

Using External Prestressing to Enhance the Safety Performance of Existing Public Buildings

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Abstract—To use external prestressing to enhance the existing public buildings suffering from loss of reliability, this paper represents the static tests on 14 low strength concrete beams reinforced by external pre-stressed, and demonstrates an experiment on the mechanical performance of model beam, such as flexural bearing capacity of normal side, rigidity and crack. The result of experimental study shows that it is feasible and significant to spread the application of external prestressing to enhance the reliability of existing public buildings.

Keywords—low strength concrete; external pre-stressing; static test; reliability

I. INTRODUCTION

In China, a considerable amount of existing buildings have been suffering from loss of reliability, because of natural disasters or the change of their own environment, and they need to be strengthened. External pre-stressing is one of the strengthening techniques, which can improve the stiffness of the structure, so as to improve the reliability of structure.

Tongji University conducted the experiment on 14 low strength concrete beams with two kinds structure to prove that using external prestressing to enhance the reliability of existing public buildings is a good method.

II. SPECIMEN DESIGN AND TEST METHOD

The test was conducted with placing a distributing girder on the span in the middle of the test beam, and applying concentrated force to the distributing girder by using loading device in order to load the test beam at two points. There are two kinds of span in the continuous beam, which is 4.2m and 2.8m respectively. The long span was loaded at the point of 1/3, and the short one was loaded in the middle.

And a resistance strain gauge was pasted in the middle of longitudinal bar's specimen to measure the variation of reinforcement stresses during loading; along with a displacement meter putting at the side of beam span to measure the strain distributing law of concrete in the side beam surface along the height of section, so that to obtain the average curvature in the beam span. Furthermore, a displacement meters were placed in the support and pure bending in the middle span separately to measure the deflection in both two ends and the middle of the span.

The crack examination was conducted by painting the two sides of span with whitewash before experiment, and drawn a 50×50mm grid. During requirement experiment, crack could be discovered with naked eyes by using magnifier. Later, after crack occurred, it enable to examine the progress for crack immediately using the tool like electric crack measurement to measure the width of crack under different loading levels until the steel strain exceeds 1800 $\mu\epsilon$ that is the time to stop.

TABLE I. ACTUAL SITUATION OF SPECIMEN

Specimen No.	f_{cu}	$b \times h \times L$ (mm)	Pre-stressed Reinforcement	Longitudinal Tensile Reinforcement ①	Erection bar ②	Stirrup ③	Reinforce ment Ratio(ρ)	Tension control of effective stress
L1-1	31.44	250×500×4800	2As15.2	2 Φ 20	2 Φ 16	Φ 12@80/200	0.50	0.65 f_{ptk}
L1-2	40.07	250×500×4800	2As15.2	2 Φ 20	2 Φ 16	Φ 12@80/200	0.50	0.55 f_{ptk}

TABLE I. ACTUAL SITUATION OF SPECIMEN (CONT.)

Specimen No.	f_{cu}	$b \times h \times L$ (mm)	Pre-stressed Reinforcement	Longitudinal Tensile Reinforcement ①	Erection bar ②	Stirrup ③	Reinforce ment Ratio(ρ)(%)	Tension control of effective stress
L2-1	31.44	250×500×4800	2As15.2	3 Φ 20	2 Φ 16	Φ 12@80/200	0.75	$0.53f_{ptk}$
L2-2	40.07	250×500×4800	2As15.2	3 Φ 20	2 Φ 16	Φ 12@80/200	0.75	$0.52f_{ptk}$
L3-1	31.44	250×500×4800	2As15.2	2 Φ 20	2 Φ 16	Φ 12@80/200	0.50	$0.43f_{ptk}$
L3-2	40.07	250×500×4800	2As15.2	3 Φ 20	2 Φ 16	Φ 12@80/200	0.75	$0.43f_{ptk}$
B1-1	16.04	250×450×4500	2As15.2	3 Φ 25	2 Φ 16	Φ 12@80/200	1.31	$0.45f_{ptk}$
B1-2	35.32	250×450×4500	2As15.2	3 Φ 25	2 Φ 16	Φ 12@80/200	1.31	$0.48f_{ptk}$
B2-1	16.04	250×450×4500	2As15.2	2 Φ 25	2 Φ 20	Φ 12@80/200	0.87	$0.51f_{ptk}$
B2-2	35.32	250×450×4500	2As15.2	2 Φ 25	2 Φ 20	Φ 12@80/200	0.87	$0.45f_{ptk}$
T3-1	16.04	250×450×4500	2As15.2	3 Φ 25	2 Φ 16	Φ 12@80/200	1.08	$0.49f_{ptk}$
T3-2	35.32	250×450×4500	2As15.2	3 Φ 25	2 Φ 16	Φ 12@80/200	1.08	$0.48f_{ptk}$
B4-1	16.04	250×400×7000	2As15.2	2 Φ 20	2 Φ 16	Φ 12@80/200	0.63	$0.41f_{ptk}$
B4-2	35.32	250×400×7000	2As15.2	2 Φ 20	2 Φ 16	Φ 12@80/200	0.63	$0.48f_{ptk}$

Beam T3-1, T3-2 is T-section; average width of compressed flange is 550mm; height of compressed flange is 80mm; Usually dispose II- Stirrup 8@200 and construction longitudinal bar 2 16 in flange

III. EXPERIMENT PROCEDURES AND PHENOMENAG

A. Experiment Procedures and Phenomena for Rectangular Simply-supported Beam

There are 10 rectangular simply supported beams, and their loading procedures are similar. Because of different concrete strength and reinforcement, their experiment phenomena are roughly analogous without significant difference. Fig.1 shows the load-deflection curve of rectangular simply-supported test beam L2-1.

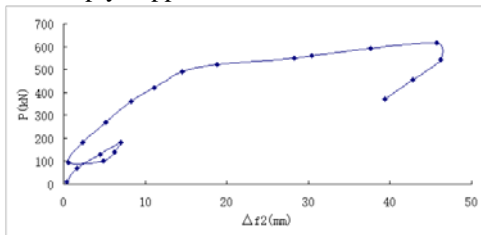
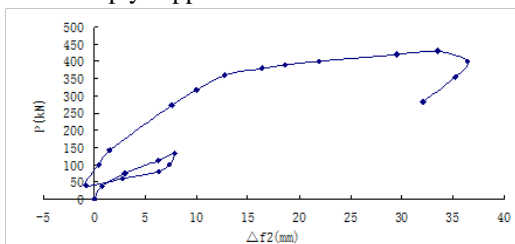


Figure 1. Load deflection curve for Test beam L2-1

B. Experiment procedure and phenomena for simply supported T-beams

There are two simply supported T-beams designed in this experiment, the loading system is same with the previous rectangular simply supported beam. However, the phenomenon was different. Fig.4 shows the load-deflection curve of the simply supported T-beam T3-2.



C. Experiment Procedure and Phenomenon for Continuous Beam

After that, we also designed 2 continuous beams in this experiment. By loading the short span and the long span simultaneously, even the loading principle was the same with the simply supported beam, but the phenomenon varied significantly. Fig.3 and Fig.4 display the load-deflection curve for the long span and the short span of rectangular continuous beamB4-1.

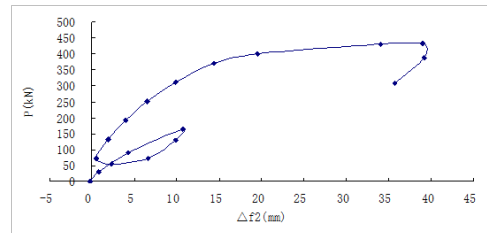


Figure 3. Load-deflection curve for test beamB4-1 (long span)

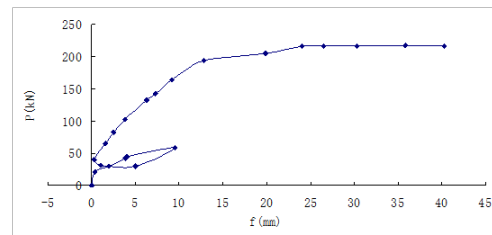


Figure 4. Load-deflection curve for test beamB4-1(short span)

IV. ANALYSIS OF EXPERIMENT RESULT

As was stated above, the following factors have been considered for the beam testing: concrete strength, section types (rectangle and T-shaped), non-pre-stressed

reinforcement ratio and loading system. The impact is mainly on the aspects such as bearing capacity, rigidity, and deflection, crack and so on. When grouped comparing the impactions of these factors, one factor can be treated as variable, while the others being constant.

A. Effect of Concrete Strength

Define abbreviations and acronyms the first time they are used in the text, even after they have been defined in the abstract. Do not use abbreviations in the title or heads unless they are unavoidable.

There are 4 levels of concrete strength for the beam testing, whose standard value for the cube compressive strength is 16.04MPa, 31.44MPa, 35.32MPa and 40.07MPa respectively. Through the comparison for 6 groups of beam (L1-1 VS L1-2, L2-1 VS L2-2, B1-1 VS B1-2, B2-1 VS B2-

2, T3-1 VS T3-2 and B4-1 VS B4-2), it can reflect that the variation of concrete strength has influence on the flexural property listing in Table 2-3for details.

From the application of external pre-stressing on the low strength concrete beam, the lowest compressive strength for the testing beam's concrete axis is 16.04MPa. After strengthening with external pre-stressing, the flexural property can be improved, especially on the bearing capacity. From the comparisons from Group 3 to Group 6 shown, the difference of bearing capacity between the low strong concrete beam (strengthened by external pre-stressing) and 35MPa concrete beam is around 10%. Hence, the external pre-stressing method can be used to strength a low strong concrete beam with an evident strengthening effect.

TABLE II. FLEXURAL PROPERTY OF TEST BEAM (STRENGTH)

Flexural property	Comparison for Group1			Comparison for Group2			Comparison for Group3		
	L1-1	L1-2	Ratio	L2-1	L2-2	Ratio	B1-1	B1-2	Ratio
f_{cu} (MPa)	31.44	40.07	1.27	31.44	40.07	1.27	16.04	35.32	2.20
A_s (mm^2)	628	628	1.00	942	942	1.00	1472	1472	1.00
P_u (kN)	437	400	0.92	432	476	1.10	425	579	1.36
Deflection f(mm)	27.25	48.84	1.79	33.54	23.40	0.70	13.94	21.20	1.52
B_s^T ($10^3 kN \cdot m$)	10.28	6.96	0.68	9.84	8.19	0.83	50.92	45.48	0.89
ω_{max}^T (mm)	0.18	0.36	2.00	0.32	0.30	0.94	0.22	0.18	0.82

TABLE III. FLEXURAL PROPERTY OF TEST BEAM (STRENGTH)

Flexural property	Comparison for Group4			Comparison for Group5			Comparison for Group6		
	B2-1	B2-2	Ratio	T3-1	T3-2	Ratio	B4-1	B4-2	Ratio
f_{cu} (MPa)	16.04	35.32	2.20	16.04	35.32	2.20	16.04	35.32	2.20
A_s (mm^2)	981	981	1.00	1472	1472	1.00	628	628	1.00
P_u (kN)	412	468	1.14	518	615	1.19	430	470	1.09
Deflection f(mm)	14.45	26.59	1.84	15.92	30.44	1.91	15.20	17.80	1.17
B_s^T ($10^3 kN \cdot m$)	34.33	17.58	0.51	95.35	21.90	0.23	47.37	29.24	0.62
ω_{max}^T (mm)	0.26	0.31	1.19	0.19	0.26	1.37	0.22	0.24	1.09

Notes: Comparing with data between short-term rigidity and short term crack width which is under $0.8f_u$ loading level, the third column is the ratio of the former one and the latter one. A_s is the Area of non pre-stressed tensile reinforcement, f is deflection in the middle of the span, B_s^T is the rigity, ω_{max}^T is maximum Crack width and P_u is bearing capacity.

B. Effect for Section Types of Concrete Beam

The impaction of section type mainly exists in the difference between T-shaped section and rectangular section, e.g. test beam B2-1 VS T3-1, B2-2 VS T3-2 showing in

Table 3 From the data demonstrated, the bearing capacity of T-shaped section is increased by 30% than rectangular section, as well as the short term rigidity is improved by 25%-178%, even with the same reinforcement, concrete strength and section size. So the influence of T-shaped

section strengthened by external pre-stressing is much better than the one of rectangular section.

C. Effect for Non Pre-stressing Tensile Reinforcement Ratio

TABLE IV. COMPARISON FOR FLEXURAL PROPERTY OF TEST BEAM (NON PRE-STRESSING TENSILE REINFORCEMENT RATIO)

Flexural property	Comparison for Group7			Comparison for Group8			Comparison for Group9			Comparison for Group10		
	L1-1	L2-1	Ratio	L1-2	L2-2	Ratio	B1-1	B2-1	Ratio	B1-2	B2-2	Ratio
f_{cu} (MPa)	31.44	34.44	40.00	40.07	40.00	1.00	16.04	16.04	1.00	35.32	35.32	1.00
A_s (mm ²)	628	942	1.5	628	942	1.5	1472	981	1.50	1472	981	1.50
P_u (kN)	437	432	0.99	400	476	1.19	425	412	1.03	579	468	1.24
Deflection f(mm)	27.25	33.54	1.23	48.84	23.4	0.48	13.94	14.45	0.96	21.20	26.59	0.80
B_s^T (10 ³ kN·m)	102.79	98.14	0.95	69.61	81.92	1.18	50.92	34.33	1.48	45.48	17.58	2.59
ω_{max}^T (mm)	0.18	0.32	1.78	0.36	0.30	0.86	0.22	0.26	0.85	0.18	0.31	0.58

The outcome of the non pre-stressing tensile reinforcement ratio is mainly presented in the comparison of these 4 groups (L1-1 VS L2-1, L1-2 VS L2-2, B1-1 VS B2-1, B1-2 VS B2-2) in Table 4. From the experimental data shown in tables, when the section sizes are same, there are growths in the tensile reinforcement, the bearing capacity, the short-term rigidity and maximum width of crack with 50%, 10%-20%, 20%-150% and 15%-40% respectively. So the increasing amount of non-pre-stressing reinforcement has great effect on the flexural property of external pre-stressing concrete beam.

D. Some Effect of Loading System

TABLE V. COMPARISON FOR FLEXURAL PROPERTY OF TEST BEAM (LOADING SYSTEM)

Flexural property	Comparison for Group11			Comparison for Group12		
	L1-1	L3-1	Ratio	L2-2	L3-2	Ratio
f_{cu} (Mpa)	16.04	16.04	1.00	35.32	35.32	1.00
A_s (mm ²)	1472	981	1.50	1472	981	1.50
P_u (kN)	425	412	1.03	579	468	1.24
f (mm)	13.94	14.45	0.96	21.20	26.59	0.80
B_s^T	50.92	34.33	1.48	45.48	17.58	2.59
sequence of pre-stressed concrete	Later	First		Later	First	

There are two kinds of loading systems: one is the load-unload-pre-tensioned steel strand-load and the other is pre-tensioned steel strand - load. The effect of loading system is mainly on the comparison of testing beams (L1-1 VS L3-1 and L2-2 VS L3-2) in Table 5. From the date shown in the table, the difference of bearing capacity between these two loading systems is less than 10% under the same condition. Besides the tensioned control of effective stress causes low bearing capacity. Also test beams are close to each other in bearing capacity under these two loading systems, therefore

two systems have little impact on the bearing capacity of test beams. However, the deflection of the latter loading system is larger by 50%-110% than the former one, thus two loading systems have too much effect on the deflection of test beam.

TABLE VI. COMPARISON FOR FLEXURAL PROPERTY OF TEST BEAM (STRUCTURE)

Flexural property	Comparison for Group13			Comparison for Group14		
	B1-1	B4-1	Ratio	B1-2	B4-2	Ratio
f_{cu} (Mpa)	16.04	16.04	1.00	35.32	35.32	1.00
A_s (mm ²)	1472	981	1.50	1472	981	1.50
P_u (kN)	425	412	1.03	579	468	1.24
Support type	s	c		s	c	

S- simply supported beam C- continuous beam

E. Effect of Structure

There are two kinds of structures: one is the simply supported beam and the other is the continuous beam. The testing results for comparison are B1-1 VS B4-1 and B1-2 VS B4-2 listed in Table 6. From the data shown in the table, after the external pre-tensioned stress reinforces the simply supported beam, its reinforcement ratio and size is larger than that of continuous beam, but with a 5% less bearing capacity. As a result, the effect on continuous beam reinforced by the external pre-tensioned stress is better than the simply supported beam in the aspect of bearing capacity.

V. CONCLUSION

Based on the following experiments, it can come to the conclusion as below:

After low strength concrete beam is strengthened by the external pre-tensioned stress, its flexural properties (such as bearing capacity, rigidity, crack and so on) are improved dramatically. For example, bearing capacity is 2-3 times higher than before. So that it can resolve the problem caused by the insufficient bearing capacity, which cannot meet related requirements. Applying external pre-stressing can

make component counter-vault, thus reducing the probability of deformation. In addition, it can also avoid the problem of excessive deformation, and make the concrete tensile region produce the pre-pressure so that increasing the cracking load for beams, postponing the appearance of cracks as well as improving the component's usability:

(1) Bearing capacity

Factors of the concrete rigidity, the non-pre-stressed tensile reinforcement ratio, section type and structure all have impacts on the effect of external pre-stressing; the section type has the most obvious impact. The bearing capacity for T-beam is 26%-31% higher than that for rectangular beam even under the same situation. Next comes to the effect of concrete strength, if the concrete strength is increased by 120%, the bearing capacity will improve by 10%-20%.

(2) Rigidity

For the rigidity of external pre-stressing concrete, both the section format and the non-pre-tensioned stress tensile reinforcement ratio are the major elements, and then is the concrete strength.

(3) Crack

As for crack, the concrete strength, the section type and the tensile reinforcement affect more, while the effect of structure impacts slightly.

As a result, it is effective to use the external pre-stressing technology to improve the the reliability of existing public buildings.

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REFERENCES

- [1] Li Yanhe. (2008) Theory and Application of effective strengthening prestressed method, Science Press.
- [2] Li Yanhe. and Chen Gui. (1998) Study on pretensioned stress strengthened method design Computing Method.Construction Quality Supervision, 1998, (2):21~29.
- [3] Xiong Xueyu, Lei Liying and Gu Wei. (1998) Assessment of pretensioned stress loss for external pretensioned stress, structure industrial architecture, 2004, 34(7):16~19.
- [4] Wang Hongju. (2010) Experimental study and analysis on concrete beam strengthened by external prestressing: Master Dissertation. Shanghai: Tongji University.