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Prestress Loss Analysis on Prestressed Simply Supported Beams under the Action of Natural Freezing-thawing Cycles

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Abstract. Under the action of natural freezing-thawing cycles, static force loading and fatigue loading tests on four simply supported beams were conducted. Various indexes of the beams such as stress, deflection and crack at each stage of loading were recorded; a comparative analysis on prestress loss of the beams was conducted, based on which a formula of relationship between freezing-thawing and prestress loss under fatigue loading was established.

1. Introduction

How to determine the value of prestress loss under the combined action of freezing-thawing cycle and fatigue in severe cold regions is an important question in design and test of prestressed concrete structures. During the past decade, a large quantity of experimental researches and analyses were conducted by researchers from various countries, through which some approximation algorithms for calculation of pre-stress loss were put forward.

In Researches [1-4], the rule of change of damage variables was studied and an evolution equation for concrete damage after freezing-thawing cycles was established; in addition, the impact of damage threshold on the constitutive model of freezing-thawing damage in concrete was discussed, and a fatigue equation of concrete with freezing-thawing damage was established. In Researches [5-8], various factors influencing cohesive action between reinforcing bars and concrete in prestressed concrete members were analyzed, and models for calculation of prestress loss of prestressed concrete members under different conditions were discussed.

In this experiment, freezing-thawing tests on concrete members were conducted under natural conditions in north China, which laid a foundation for damage test and health assessment on concrete members under natural freezing-thawing conditions.

2. Experiment Design

2.1 Design of Test Pieces

Four members were made, on which prestress was applied with the post-tensioning method. Corrugated steel tubes were used, and the tension control stress under anchorage shall be 1260Pa. See Table 1 and Figure 1 for detailed information.
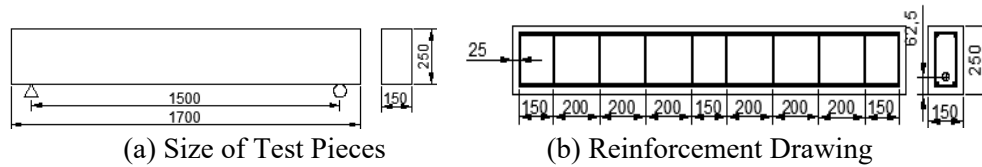
(a) Size of Test Pieces   (b) Reinforcement Drawing

Figure 1   Size of Test Piece & Reinforcement Drawing

2.2 Loading Method Design

Test pieces were numbered as P1, P2, P3, P4 based on different loading methods. See the following table for the specific loading conditions:

Table 1 . Table of Reinforcement & Loading of Test Pieces

Test Piece No.	P1	P2	P3	P4
Size	150×250	150×250	150×250	150×250
Concrete Grade	C40	C40	C40	C40
Tensile Longitudinal Bar at the Bottom	2 ϕ 12	2 ϕ 12	2 ϕ 12	2 ϕ 12
Constructional Reinforcing Bar on the Top	2 ϕ 10	2 ϕ 10	2 ϕ 10	2 ϕ 10
Stirrup	Φ8@150	Φ8@150	Φ8@150	Φ8@150
Prestressed Steel Strand	7ψ5	7ψ5	7ψ5	7ψ5
Number of Freezing-thawing Cycles	0	0	100	200
Loading Method	Static Force	Fatigue	Fatigue	Fatigue

2.3 Loading Device

A hydraulic jack was used for static force loading (Figure 2); a static resistance strain indicator was used for measurement of concrete strain and reinforcing bar strain; a dial indicator was used for measurement of deflection. A PA-100 electro-hydraulic Servo-based dynamic and static fatigue testing machine was used for dynamic force loading (Figure 3).

Figure 2 Hydraulic Jack-based Static Force Loading Device

Figure 3 PA-100 Electro-hydraulic Servo-based Dynamic and Static Fatigue Testing Machine

3. Experimental Data

3.1 Experimental Phenomenon of P1

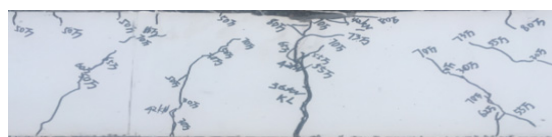Figure 4 Image of Cracks on Test Piece P1

Figure 5 Image of Cracks on Test Piece P2

During the process of loading, development of cracks on the test piece is shown in Figure 4 and Figure 5. When the load was within a range from 0 to 45KN, no crack showed on P1; the test beam was at the

elastic stage and the mid-span deflection curve showed approximately linear variation. When the load reached 45KN, three minor cracks showed on the concrete in the tensile area of the test beam, after which its stiffness decreased. With increase in load, generation of new cracks and upward extension of the old cracks, its stiffness further decreased. When load reached 120KN, width of the bottom of the major mid-span crack on the test beam reached 1.5mm, and loading was finished at this moment. Figure 6 shows that with increase in load, strain change of concrete in the middle of the test beam span at the height of the section conforms to the plane-section assumption.
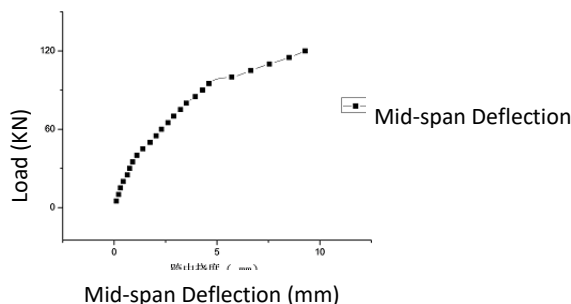

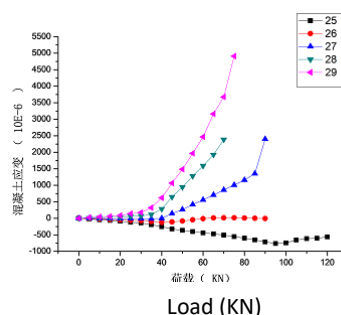Figure 6 Load-Mid-span Deflection Curve of P1

Figure 7 Mid-span Concrete Strain Curve of P1 along Height of Section

3.2 Experimental Phenomenon of P2
When the number of cycles of loading was within the range from 0 to 200,000, the upper limit of load was relatively small and didn't reach the cracking load. When the sine wave load peak reached 39KN and the number of cycles of fatigue loading reached 500,000, two symmetrical inclined cracks showed in the area at a distance of 1/3 from the mid-span point. When the number of cycles of fatigue loading reached 550,000, several minor cracks showed at the edge of the compressed area and developed continuously with increase in load amplitude and number of cycles. When the number of cycles of loading reached 800,000, the test beam yielded and its displacement increased continuously with the load unchanged. At this moment, the test beam was damaged (Figure 7).

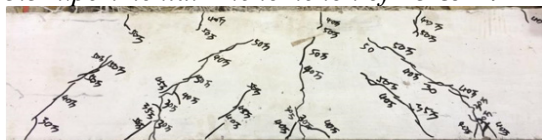*3.3 Experimental Phenomenon of P3 & P4*

Figure 8 Image of Cracks on Test Beam P3 Due to Fatigue Loading

Figure 9 Image of Cracks on Test Beam P4 Due to Fatigue Loading

It can be seen in Figure 8.9 that minor cracks showed on Test Beams P3 and P4 when the number of cycles of fatigue loading reached 300,000, and the corresponding load value was 30kN. Development of cracks was similar to that of P2. P3 entered the stage of yield when the number of cycles of fatigue loading reached 500,000; P4 yielded when the number of cycles of fatigue loading reached 400,000.

4. Calculation of Prestress Loss of Members at the Time of Cracking
The formula for calculation of the relationship between cracking stress and prestress on structural concrete in P1:

$$\sigma_{con} - \sigma_l + f_t = \frac{M}{W} \qquad (1)$$

The formula for calculation of the relationship between cracking stress and prestress on structural concrete in P2, P3 and P4:

$$\sigma_{con} - \sigma_l + \gamma_\rho f_t = \sigma_1 \qquad (2)$$

Where, σ_1 -- the stress value measured at the mid-span point at the time of cracking.

It can be seen in that for members subject to no freezing-thawing cycle, fatigue loading has a relatively big impact on prestress loss of prestressed beams, and prestress loss increased by 3.7% in this experiment. When fatigue loading was applied, freezing-thawing cycles increased prestress loss of members. After 100 freezing-thawing cycles, prestress loss increased by 1.2%; after 200 freezing-thawing cycles, prestress loss increased by 2.3% (Figure 10).
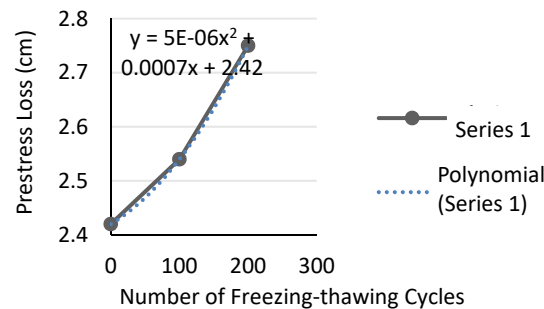

Figure 10 Curve of Relationship between Freezing-thawing and Prestress Loss under Fatigue Loading

Other prestress losses should be subtracted, and at the time of cracking, the relationship between number of freezing-thawing cycles and prestress loss under fatigue loading can be represented by the following curve:

$$\sigma_{ldp} = 5E^{-0.6n^2} + 0.0008n \tag{3}$$

The last item with a relatively small impact is neglected, and then Formula (3) can be represented as:

$$\sigma_{ldp} = 5E^{-0.6n^2} \tag{4}$$

Where: σ_{ldp} -- prestress loss of prestressed concrete beams under fatigue loading at the time of concrete cracking. n -- number of freezing-thawing cycles.

5. Conclusions

1. For members subject to no freezing-thawing cycle (P1, P2), fatigue loading increased the cracking load of prestressed beams, decreased their stiffness during the stage when they had cracks, decreased their yielding load and increased prestress loss;

2. Under the combined action of freezing-thawing cycles and fatigue loading, freezing-thawing cycles decreased cracking load and yielding load and increased prestress loss. After 100 freezing-thawing cycles, prestress loss increased by 1.2%; after 200 freezing-thawing cycles, prestress loss increased by 2.3%;

3. A formula of relationship between number of freezing-thawing cycles and prestress loss under fatigue loading at the time of cracking was established;

Acknowledgments

References

[1]   Guan Xiao, Niu Ditao, Wang Jiabin, Jiang Lei. Research on constitutive model of freezing-thawing damage in concrete with consideration of plastic strain & damage threshold[J]. Journal of Disaster Prevention and Mitigation Engineering, 2015, 35(06): 777-784.

[2]   Zhang Yiduo, Xu Lulu, Liu Ronggui, Liu Tao. Research on damage in prestressed concrete beam under the alternate action of freezing-thawing cycles and fatigue loading[J]. Industrial Construction, 2013, 43(04): 57-61.

[3]   Hong Jinxiang, Miao Changwen, Huang Wei, Liu Jiaping, Wan Yun. Impact of freezing-thawing damage on fatigue property of concrete[J]. China Civil Engineering Journal, 2012,45(06): 83-89.

[4]   Wang Xin. Numerical simulation and reliability research on fatigue of prestressed bending concrete members in freezing-thawing environment[D]. Jiangsu University of Science and Technology, 2017.

[5]   Aidas Jokūbaitis,Juozas Valivonis,Adomas Zubrus. The influence of prestress losses on the anchorage zone of prestressed concrete member[J]. Engineering Structures and Technologies, 2014.

[6]   Tong Guo, Zheheng Chen, Shuo Lu, Ruigen Yao. Monitoring and analysis of long-term prestress losses in post-tensioned concrete beams[J]. Measurement, 2018,122.

[7]   Fengtao Bai, James S. Davidson. Composite beam theory for pretensioned concrete structures with solutions to transfer length and immediate prestress losses[J]. Engineering Structures,2016.

[8]   S. Biswal, A. Ramaswamy. Uncertainty based model averaging for prediction of long-time prestress losses in concrete structures[J]. Construction and Building Materials,2017.