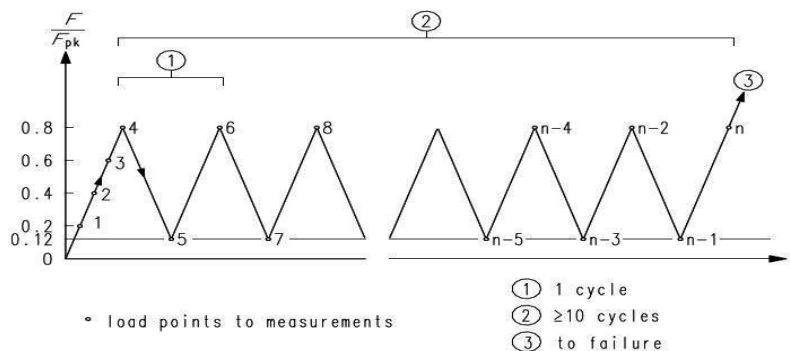


Fig. 4 Strain stabilizing cycle

TABLE V: Conditions to the Strain Stabilizing

	Loads	Limitations
1	First load: Up to 80% of strand's nominal tensile strength	Crack width $\leq 0.1\text{mm}$
2	Repeat at least 10 cycle loading up to 12~80% of strand's nominal tensile strength	Step 2 - Strain increase $\leq 0.5\%$ - Crack width $\leq 0.02\text{mm}$ Final Step - $0.12F_{pk}$ Crack $\leq 0.1\text{mm}$ - $0.8F_{pk}$ Crack $\leq 0.25\text{mm}$ - Specimen surface must be stabilized
3	Gradually loading when the specimen failure	$F_u \geq 1.1F_{pk}$

4. Experimental Result and Discussion

All specimens satisfied the strain stabilization conditions except for NS-1 and NS-2. The loading proceeded to the maximum load after the strain stabilization except for NS-1 and NS-2. All of NS specimens didn't satisfy $1.1F_{pk}$, but NS-3 and NS-4 finished the experiment at near $1.0F_{pk}$. The relations between load and crack width from experiment results are shown in Fig. 5.

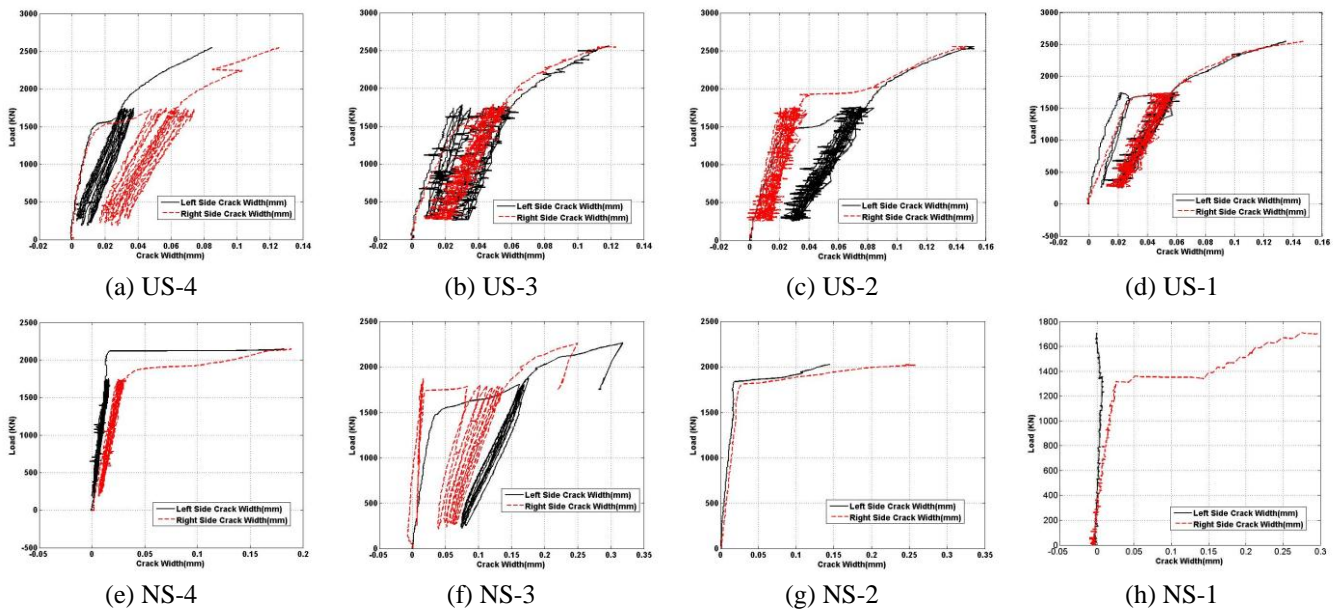
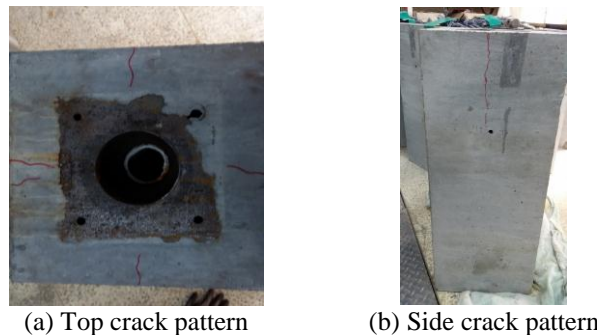


Fig. 5 Load-crack width relations

All the NS specimens showed the first cracks at initial loading, and US-2, US-3 specimen underwent initial cracking after the strain stabilization step, while the US-1 specimen underwent initial cracking at the second stage of the strain stabilization. The initial crack of US-4 specimen generated at the fifth stage of the strain stabilization. The cracking pattern of NS and US specimens is shown in Fig. 6 [6].



(a) Top crack pattern (b) Side crack pattern
Fig. 6 Experiment result of specimen crack pattern

Cracks due to spalling force and bursting force were observed at the top of specimens, and at the all surfaces of specimens. After the first cracking, it was found to extend upward and downward.

In the case of lateral reinforcements, all NS specimens yielded at the final load point, but the US specimens did not yield either the spiral reinforcement and lateral reinforcements at the final load 2551KN. The results of the reinforcements are shown in Fig. 7, and the results of the load and the reinforcements stress are shown in TABLE VI.

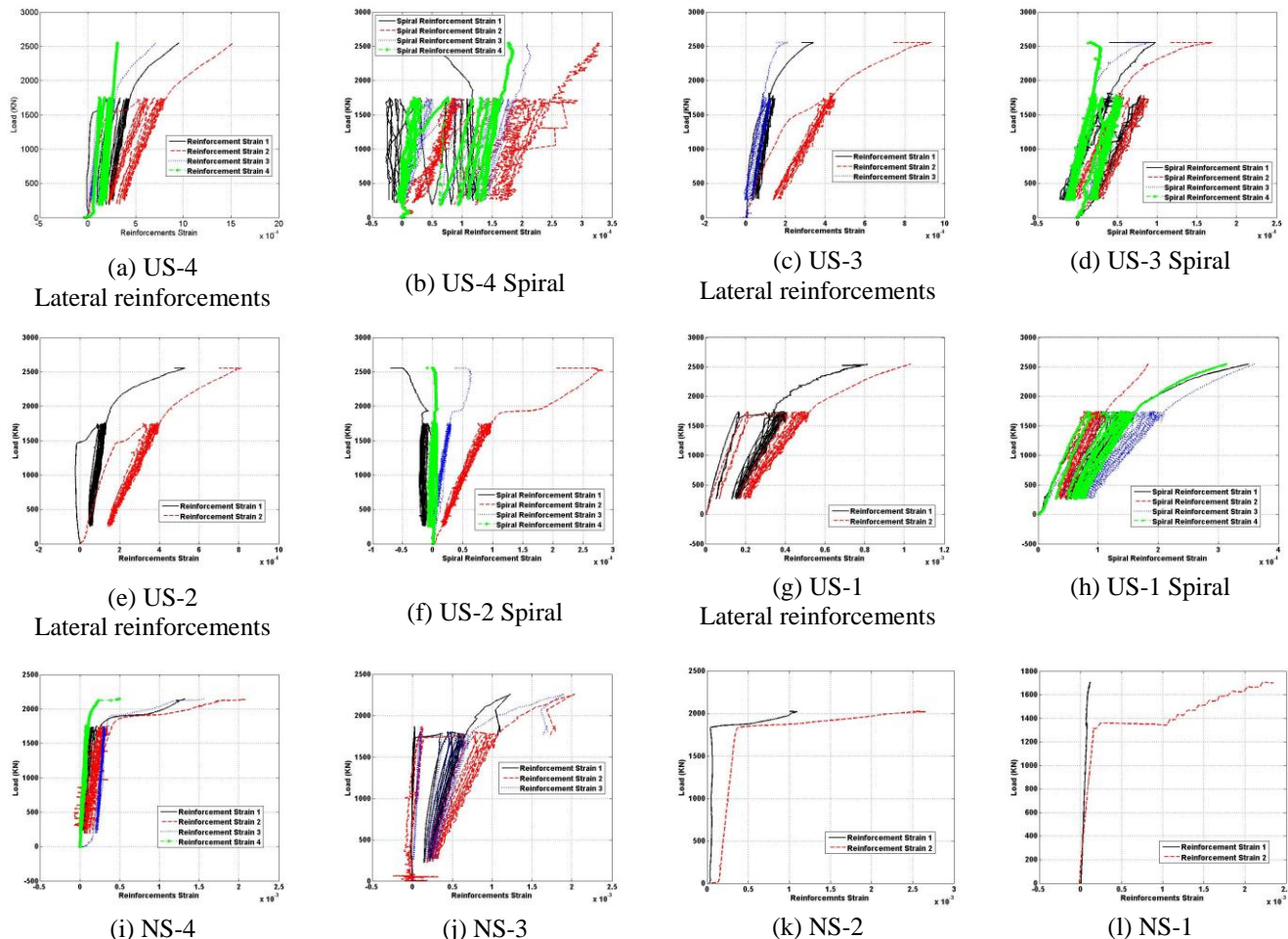


Fig. 7 Load-reinforcements stress relations

The NS specimen's reinforcements yielded, but the US specimen's reinforcements did not yield as shown in the load-reinforcements stress relationship in fig. 7. However, the US-4 of the US specimens showed the largest stress in the lateral reinforcements. The reason for this is that the lateral reinforcements of US-1 and US-4 burdened more than the other specimens due to cracks in the gauge attachment area.

TABLE VI: Reinforcements Stresses and Loads

Specimen	Final Load(KN)	Stresses(MPa)
US-4	2556	Lateral reinforcements: 306, Spiral: 65.8
US-3	2556	Lateral reinforcements: 186.8, Spiral: 33.8
US-2	2556	Lateral reinforcements: 162.2, Spiral: 56.6
US-1	2551.4	Lateral reinforcements: 206, Spiral: 72
NS-4	2147.2	400 (Yielded)
NS-3	2266.3	400 (Yielded)
NS-2	2029	400 (Yielded)
NS-1	1708	400 (Yielded)

From the experimental results, it is expected that the US specimen can be loaded greater than $1.23F_{pk}$, which may suggest the simplification of lateral reinforcements. NS specimens showed that NS-1 and NS-2 resisted higher than expected and NS-3 and NS-4 met the strain stabilization conditions of ETAG013, it might can be the basis of removal of spiral reinforcement, but reinforcing should be stronger than those given in [4].

5. Verification of highway bridge design code

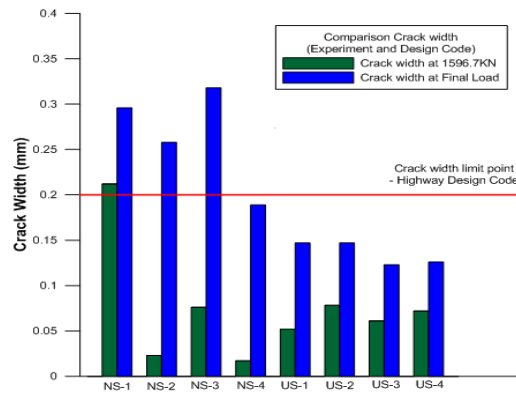
In this study, the crack widths and reinforcements stress for various load steps are compared with those specified in Korea Highway Bridge Design Code. TABLE VII is the limitation of the cracks and reinforcements stress specified in [4].

TABLE VII: Load, Crack and Reinforcements Limit [4]

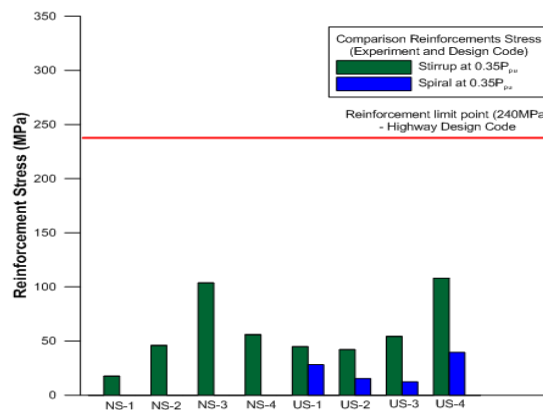
Case	Limit Condition	
Crack (PS Strand)	Dry Condition	Max. (0.2mm or $0.005t_c$)
	Wet Condition	Max. (0.2mm or $0.004t_c$)
Reinforcements Stress	Min. ($0.6f_y$ or 250MPa) at $0.35P_{pu}$	
Load	Min. ($0.8F_{pu}$ or $0.9f_{py}$)	

Where, t_c is the minimum cover thickness between outer concrete surface and reinforcements surface of the outermost, and f_y is the yield stress of reinforcements. The yield stress of reinforcements applied to this experiment is 400MPa and the limiting stress of reinforcements proposed in [4] is 240MPa. P_{pu} is the maximum load considering the number of strands used and is the same value as F_{pk} . F_{pu} is the tensile strength of the tendon(MPa), and f_{py} is the yield stress of tendon(MPa).

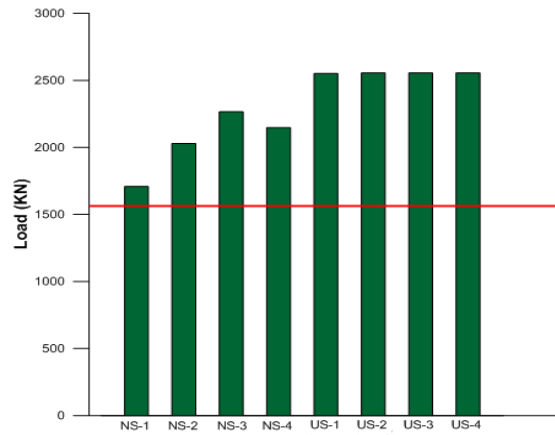
To meet the specified criteria in TABLE VII, the crack width must be 0.2mm when the cover thickness of lateral reinforcements was applied 20mm. The reinforcements stress limit is 240MPa and load limit is $0.9f_{py}$, each comparative graph is shown in Fig. 8.



(a) Crack widths



(b) Reinforcement stresses



(c) Loads

Fig. 8 Comparison experiment results and design code

In the comparison of the crack widths, the crack width tends to be considerably less than 0.2mm at the load point $0.9f_{py}$ except for the NS-1 specimen. At the final loads, the measured crack widths of each specimen were less than 0.2mm except NS-1, NS-2 and NS-3 specimens. Also, in the case of the reinforcements stress, a considerable margin was left at $0.35P_{pu}$, and the load is higher than the 2010 Korea Highway Bridge Design Code's load limitation. From the results, it can be concluded that post-tensioned anchorage zones using 100MPa high strength concrete is significantly underestimated when design code is applied. Therefore, it is necessary to apply the new design criteria for the post-tensioned anchorage zones using high strength concrete.

6. Conclusions

In this study, the behaviors of post-tensioned anchorage zones using 100MPa high strength concrete was examined through the evaluation of crack widths and reinforcements stress, and compared with 2010 Korea Highway Bridge Design Code.

- In the NS-3 specimen, it was possible to remove the spiral reinforcement, but a somewhat stronger reinforcing was required than those given by the Korean Design Code. And it was confirmed that the lateral reinforcements reinforcing can be simplified through the US specimens.
- The load test results of all specimens had a considerable margin to those specified in the Code. Especially, NS-1 specimen showed that more than $0.9f_{py}$ load limit, so it is necessary to make a new test procedure for post-tensioned anchorage zones using high strength concrete.

The crack widths and reinforcements stresses from this experiments show a considerable difference to those in current Code. It is suggested that the criteria for reinforcements stress, reinforcements spacing design and crack widths of the post-tensioned anchorage zones using high strength concrete should be newly regulated.

7. References

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