EXPERIMENTAL STUDY ON FLEXURAL BEHAVIOR OF RC BEAMS STRENGTHENED WITH SMPM

Z.H. Yao[1], Q.L. Yao[2], S.M. Huang[3] and B. Song[4]

[1] *M.S. Candidate, University of Science and Technology Beijing, Beijing, China*
[2] *Senior Engineer, China Academy of Building Research, Beijing, China*
[3] *Professor, China Academy of Building Research, Beijing, China*
[4] *Professor, University of Science and Technology Beijing, Beijing, China*
Email: sunrise_leave@163.com

ABSTRACT :

Rehabilitation with SMPM (high-strength steel wire mesh and polymer mortar) is a new technique of structural strengthening with a series of obvious advantages comparing with other traditional ones. Experiments were conducted to investigate the flexural behavior of 5 RC beams including 4 strengthened specimens and 1 comparative beam. The mode of failure, cracking behavior, stress of reinforced bars and steel wires, load versus deflection curves and ultimate load-carrying capacity of the strengthened specimens were analyzed. The results showed that the strengthened beams have good strengthening effect and the working behavior of the two sections is excellent. Based on the tests and numerical simulation results, the design formulae of the flexural load-carrying capacity and stiffness were supposed. The calculated results are in good agreement with the experimental ones.

KEYWORDS: SMPM, high-strength steel wire mesh, polymer mortar, Flexural Strengthening, Experimental study

1. INTRODUCTION

Rehabilitation with SMPM is a new technique (Yao *et al*, 2005) of structural strengthening. Compared to other strengthening methods, it has a series of obvious advantages. There have been a few studies on the behavior of RC beams strengthened with SMPM including beam flexural and shearing tests (Nie and Wang *et al*, 2005& Nie and Cai *et al*, 2005) by tsinghua university and Fire Resistance Test of RC Beam Rehabilitated with SMPM (Wang *et al*, 2007) by china academy of building research. But the experimental study on Flexural Strengthening of RC Beam is of great significance to provide project a scientific basis and technological support.

2. EXPERIMENTAL PROGRAMMING

2.1. Design of The Specimen

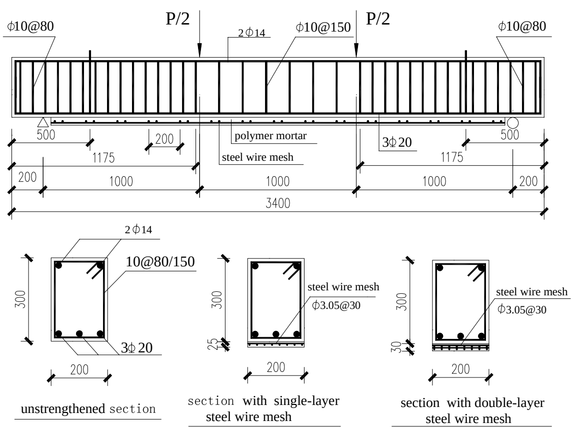

Fig. 1 Dimensions of specimens and arrangement of reinforcement

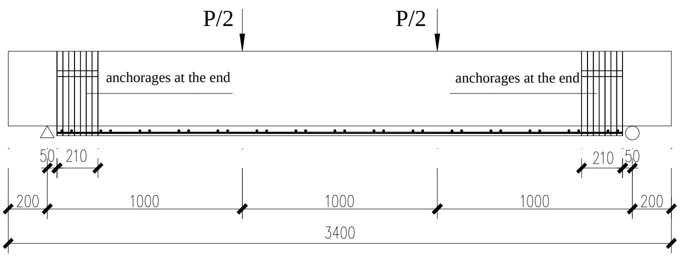

Fig. 2 anchorages at the two ends

Five RC specimens were designed and produced. Dimensions of specimens, arrangement of reinforcement and anchorage are showed in Fig. 1&2. The design strength of concrete is C20.
After production and maintenance finished, four beams were strengthened with SMPM. The style of the high-strength steel is 6 × 7 + IWS with the tensile strength limit 1641 MPa, elasticity coefficient 1.34×10^5 MPa. The nominal diameter is 3.05 mm. Polymer mortar used in the experiment was mixed by polymer latex, cement and sand in a certain percentage. Number and characteristics of the specimens are showed in Table 1.

Table 2.1 Number and strengthening forms

No.	Strengthening forms
BF-1	Comparative beam
BF-2, BF-3	Specimens strengthened with single-layer steel wire mesh; diameter of the steel wire mesh is 3.05@30; Thickness of the polymer mortar is 25mm
BF-4, BF-5	Specimens strengthened with double-layer steel wire mesh; diameter of the steel wire mesh is 3.05@30; Thickness of the polymer mortar is 30mm; U-shaped ring was disposed at the two ends

2.2 loading System

1) Loading machine decided by laboratory conditions .Test setup is showed in Fig. 3.
2) Preparing before loading: three to four times pre-loading was done before loading to make sure that all parts of the test device has good contacts and can do a normal work. Formal loading can be done when the load and deformation have a stabilized relationship. Pre-load value is about 20 percent of the calculated limit load.
3) Loads were increased gradually in several grade.
4) Calculation of load-carrying capacity referred to the literature (Nie and Wang *et al*, 2005) and norms (GB 50010-2002).

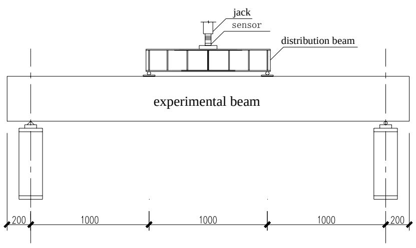

Fig. 3 Test setup

3. ANALYSIS OF THE EXPERIMENTAL PHENOMENON AND RESULTS

3.1 The Main Experimental Phenomenon

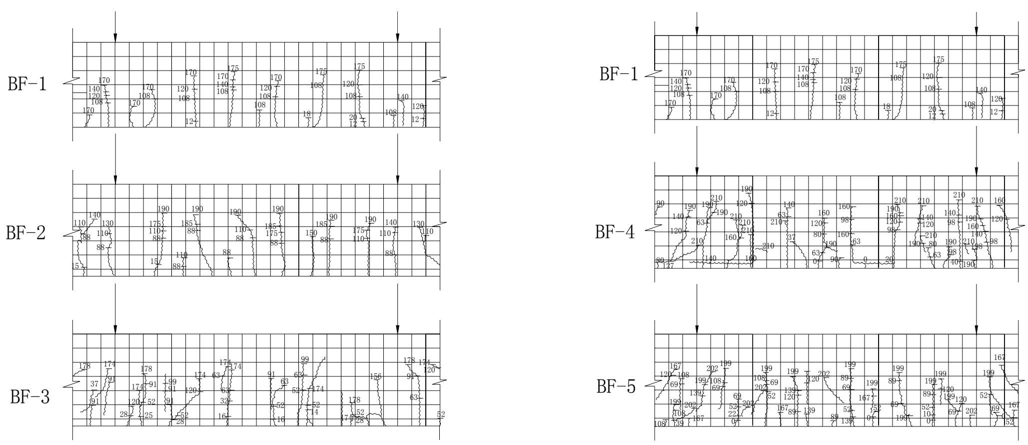

Fig. 4 Cracking behavior of the five beams

Note: Dates in Fig. 4 which could be read on computer was the load applied by oil jack

BF-1 experienced three stages including flexible working stage, the stage with cracks and steel yield stage. Ratio of reinforcement of this beam is of 1.7 percent meeting the fitness demands of the reinforcement beams. Cracking behaviors were similar to normal reinforcement beams. Strengthened specimens have the similar destruction process with BF-1. The differences are that the growth of cracks was blocked up. This conclusion can be drawn from Fig. 4.

3.2 The Main Experimental Results

Table 3.1 shows the main experimental results. Based on the analysis of the data in Table 3.1, conclusion that the cracking load-carrying capacity, yield-carrying load capacity and the limit-carrying load capacity of the strengthening beams have been increased can be drawn. Load-carrying capacities of the specimens strengthened with double-layer steel wire mesh had more obvious improvement.

Table 3.1 The main experimental results

No.	M_{cr} (KN•m)	M_y (KN•m)	M_u (KN•m)	α	β	Cracking behavior
BF-1	8	92	95	——	——	Concrete crushed after reinforcement had yield
BF-2	9	94	101	1.02	1.06	Concrete crushed after reinforcement had yield; One strand of the steel wire broken
BF-3	10	90	98	0.97	1.03	Ibid
BF-4	15	100	111	1.09	1.17	Ibid
BF-5	11	95	104	1.03	1.09	Concrete crushed after reinforcement had yield; All of the steel wire broken

Note: M_{cr} is the bending moment when the first crack appeared in the polymer mortar; M_u is the bending moment when reinforcement began to yield; α is the yield bending moment ratio of strengthened beams with Comparative one; β is the limit bending moment ratios of strengthened beams with Comparative one.

3.3 Strain of Steel bar at Mid Span of The Five Specimens

Fig. 5 shows the steel strains at mid span of the five specimens. This graph suggests that the yield-carrying load capacity and the limit-carrying load capacity of the strengthening beams have been increased. The specimens strengthened with double-layer steel wire mesh have a better performance.

3.4 Strain of The Steel Wires

Fig. 6 compared the steel wires' biggest strain of the four strengthened beams.

From Fig. 6, it is found that the strain value of the specimens strengthened with double-layer steel wire mesh was greater than that of corresponding single-layer reinforcement on average. The exerting of the steel wires' stress of the is not uniform. The maximum strain of BF-2 is about 6500$\mu\varepsilon$; of BF-3 is about 21000$\mu\varepsilon$; of BF-4 is about 10500$\mu\varepsilon$; of BF-5 is about 12000$\mu\varepsilon$.

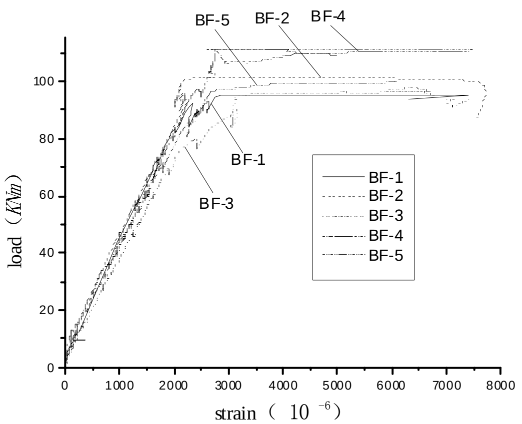

Fig. 5 Steel strain curves at mid span of the five specimens

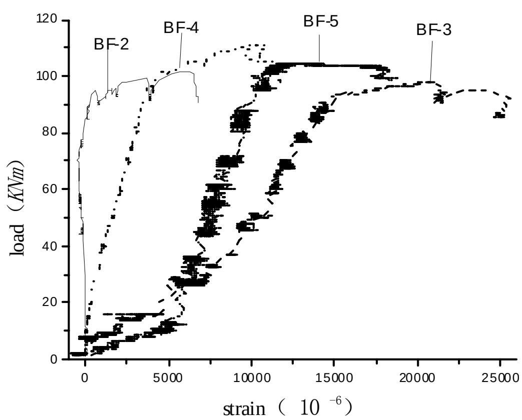

Fig. 6 Steel wires strain curves at mid span

3.5 Longitudinal Strain by Height at Mid Span

The meanings of the abscissas at corresponding ordinates are showed in Table 3.2

Table 3.2 The meanings of the abscissas at corresponding ordinates

Ordinate	Meaning of the abscissa
-275	Strain of the reinforcement bar at mid span
-300	Strain of the steel wires at mid span
-325/330	Strain of the polymer mortar at mid span
others	Strains of the concrete at mid span

Destruction of the strain foil caused by the fracture at bottom through the strain foil can explain the phenomenon at the point of which the ordinates are respectively -300(BF-1), -325(BF-2, BF-3) and -330(BF-4, BF-5) in Fig. 7. Strain distribution, illustrated as Fig. 7, showed that compression depth of concrete in the cross-section decreased compared to the unstrengthened beam.

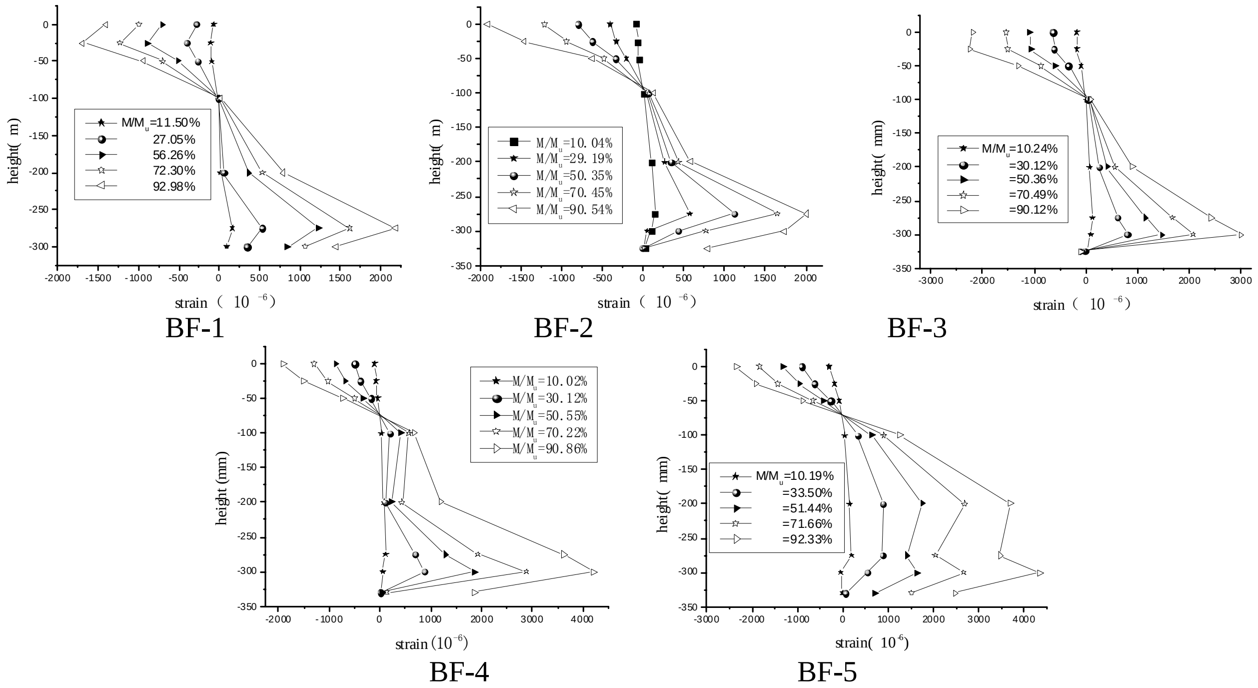

Fig. 7 Longitudinal strain by height at mid span

3.6 Comparison of The Deflections

To compare deflections of the five beams, curves of the deflections at mid span was drawn in one graph as shown in Fig. 8.

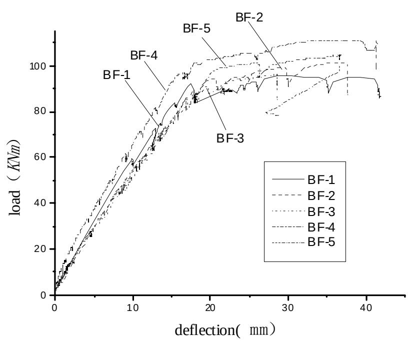

Fig. 8 Comparison of mid span deflection curves

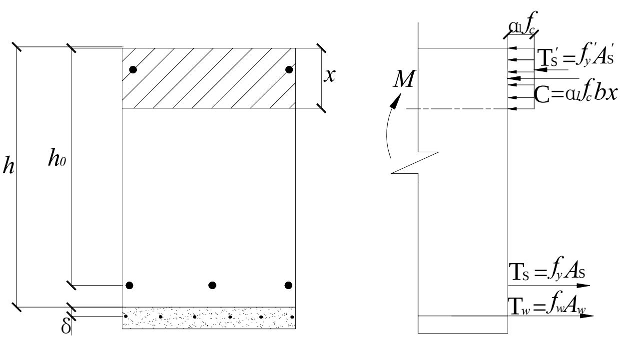

Fig. 9 calculating graph of flexural capacity

In the initial stage of loading, looseness of the steel wires probably cause the result that the changing of the deflections of the strengthened beams is similar to the one without strengthening. But as the load rising, the increasing speed of the deflections of the strengthened beams is slower than the compared one especially BF-4. Compared BF-4&5 to BF-2&3, the increasing speeds of the specimens strengthened with double-layer steel wires are slower than the ones strengthened with single-layer. On the whole, the stiffness of the beams strengthened with SMPM can be improved, and the increasing of the stiffness is more obvious as the augment of strengthening quantity.

4 SUGGESTED FORMULAS OF LOAD-CARRYING CAPACITY OF REINFORCEMENT BEAM

Method as follows is suggested to calculate the load-carrying capacity of reinforcement beam.

$$\alpha_1 f_c bx + f_y^{'} A_s^{'} = f_y A_s + \psi_{rw} f_w A_w \,, \tag{4.1}$$

$$\psi_{rw} = \frac{0.8\varepsilon_{cu} h / x - \varepsilon_{cu}}{f_w / E_w} \,. \tag{4.2}$$

ψ_{rw} can be gotten from the two equations above. Then ψ_{rw} was amended by η as follow.

$$\eta = \alpha(0.85 - \psi_{rw}) \tag{4.3}$$

α equals to 5. When ψ_{rw} is bigger than 0.65, it won't be amended. Then load-carrying capacity of the fire-exposed RC beam can be calculated through the equations (4.4&4.5). Figure 9 can be referred.

$$\alpha_1 f_c bx + f_y^{'} A_s^{'} = f_y A_s + \eta\psi_{rw} f_w A_w \,, \tag{4.4}$$

$$M = \alpha_1 f_c bx \cdot (h - x/2) + f_y^{'} A_s^{'} (h - \alpha_s^{'}) - f_y A_s (h - h_0) \,. \tag{4.5}$$

ψ_{rw} in the equation(4.4) was gotten from equations 4.1&4.2.
Table 4.1 compares the calculation and test results.

Table 4.1 Comparison of the calculation and test results

No.	Stress coefficient of the steel wire（ψ_{rw}）	Calculation result	Test result	Calculation result/ Test result
BF-1	——	91.42	95.48	0.96
BF-2	0.69	98.42	101.20	0.97
BF-3	0.69	98.42	98.07	1.00
BF-4	0.80	106.02	111.28	0.95
BF-5	0.80	106.02	104.70	1.01

5 CONCLUSIONS

Conclusions can be drawn by the experiment and analysis.
(1) The working condition of the strengthened beams especially the specimens strengthened with double-layer steel wire improved obviously.
(2) After strengthened, the load when the first crack appeared has a little increase. The growth of cracks was blocked up. More fine cracks and the smaller distance between them indicate a good performance in regular service time.
(3) The failure modes of the strengthened ones were the same as the comparative beam. Crush and flake-off of the polymer mortar or crack at anchorage of the steel wires with the beams didn't appear in the experiment.
(4) The results show that the close binder is of better bonding, and the reinforcement layer works coordinately with the original RC beams.
(5) Formula results have a good agreement with the experimental data. The formula can provide basis to project in some extent.

REFERENCES

Q. L. Yao, Z. H. Wang, Y. Y. Wang, S. M. Huang and S. G. Cheng. (2005). High strength steel wire mesh-polymer mortar composite coating reinforced technique — A new 'green' reinforcement technique. *Engineering Quality* **12**, 17-20. (Chinese).

J. G. Nie, H.B. Wang, T. S. Zhang, Q. Cai and K. Qin. (2005). Experimental study on flexural behavior of RC beams strengthened with stainless steel wire mesh and permeability polymer mortar. J*ournal of Building Structures* **26:2**, 1-9. (Chinese).

J. G. Nie, Q. Cai, T. S. Zhang, H. B. Wang and K. Qin. (2005). Experimental study on shear behavior of RC beams strengthened with stainless steel wire mesh and permeability polymer mortar. Journal of Building Structures **26:2**, 10-17. (Chinese).

Y. Y. Wang, Q. L. Yao, Z. H. Wang, M. G. Yue and L. F. Zhang. (2007). Fire Resistance Test of RC Beam Rehabilitated with High-strength Steel Wire Mesh and Polymer Mortar. Journal of Building Structures **37:1**, 112-113. (Chinese).

GB 50010-2002. Code for Design of Concrete Structures. (2002). China Architecture & Building Press, Beijing. (Chinese).