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Relations between Structural Damage and Level of External Prestressing Force on the Flexural Behavior of Post-Tensioned Prestressed Concrete Beams

Thananun Phuwadolpaisarn [a], **Sayan Sirimontree** [a*], **and Boonsap Witchayangkoon** [a]

[a] *Department of Civil Engineering Faculty of Engineering, Thammasat University, THAILAND*

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ABSTRACT

Prestressed concrete beams can be damaged by overloading beyond cracking stage leading to the reduction of flexural rigidity and excessive deflection. The progressive of damage, crack and permanent deflection can be occurred at the high level of load after cracking. Structural performance of damaged girder can be recovered and improved by external post tension. The level of external prestressing force required in strengthening depends directly on the level of damage due to overloading. This research studied the effect of levels of damage on flexural rigidity, crack and deflection of the test girder. Three levels of damage can be expressed in terms of 0.65, 0.75 and 0.85 times the predicted ultimate load of the test beam. Three levels of external prestressing forces (2, 2.5 and 3 times of the internal prestressing force applied in undamaged reference beam) are applied in strengthening at each level of damage. The results show that reduced flexural rigidity, increased permanent deformation and crack width due to overloading can be recovered by external post tension. Strengthening by means of external post tension can be effectively applied to the damaged beam at the level of damage not more than 0.65 times of predicted ultimate load.

1. Introduction

Concrete beam has been widely used in the long span bridge structure as prestressed

*Corresponding author (S.Sirimontree). Tel/Fax: +66-2-5643008 Ext 3112 E-mail address: ssayan@engr.tu.ac.th

concrete (PC) is designed uncrack section under applied load. This makes deflection and cross-sectional area less than reinforced concrete (RC) beams. However, when the applied load exceeds uncrack load, PC beam behavior becomes similar to RC beam with increased deflection. In addition, enlarged crack-widths cause reinforced steels to grow rusty. As a result, flexural rigidity is reduced. Such increasing crack and higher deflection make the beam unsuitable for use anymore. Strengthening the deteriorated beam by external prestressing can help reduce the crack and deflection. Flexural rigidity should be increased such that it makes the beam to serve its regular job. In addition, beam flexural moment capacity is higher at the ultimate state. The level of external prestressing force is correlated with the damaged level of the flexural rigidity of concrete post-tension system.

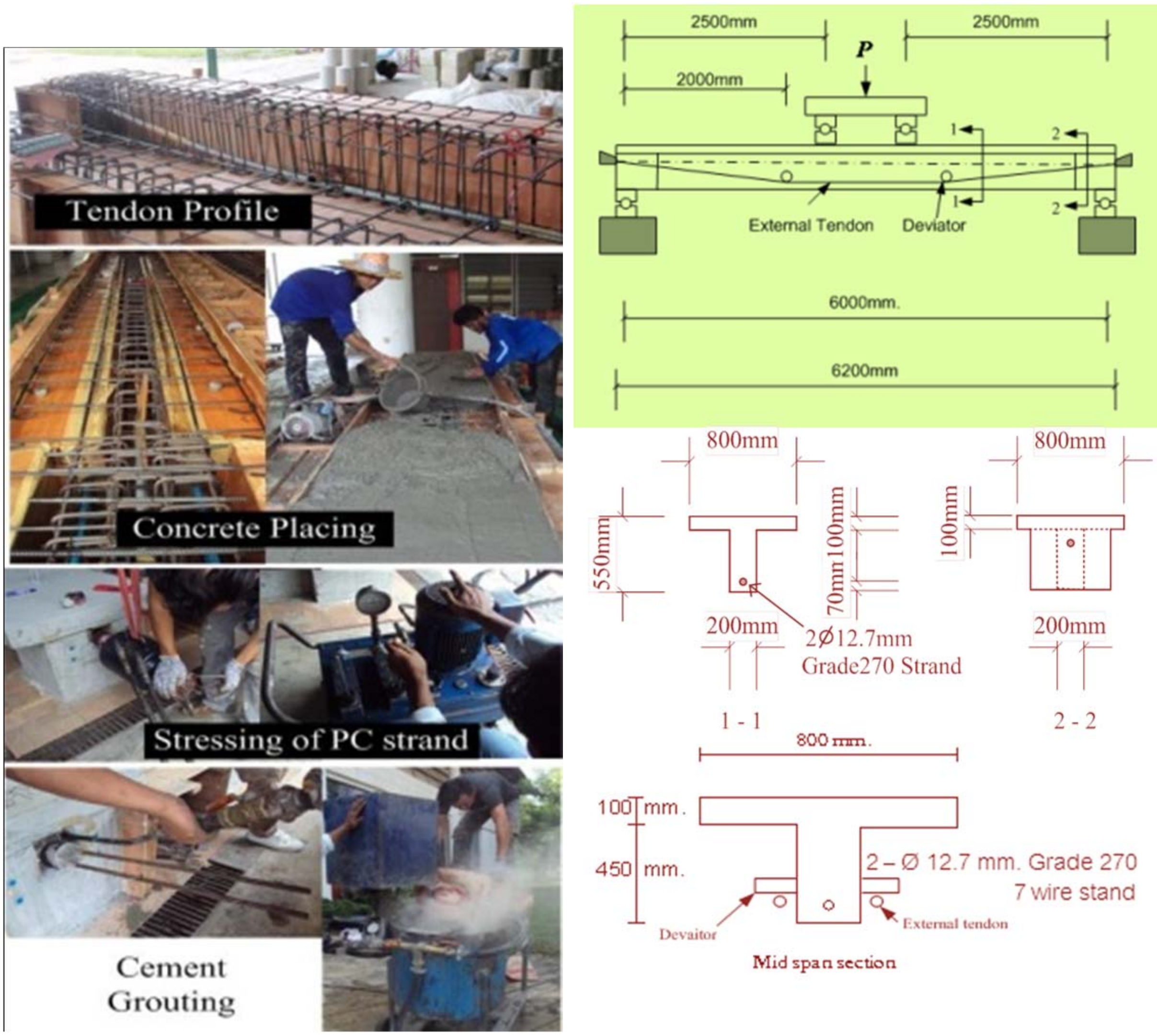

Figure 1: Casting and Details of tested PC-beam specimen.

This research studied the effect of external prestressing force on the flexural behavior of damaged prestressed concrete beams under cyclic static loading. This work focuses flexural behavior in terms of flexural rigidity, cracks, deflection, and flexural moment capacity. We test the beam with overloading 0.65, 0.75 and 0.85 times the predicted ultimate load. At each overloading level, varied strengthening with external prestress is executed.

2. Method

2.1 Test Bean Design

PC T-beam has been built having length 6m, depth 0.55m, flange width 0.8m, and thickness 0.1m. Concrete strength (f_c') is 35Mpa. This beam is installed with two prestressing strands grade 270 (f_{pu} 1860Mpa), each with diameter 12.7mm. The strands are placed with parabola shape as shown in Figure 1.

The beam has been predesigned to have enough shear reinforcement steel to prevent shear failure. PC strands were stressed to $0.75f_{pu}$ at transfer stage. Cement grouting is filled into the steel duct to bond the strands to surrounding concrete.

2.2 Loading Setup

Static loading and unloading is performed in testing process. Load is applied using hydraulic hand pump. Two-point loading is set up through the use of transfer beam. Distance between two-point loading is 2.5m. This setup makes zero shear between two-point loading, thus moment effect can be fully observed.

2.3 Instrumental Setup

Applied load can be measured by load cell. Dial gauges and displacement transducers are installed throughout beneath the beam to measure deflection. Strain gauges are installed at top and bottom longitudinal steels and both side concrete surface of tested beam. Measured data are monitored by data logger and recorded in the computer system. Cracks are visually observed and marked.

2.4 Testing and strengthening Process

Loading is increased 1 ton at a time until the first crack (P_{cr} theoretically 8.5 tons) is

*Corresponding author (S.Sirimontree). Tel/Fax: +66-2-5643008 Ext 3112 E-mail address: ssayan@engr.tu.ac.th

visually observed, then load is increased at 0.5 ton at a time until the load reaches 1.2 time of actual P_{cr}. Then, the load is fully unloaded and then loaded to $1.2P_{cr}$. The unloaded and then loaded process is repeated for ten cycles. This cyclic process is for observation of flexural rigidity loss, cracking and permanent cumulative deflection. Figure 2 shows levels phase of the test beam applied load is inflate.

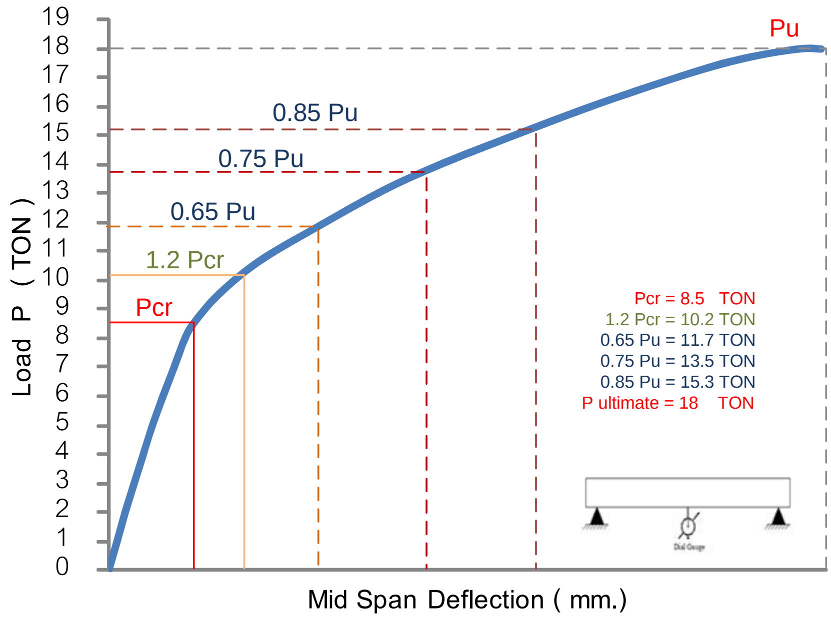

Figure 2: Level phase of loading and external prestressing.

The applied load is further increased to 0.65 time of predicted ultimate loading capacity of the test beam ($P_u = 18\ ton$). The cyclic process of fully unloaded and loaded to $0.65P_u$ (11.7 ton) is repeated for ten cycles. The deflection after the tenth cyclic is used for deflection control in the subsequence test of the degraded beam strengthening by external post tension (*see* Figure 3). The 1st level of external prestressing force, 28 tons ($2P_0$, P_0= internal prestressing force of original undamaged beam), was used to strengthen the degraded beam and then testing to the specified deflection and unload. External strands were removed and then the new external strands were applied to the damaged beam with the external prestressing force equal to $2.5P_0$ or 40 tons. The specimen was tested to the maximum specified deflection. After unloading, external strands were removed and new strands with external prestressing forces equal to $3P_0$ or 52 tons were applied to damaged beam and test to specified deflection.

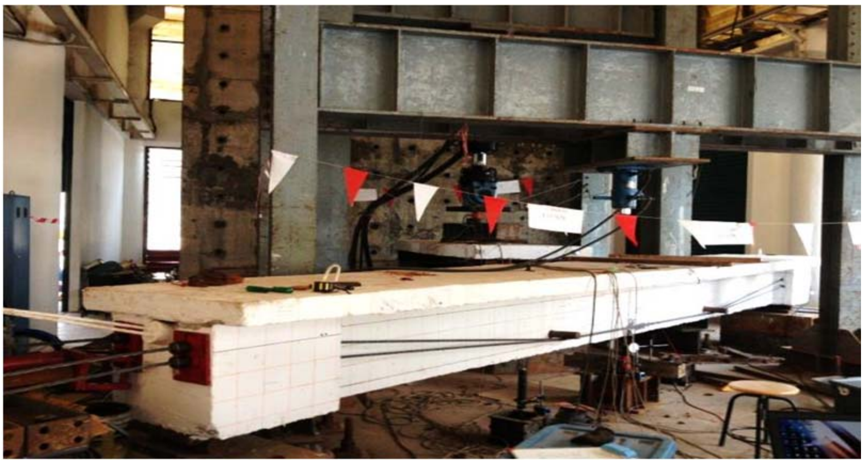

Figure 3: Testing beam with external post-tension.

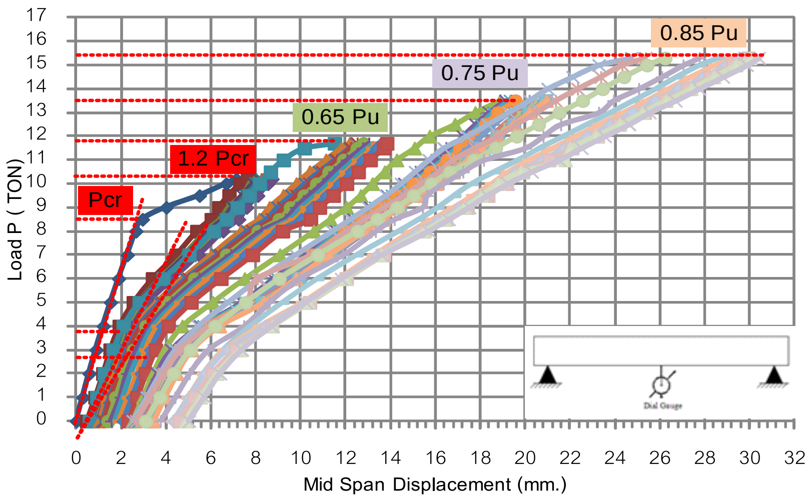

Figure 4: Relationship of load and mid span deflection of all cyclic load.

Figure 5: Crack width damage and external post-tension

External strands were removed and the test specimen was tested cyclically to $0.75P_u$. Maximum deflection in this test was used as specified deflection in subsequence test. Three levels of external prestressing forces were applied to the degraded beam and test in the same manners as for the beam with damaged level of $0.65P_u$.

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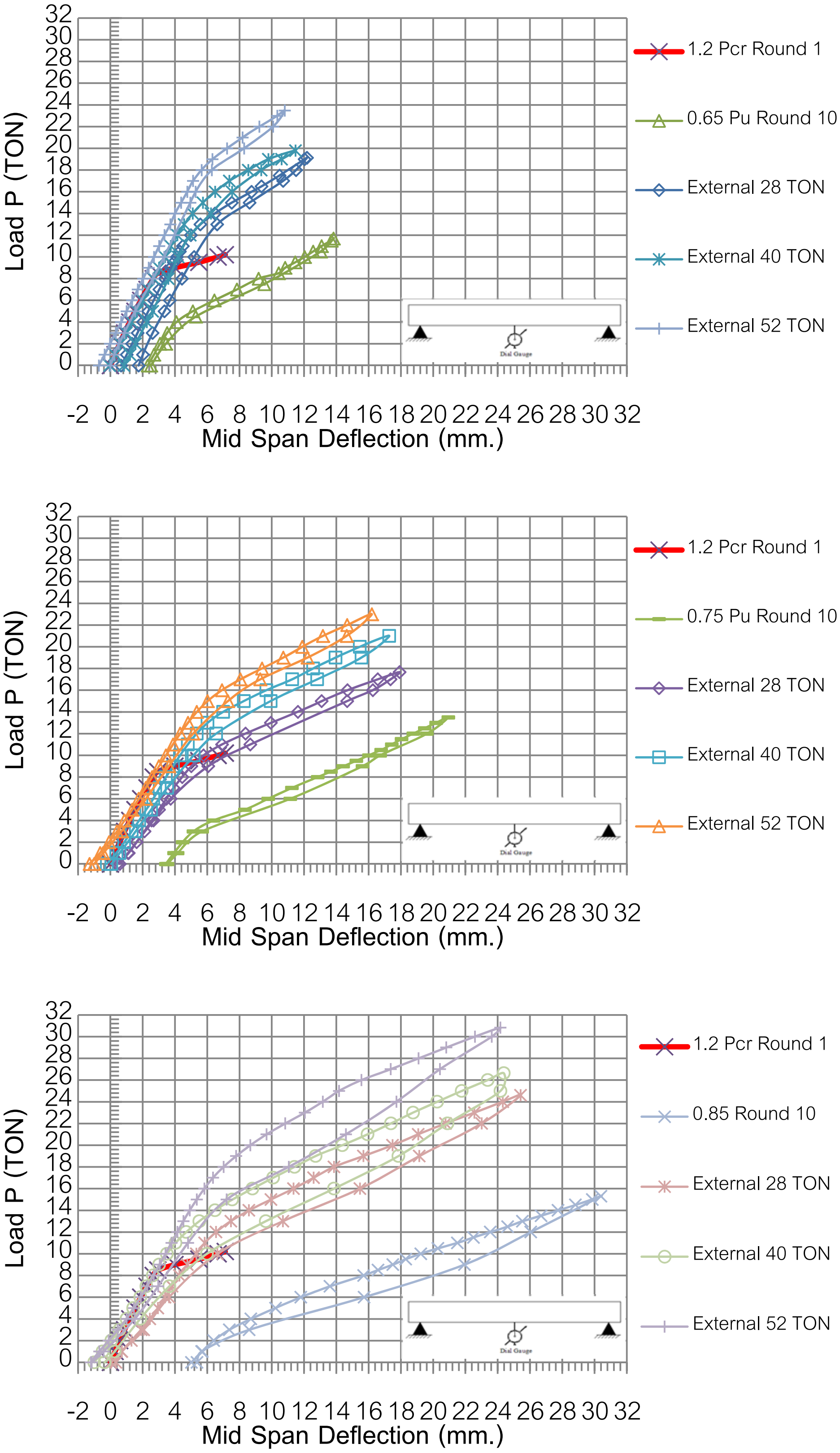

Figure 6: Relationship of load and mid span deflection each level of damage strengthened by external post tension.

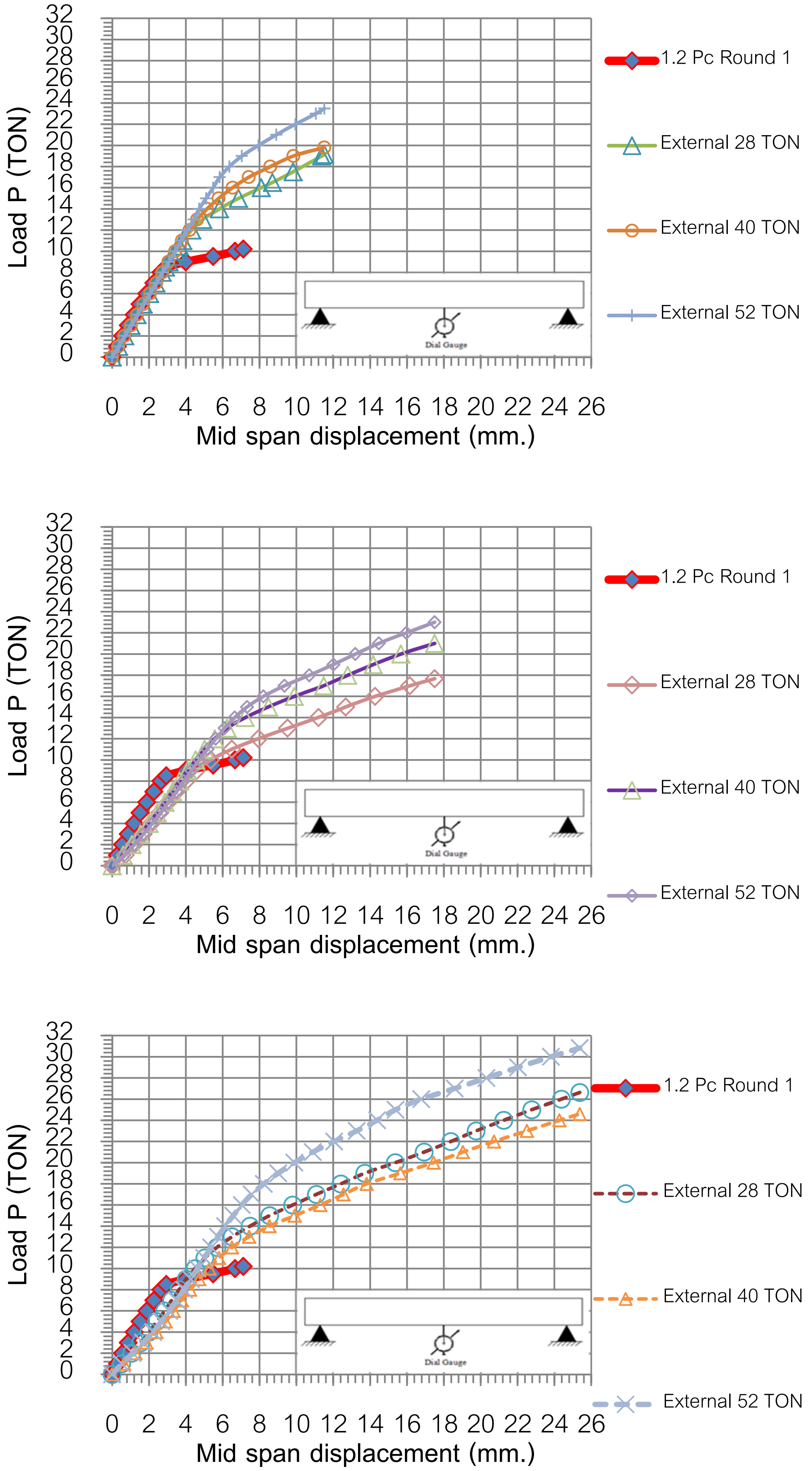

Figure 7: Relationship of load and mid span deflection each level of damage strengthened by external post tension shift graph

*Corresponding author (S.Sirimontree). Tel/Fax: +66-2-5643008 Ext 3112 E-mail address: ssayan@engr.tu.ac.th

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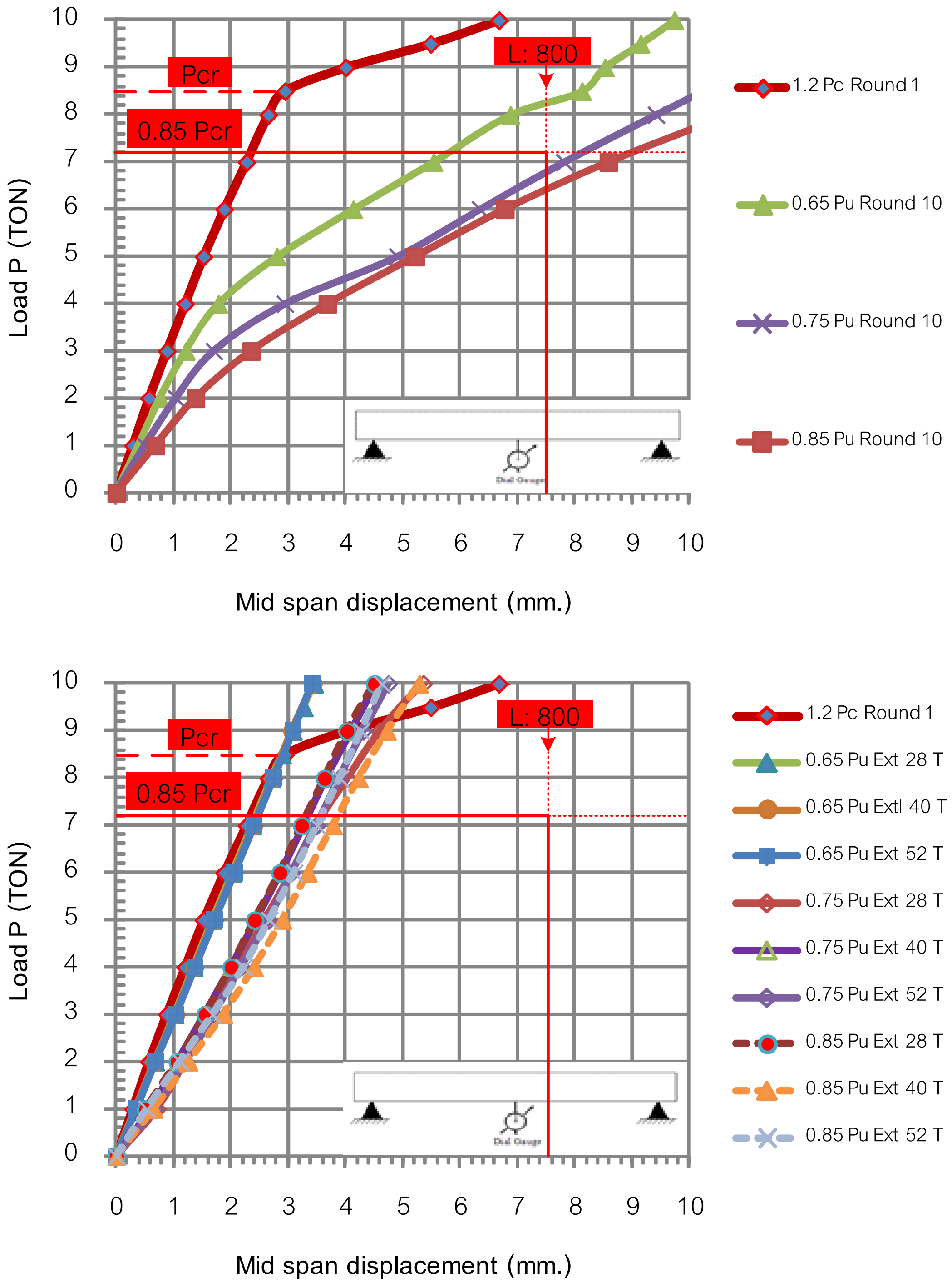

Figure 8: Working load and allowable deflection.

The same testing procedures and external post tension were applied to the damaged beam which was loaded to $0.85P_u$.

3. Results

Figure 4 shows the relationship between the load and deflection pattern, repeated for 10 cycles at load 1.2 Pcr, 0.65 Pu, 0.75 Pu and 0.85 Pu. When reaching crack load Pcr (8.5 tons add), cracks can be observed, as in Figure 5. Main crack is larger causing loss of section properties and thus flexural rigidity is reduced. This is indicated by the slope of the linear relationship between load and deflection (Figure 4). Moreover, the permanent deflection is increased according to damaged level. It can be noticed that the beam has a lower elasticity depending on the level of damage. After crack with loading between 1.2 Pcr - 0.65 Pu, the test gives that proportional limit is reduced from 8.5 tons to 4 tons. With increased damage from additional load, permanent cumulative deflection becomes higher while proportional limit is lower.

Figure 6 shows beam strengthening with external post tension at various damaged level. At all levels of applied load, when using external prestressing force 28tons, the beam cannot rehabilitate into its original state. However, when using external prestressing force 40 and 52tons, the beam has cambered compared to its original state. This external post tension helps crack reduction, improves section properties to become almost uncrack section (smaller crack width), enhances elasticity of the beam, and develops higher flextural rigidity. In addition, ultimate load is likely to increase with increased external prestressing force.

4. Discussion

From the test when overloading is applied, crack seems to cumulate. Likewise, permanent deflection seems to increase according to increased damage. These result in flexural rigidity to decrease. When the damaged beam is rehabilitated via external post-tension, crack width and permanent deflection appear to decrease and flexural rigidity to increase. Figure 7 shows slope of load and deflection. When damage is little, external post-tension improves flexural rigidity to level almost similar to undamaged beam. On the other hand, when beam damage is huge, effect of external post-tension per flexural rigidity will decrease. However if the deflection at service stage is within standard specification, external post-tension should be acceptable. For all cases, rehabilitated beam by external post-tension can bear higher ultimate load.

*Corresponding author (S.Sirimontree). Tel/Fax: +66-2-5643008 Ext 3112 E-mail address: ssayan@engr.tu.ac.th

Considering deflection at working load, this study uses working load at 85% of cracking load ($0.85P_{cr}$) of undamaged beam. When damage increases, working load deflection will increase accordingly due to loss flexural rigidity as a result of crack. Normal maximum bridge deflection is $\frac{L}{800}$, where L is bridge beam span. It can readily be seen that damaged beam under load $0.75P_u$ and $0.85P_u$ the deflections is higher than maximum allowable deflection, see Figure 8. For all cases, when the crack beam is rehabilitated, working load deflection is reduced to be less than allowable deflection. Taking advantage of prestressing, deflection due to excessive loading over standard specification can be reduced by means of external post-tension.

5. Conclusion

Prestressed concrete beams subjected to overloading beyond cracking stage leads to crack, reduction of flexural rigidity and excessive deflection. The damage, crack and permanent deflection can be progressed at the high level of load after cracking stage. Structural performance of damaged girder can be recovered and improved by external post tension. This work studied about the effects of damage level on flexural behaviors of PC beam and level of external prestressing forces on flexural behaviors of damaged girder atrengthened by external post tension. The following conclusions can be made.

Flexural rigidity of the test girder reduced with the increase level of damage due to the accumulation of crack caused by overloading. Proportional limit reduce while permanent deformation increase due to the deposition of damage. Deflection of the test girder at service stage exceed the acceptable limit at high level of damage.

External post tension with various external prestressing force can be applied to the damaged girder to recover flexural stiffness and ultimate moment capacity of the test beam. Elasticity in terms of proportional limit can be improve due to the reduction of crack width leading to the deflection of the beam fall into the acceptable limit at working stage. Strengthening of damaged beam can be effectively applied to the test beam for the damage level not greater than 0.65 times of predicted ultimate load.

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Thananun Phuwadolpaisarn earned his bachelor degree in Civil Engineering from Thammasat UniversityThailand, in 2009. He has been studying for the M. Eng. Degree in the Department of Civil Engineering, Thammasat University. He is currently working at the E.K.D. Engineering and Supply

Dr. Sayan Sirimontree earned his bachelor degree from Khonkaen University Thailand, master degree in Structural Engineering from Chulalongkorn University Thailand and PhD in Structural Engineering from Khonkaen University Thailand. He is an Associate Professor at Thammasat University Thailand. He is interested in durability of concrete, repair and strengthening of reinforced and prestressed concrete structures.

Dr. B. Witchayangkoon is an Associate Professor of Department of Civil Engineering at Thammasat University. He received his B.Eng. from King Mongkut's University of Technology Thonburi with Honors. He continued his PhD study at University of Maine, USA, where he obtained his PhD in Spatial Information Science & Engineering. Dr. Witchayangkoon current interests involve applications of emerging technologies to engineering.

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*Corresponding author (S.Sirimontree). Tel/Fax: +66-2-5643008 Ext 3112 E-mail address: ssayan@engr.tu.ac.th