Use of Polypropylene Fibre Reinforced Shotcrete (PFRS) for Rock Slope Protection at Tala Hydroelectric Project in Bhutan – A Case Study

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ABSTRACT

At Tala hydroelectric project in Bhutan, the total quantity of concrete and shotcrete for the construction of different components of the project structures worked out as 11,00,000 m^3 and 1,50,000 m^3, respectively. Application of polypropylene fiber reinforced shotcrete (PFRS) was completed successfully for right bank slope protection work on the downstream of the concrete gravity dam. The mix design trials were carried out in the laboratory of Tala Hydroelectric Project Authority (THPA) and site trials were also carried out before adoption of final mix. The details of mix design and features of site application including difficulties encountered in PFRS application have been brought out in this paper. A comparison between the performance of steel fibre reinforced shotcrete (SFRS) and PFRS has also been studied and presented.

1. INTRODUCTION

As per the report of ACI Committee 506-1R fibre reinforced concrete/shotcrete is defined as mortar or concrete containing discontinuous discrete fibre that is pneumatically projected at a high velocity on to the rock surface. Fibres for shotcrete can be made of steel, glass, synthetic and natural materials. When the fibres are made of synthetic material polypropylene, the material may be called polypropylene fibre reinforced shotcrete (PFRS). PFRS is thus essentially a conventional shotcrete to which polypropylene fibres are added. The PFRS/shotcrete may also contain pozzolana and other admixtures used with conventional concrete.

At Tala Hydroelectric Project in Bhutan, plain shotcrete and steel fibre reinforced shotcrete (SFRS) were used for temporary and permanent support of rock mass in underground structures along with other supporting systems such as rock bolts, anchors, steel ribs, RCC etc. This application of PFRS was limited to slope protection work at dam site. However, its use may be extended to other applications when sufficient experience about its usage is gained.

This paper essentially deals with the application of polypropylene fiber reinforced shotcrete (PFRS), details of mix design and difficulties encountered during its application for slope stabilization of right abutment at downstream of concrete gravity dam of 1020 MW Tala Hydroelectric Project in Bhutan.

2. PROJECT DESCRIPTION

Tala Hydroelectric Project is a run-of-the-river scheme, located 3 km downstream of the existing 336 MW Chukha Hydroelectric Project on river Wangchu in South West Bhutan in Eastern Himalayas. The project consists of a 92m high concrete gravity dam; three desilting chambers each of 250m x 13.90m x 18.5m size for removal of suspended sediments (0.2mm) flowing with the river water diverted through the intake structure; a modified horse-shoe tunnel of 6.8m diameter and 23km in length to carry the water to underground powerhouse (206m x 20m x 44.5m) for utilizing a gross fall of 861.5m. A tail race tunnel of 3.1 km length and 7.75m diameter discharges the water back into river Wangchu. The installed capacity of powerhouse is 1020MW (6 x 170MW).

The project was taken up for execution from 1st October 1997 and 1st and 6th units were commissioned on 31st July 2006 and 31st March 2007, respectively. The project was executed by the Tala Hydroelectric Project Authority (THPA), an autonomous body jointly under the Govt. of India and the Royal Govt. of Bhutan.

3. SLOPE PROTECTION WORK

The concrete gravity dam has five sluice spillways and one overflow spillway. The dam orientation with respect to river gorge is such that the water trajectory from two spillways on extreme right of dam impinges on the rock slope at downstream of the dam as shown in Fig. 1. Therefore, extensive rock cutting was undertaken to clear the water passage on right bank. The support system for slope protection work consisted of 32mm diameter, 10 m long rock bolts spaced at 1.05 m both ways and 100 mm thick shotcrete layer. Based on various considerations, it was decided to use polypropylene fibre reinforced shotcrete (PFRS) in place of wire mesh or steel fibre reinforced shotcrete.

Fig. 1- Right bank slope stabilisation at downstream of the dam with PFRS

3.1 Rock Bolts

The 32 mm diameter and 10 m long rock bolts spaced at 1.05 m both ways were installed in 51 mm diameter holes. The end anchorage was achieved by fast set resin capsules with minimum compressive strength of 60 MPa at 1 hour. The end anchorage of 1.5 m was achieved by 15 resin capsules of size 28 mm diameter and 200 mm length. The rock bolt was pre-tensioned up to 10 tonnes load. The remaining length of rock bolt was grouted with cement mortar after pre-tensioning. The rock bolts were designed for 20 tonnes load. As the slope was almost vertical with deep gorge, rock bolting machine could not be employed and the installation of rock bolts was carried out manually. Different combinations of anchorage such as mechanical anchorage, cement capsules, resin capsules etc and installation methods were tried and their efficacy tests were conducted. The pull out tests was conducted in each case with pull out load up to 20 tonnes. A typical load deformation characteristic of one resin grouted rock bolt is plotted in Fig. 2. After pre-tensioning up to 10 tonnes load, the unanchored portion of rock bolt was grouted with cement grout. Then a 100 mm thick layer of PFRS was laid on the rock surface.

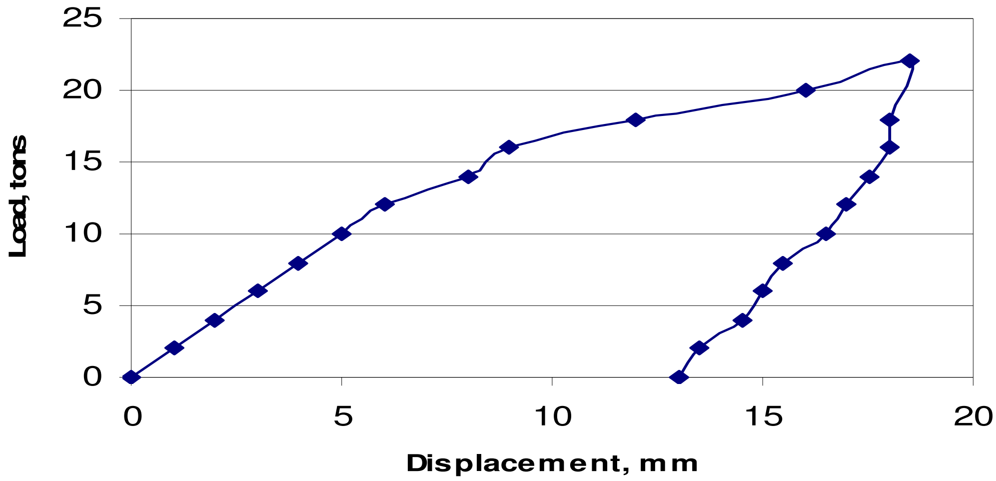

Fig. 2 - Load deformation curve of resin grouted rock bolt

3.2 Fibre Reinforced Shotcrete

Unreinforced shotcrete has a low tensile strength and low strain capacity at fracture. These shortcomings are traditionally overcome by adding reinforcing bars or pre-stressing steel. Fibres are discontinuous and unlike conventional reinforcement, they are distributed randomly through out the concrete matrix. There are numerous fibre types available for use in concrete/shotcrete. The basic fibre categories are steel, glass synthetic and natural fibres. The technology of using synthetic fibres in concrete and shotcrete is relatively new compared to steel fibres and growing rapidly. A wide spectrum of synthetic fibre types is available. Currently, the largest use of synthetic fibres is aimed at controlling plastic shrinkage cracking in which about 0.1% by volume of synthetic fibres is used. High volume (0.4 - 0.7%) of fibres significantly increases toughness and reduces crack width and make it suitable for rock supports.

3.3 Steel Fibres

Generally, the ultimate tensile strength of steel fibres varies from 345 MPa to 2070 MPa. ASTM A 820 specifies a bending requirement. Steel fibres shall withstand bending of around 3.18 mm inside diameter to an angle of 90^0 at temperatures not less that 16^0C without breaking. As per ACI 506, fibre sizes range from 13 x 0.25 mm to 64 x 0.76 mm, with popular fibre size range for shotcrete being 25 to 30 x 0.40 mm. This size range is easily handled. Shorter fibres are easier to mix and shoot at low rebound loss, but the shotcrete properties, particularly toughness and post-crack resistance, are lower. Longer fibres, although superior in producing high strength and toughness properties, usually result in more plugging and have a higher fibre rebound rate. Some of the problems with shorter fibres have been over come with the introduction of fibres having deformations or end anchorage provisions. Steel fibres with bent or deformed ends have a high pullout resistance and may be used in smaller quantities than straight fibres to achieve the same properties. The aspect ratio (length/equivalent diameter) ranges from 50 to 75.

3.4 Synthetic Fibres

Synthetic fibres are derived from organic polymers. Synthetic fibre types used in concrete are acrylic, aramid, carbon, nylon, polyester, polyethylene and polypropylene.

3.5 Polypropylene Fibres

The monofilament form of these fibres are produced in an extrusion process in which the material is hot drawn through a die of circular cross section generating a number of continuous filaments at one time called a tow. Fibrillated polypropylene fibres are produced in an extrusion process where die is rectangular. The resulting film sheets of polypropylene are slit longitudinally into equal width tapes. Polypropylene fibres are not bonded chemically in a concrete matrix, but bonding is present due to mechanical interaction. Important physical properties of some commercially available fibres are given in Table 1.

Table 1- Properties of some common synthetic fibre types (ACI 544,1R-96)

Fibre Type	Diamer Equivalent Diameter mm x 10^{-3}	Specific Gravity	Tensile Strength MPa	Elastic Modulus MPa	Ultimate Elongation percent
Acrylic	12.7 – 104.1	1.16 – 1.18	269 – 1000	13790 – 19306	7.5 – 50.0
Aramid I	12	1.44	2930	62055	4.4
Aramid II	10.1	1.44	2344	117215	2.5
Nylon	22.9	1.14	965	5171	20
Polyester	19.8	1.34 – 1.39	228 – 1103	17237	12 – 150
Polyethylene	25.4 – 1016	0.92 – 0.96	76 – 586	5000	3 – 80
Polypropylene	-	0.90 – 0.91	138 – 690	3448 – 4826	15

4. POLYPROPYLENE FIBRE REINFORCED SHOTCRETE (PFRS)

The concrete composites containing polypropylene fibres ranging from 0.1 – 10.0% by volume have been reported in literature. High volume of fibres results in considerable loss of workability which is partly compensated by use of appropriate quantity of super plasticizers. Addition of fibres does not significantly affect the compressive strength of concrete. However, a slight increase in flexural strength (0.7 – 2.6%) at 0.1% fibre by volume and a slight decrease at 0.2 – 0.3% by volume of fibres is reported. The main advantage of adding fibres is in terms of achieving improved toughness, impact and fatigue strengths etc. and reduction in crack width.

4.1 Mix Design of PFRS

4.1.1 Materials

The Portland Slag Cement (PSC) with microsilica was used in first few laboratory trials but afterwards the required (IS: 455:1989) properties were achieved with PSC alone. Sand grading conforming to IS: 383:1970 was used in PFRS applications. Superplasticizer (IS 9103: 1999), lignosulfonate based at the rate of about 1.5% by weight of cement was added for increasing the workability of the fresh mix. Accelerator, sodium silicate based was used at site and not in laboratory trials. The dosage of accelerators was fixed at 4 % by weight of cement for increasing the early strength of shotcrete/ PFRS.

There is a normal tendency to use higher dosage of accelerator to reduce the rebound, but higher dosage results in lower 28 days strength. The rebound should be reduced by proper mix design and keeping the optimum workability. Polypropylene fibres (Fibrecon-CF) were used with the engineering properties mentioned in Table 2.

Table 2 - Properties of polypropylene fibre (Fibrecon-CF)

Sl. No.	Property	Value
1	Tensile strength, MPa	506.2
2	Elongation at peak load, %	24.74
3	Elastic Modulus, GPa	5.265
4	Melting point, degree	138.5-170.3
5	Alkali resistance	Excellent
6	Fineness, denier	45
7	Length, mm	32-40

4.1.2 Effect of fibre dosage

The mix design of PFRS consists of designing a basic shotcrete matrix and optimising dosage of fibres. Proportioning basic matrix is no different than conventional shotcrete. For present application, PFRS was designed first as dry shotcrete and then as wet shotcrete. Site trials of dry shotcrete showed that the fibres were flying away in the air due to air pressure of dry shotcreting. Moreover, there was poor control of water quantity at nozzle. Therefore, the idea of dry shotcrete was dropped and wet shotcreting method was adopted.

Wet shotcrete trials were carried out in laboratory. Generally Ordinary Portland Cement (OPC) conforming to IS 8112:1989 is used in shotcrete, but in this application, PSC was used due to its resistance against alkali silica reaction and overall durability. It was observed that increase in fibre dosage reduced slump considerably even after increasing water content as given in Table 3.

Due to increase in water demand also, the compressive strength got reduced with increase in fibre dosage. At fibre content beyond 3 kg/m^3, excessive balling was observed. The entire paste was entrapped within fibres leading to segregation and the dispersion of fibres was inadequate. After these trials, the matrix design was improved to accommodate maximum fibre content up to 3 kg/m^3 without causing attendant problems as described above. The results show that maximum compressive and flexural strengths are obtained at a fibre dosage of 1.5 to 2.5 kg/m^3.

Next trials were carried out without microsilica to reduce ultrahigh fines content. Cement (PSC) was increased and coarse aggregate was reduced. A satisfactory mix at cement content of 500 kg/m^3 was obtained at fibre content of 2 to 3 kg/m^3 in final trials discussed later.

Table 3 - Mix proportion with varying fibre dosage

Sl. No.	Material/ Property	Polypropylene Fibre Dosage, kg/m^3				
		0	1.5	2.5	3.0	6.0
1	Cement, kg/m^3	475	475	475	475	475
2	Microsilica, kg/m^3	25	25	25	25	25
3	Water, kg/m^3	210	210	210	215	225
4	Fine aggregate, kg/m^3	947	947	947	947	947
5	Coarse aggregate (10-4.75 mm), kg/m^3	631	631	631	631	631
6	Fibres, kg/ m^3	0	1.5	2.5	3.0	6.0
7	Superplasticizer, kg/m^3	7.5	7.5	7.5	7.5	7.5
8	Slump, mm	250	150	125	115	45
9	Compressive strength, MPa 7 days 28 days	 14.22 28.89	 16.89 30.89	 15.22 30.19	 12.89 26.44	 11.55 25.33
10	Flexural strength, MPa 7 days 28 days	 2.8 6.0	 2.8 6.8	 3.0 6.8	 2.6 5.2	 2.4 4.8

4.1.3 Effect of fibre types

Two different types of synthetic fibres, Polypropylene (FIBRECON-CF) and Polyester (RECRON 3S) were available. RECRON 3S Polyester fibre was 15 mm long and a dosage of 1.5 kg/m^3 was recommended by the manufacturer. Therefore, trials were made with both fibres as per manufacturer's recommendations. A control mix without fibres and one with steel fibres were also made for a comparison. The details are given in Table 4. No substantial difference in flexural strength was obtained. However, the maximum flexural strength of 6.7 MPa was obtained with Polypropylene fibre (FIBRECON-CF). The dispersion of polyester fibres which were shorter in length was excellent. The slump reduction with steel and polyester fibre compared to control mix was minimal (20 to 30 mm) but polypropylene fibres reduced slump by 120 mm. Since the durability of polypropylene fibres is well established, these fibres were adopted instead of polyester fibres.

Table 4 - Effect of fibre types

Sl. No.	Material/ Property	Fibre type and dosage, kg/m^3			
		Fibre 0	Polypropylene (FIBRECON) 2.5	Polyester (RECRON 3S) 1.5	Steel 40
1	Cement, kg/m^3	500	500	500	500
2	Microsilica, kg/m^3	25	25	25	25
3	Water, kg/m^3	185	215	203	185
4	Fine aggregate, kg/m^3	1073	1073	1073	1073
5	Coarse aggregate (10-4.75 mm), kg/m^3	460	460	460	460
6	Fibres, kg/m^3	0	2.5	1.5	40
7	Superplasticizer, kg/m^3	7.9	7.9	7.9	7.9
8	Slump, mm	200	80	190	180
9	Flexural strength, MPa 7 days 28 days	 3.3 6.0	 5.1 6.7	 3.3. 6.0	 4.5 6.2

4.1.4 Adopted mix

Based on observations of laboratory trials, the shotcrete matrix was revised and the adopted mix proportion is given in Table 5.

Table 5 - Adopted mix proportions

Sl. No.	Material/ Property	Polypropylene Fibre Dosage, kg/m^3	
		2.5	3.0
1	Cement, kg/m^3	550	500
2	Water, kg/m^3	198	200
3	Accelerator, kg/m^3	22	20
4	Fine aggregate, kg/m^3	1011	1047
5	Coarse aggregate (10-4.75 mm), kg/m^3	544	564
6	Fibres, kg/m^3	2.5	3.0
7	Superplasticizer, kg/m^3	8.25	7.5
8	Slump, mm	125	125
9	Compressive strength, MPa 7 days 28 days	 19.05 37.33	 31.55 38.67
10	Flexural strength, MPa 7 days 28 days	 4.8 7.5	 5.6 8.25

Polypropylene fibres have shown high slump loss as compared to steel fibres. Mix with steel fibres showed slump loss beyond 30 kg/m^3 dosage of fibres and a slump loss of about 50 mm were observed at 50 kg/m^3 dosage. In case of polypropylene fibres, a slump loss of 125 mm was observed at 2 kg/m^3 and 175 mm at 3 kg/m^3 dosage.

4.1.5 Slump loss

Slump loss due to addition of fibres was an obstacle in adding sufficient quantity of fibres to achieve desired toughness. Therefore, a separate study on slump loss using adopted mixes with varying polypropylene and steel fibre dosages was conducted and the results are plotted in Fig. 3.

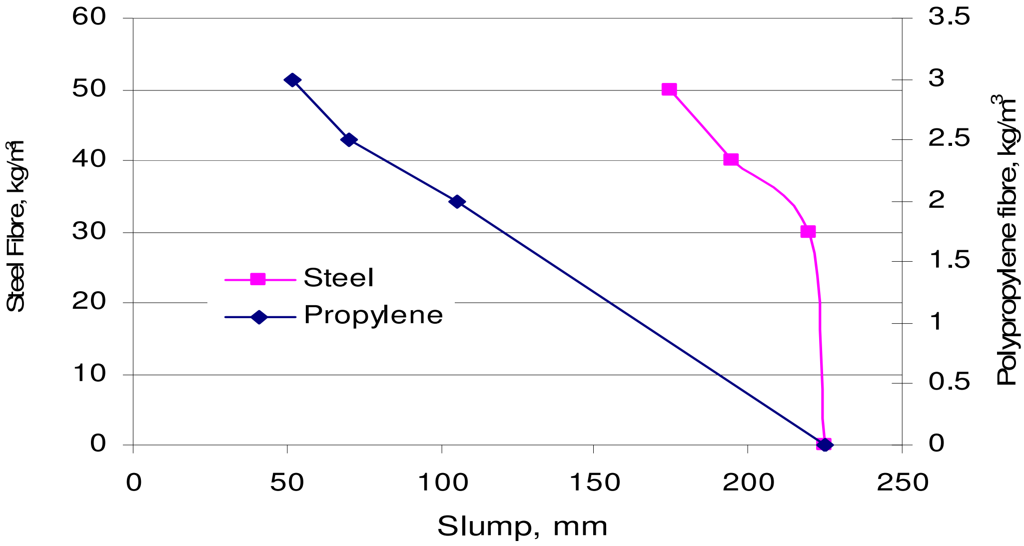

Fig. 3 - Slump loss with varying dosage of polypropylene and steel fibre

4.1.6 Load deformation curve

Load deformation curves obtained for PFRS and SFRS using load controlled machine are plotted in Figs. 4 and 5, respectively. An increase in elastic modulus was obtained as the fibre dosage was increased. In case of polypropylene fibres, perceptible increase in modulus value was obtained with fibre dosage of 3.0 kg/m^3. However, in case of steel fibres, increase in modulus value was consistent with the increase in fibre dosage from 0 to 50 kg/m^3.

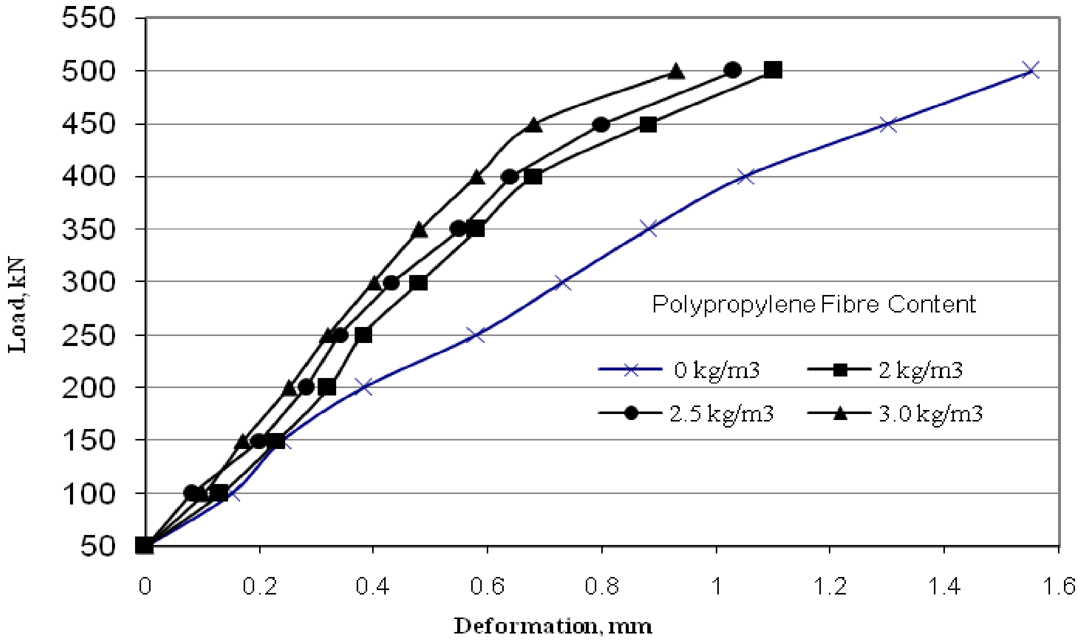

Fig. 4 - Load deformation curve in compression for PFRS

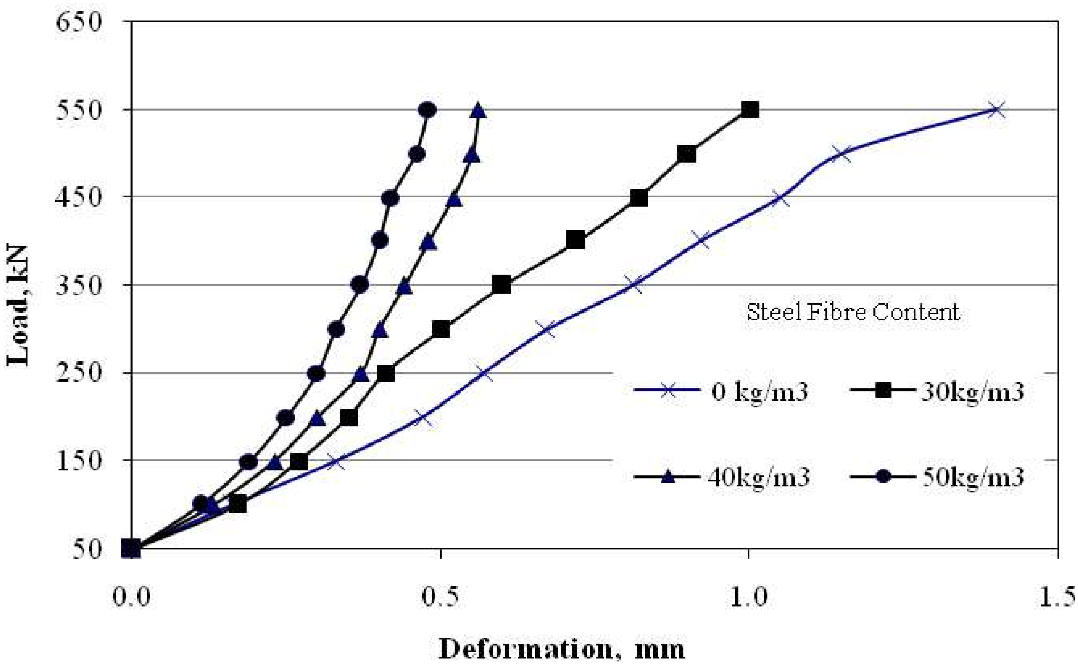

Fig. 5 - Load deformation curve in compression for SFRS

5. CONCLUSIONS

Based on the application of PFRS for rock slope stabilization on downstream of the right bank of dam at Tala Hydroelectric Project in Bhutan, the following conclusions are drawn:

- Resin grouted rock bolt 10 m long and 32 mm diameter with 1.5 m anchorage length were successfully installed manually as a part of support system with 100 mm thick PFRS.

- Polypropylene fibres of 38 mm length were used with 2.5 to 3.0 kg/m^3 dosages.
- The compressive strength for PFRS was achieved in the range of 37 MPa to 38 MPa and flexural strength varied from 7.5 MPa to 8.25 MPa.
- Addition of Polypropylene fibres reduced slump considerably. The proper mix proportioning is required to compensate for slump loss and to make a smooth and workable mix.
- Dry mix PFRS could not be adapted in view of loss of fibres due to their flying away in the air and improper dispersion of fibres.
- High dosage of fibres beyond 3 kg/m^3 caused difficulty in handling and pumping of PFRS. Therefore more study is required on utilising high dosages of polypropylene fibres.
- In case of steel fibres, consistent increase in the Modulus of elasticity was obtained as the fibres dosage increased, from 0 to 50 kg/m^3. In case of polypropylene fibres, increase in elastic modulus was obtained only at higher dosages beyond 2.5 kg/m^3.

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