PERFORMANCE OF CONCRETE MASONRY PRISMS FILLED WITH STEEL FIBRE REINFORCED GROUT

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SUMMARY

Compressive strength of concrete masonry filled with grout is adversely affected by the incompatible lateral expansion of the grout fill and the masonry shell. By confining the grout laterally significant improvement in the compressive strength of masonry is achieved. Various designs of lateral reinforcement were tried by several researchers in the past. A simple method of adding steel fibres into the grout mix as an alternative to lateral reinforcement design is examined in this paper. It is shown that this approach is superior to other attempts reported in the literature provided the grout is compacted by the needle vibration technique.

INTRODUCTION

Compressive strength is the most important property of the materials used in structural design. Compressive strength is usually evaluated experimentally by testing prisms or cylinders whose height to width (or diameter) ratio is greater than or equal to two. These specimens fail predominantly by developing cracks parallel to the direction of loading. In some countries specimens of cubic shape are used particularly for the determination of concrete strength. Concrete cubes fail predominantly by developing conical failure surfaces close to the loading platens. Concrete masonry strength is assessed through three high stack bonded prisms whose height to width ratio is slightly higher than two.

In the concrete masonry construction selected cores of the hollow masonry is grouted either to hold the vertical reinforcement in position or to locally strengthen the masonry against vertical concentrated load. The grout in the cores of the concrete masonry is left unconfined laterally because the lateral steel reinforcement detailing is difficult to be accommodated within the limited space between the inside of the concrete block shells without violating the cover to reinforcement rule.

As the ingress of moisture through the mortar joint can not be prevented, the cover to reinforcement is measured from the outer surface of the grout which further limits the space to detail the lateral steel reinforcement.

Grout exerts bursting pressure due to the incompatible lateral expansion between the grout and concrete masonry shells triggering the failure of the masonry. The shells of the concrete block often do not possess the capability to confine the grout that is poured within its core. As a net result the grouted concrete masonry fails at stress levels that are far lower (up to 50%) than the stress at failure of both the concrete blocks and the grout. In other words grouted masonry fails at lower axial stress levels compared to both the hollow ungrouted masonry units and the grout cylinders.

Lateral reinforcement has the potential to confine the grout more than the shell. In the past researchers have tried in many ways to minimise the lateral movement of the grout by providing ties to the vertical steel reinforcement and fixing wire mesh around the grout [5]. Through some previous studies the author observed that the steel fibre reinforced concrete cylinders exhibit markedly reduced lateral expansion (and hence increase in compressive and direct and indirect tensile strengths). This has led to the belief that inclusion of steel fibre reinforcement to the grout could improve the performance of masonry prisms to compressive loading and increase its compressive strength. In this paper results of a pilot study on grouted concrete masonry with fibre reinforced grout carried out by the author are described.

PREVIOUS RESEARCH

The properties and behaviour of masonry is reported widely in the literature. Masonry with and without grout has typically been investigated [3,6,7,11,12,13]. The failure mechanism of concrete block masonry is discussed in the literature by several researchers [3,7,12]. These investigators have reported that the Poisson's ratio of concrete block is in the range of 0.12 - 0.15. The Poisson's ratio of the grout material is however higher than that of the units with the values ranging from 0.18 to 0.22. When the prism is subjected to axial compressive force, the grout material expands more than the units in the lateral direction and exerts lateral pressure to the outer shell that induces premature failure of prisms.

Recently some investigators have tried several lateral reinforcement design patterns for the masonry to confine its grout (Kumar and Dhanasekar [4], Khalaf et al [8], Singh and Cooke[14] and Dhanasekar et al [5]). Their results showed that the confinement of grout provided by the lateral ties increases the strength of a masonry prism. Detailing of lateral ties are more complex in masonry and the calculation of the exact amount of steel used for confining the grout is also difficult.

The author has ongoing research projects on steel fibre reinforced concrete (SFRC). As part of this research the effect of the method of compaction of steel fibre reinforced concrete on its compressive strength was studied [1]. It was concluded that the compressive strength of fibre reinforced concrete compacted by the needle vibration method was 28% higher than the compressive strength of the ordinary concrete. It was also concluded that a fibre content of 3% of the weight of concrete was the optimum. The increase in strength of the steel fibre reinforced concrete was attributed to the minimisation of the lateral expansion of the concrete (in other words lowering of the Poisson's ratio).

This paper describes the behaviour of masonry prisms filled with steel fibre reinforced grout. The optimum grout mix ratio identified by Kumar [9] and the optimum percentage of steel fibre identified by Bako [1] were used in this study.

EXPERIMENTAL PROGRAM

A total of 16 Concrete prisms were constructed and tested at the structural engineering laboratory of the central Queensland university Eight prisms were filled with ordinary concrete grout and the remaining eight prisms were filled with fibre reinforced concrete grout. Amongst the groups of eight prisms, four prisms were compacted using manual rodding and the other four were compacted using needle vibration..

The steel fibres used in this experimental study was FS186EE, in which 'FS' and 'EE' stands for fibre steel and enlarged end respectively. The nominal dimensions of the fibres are 18mm length, 0.6mm width and 0.3mm thickness with an average tensile strength of 450MPa(2).

The ingredients used in the concrete grout mix and the fibre reinforced concrete grout mix are given in Table-1.

Table 1. The ingredients used in grout mix

ordinary concrete grout	kg/m^3		Steel fibre reinforced concrete grout	kg/m^3
cement	350		cement	350
water	275		water	275
coarse sand	747		coarse sand	715.3
10mm aggregate	768		10mm aggregate	735.5
steel fibre	0		steel fibre	64.2

The amount of fibre added in the grout mix was 3% of its weight. Water-cement ratio (W/C ratio) and the aggregate cement ratio (A/C ratio) were kept constant for all sixteen prisms. From the mix proportion given in Table-1, it could be observed that the steel fibre is used as an aggregate. Even though the absorptivity of steel fibre is far less (almost negligible) than that of the other aggregates, no attempt was made to reduce the water content to compensate for the reduction in water absorption. The steel fibre reinforced grout mix was therefore sloppier than the normal grout. This was considered acceptable considering the field practices followed in masonry construction.

Grouted Masonry prisms

All prisms were constructed by a qualified brick layer. The block dimension was 190 mm X 190 mm X 390 mm. All masonry prisms were of three-high stack bonded type with height 590 mm, width 390 mm and thickness 190 mm.

The prisms were constructed on a firm flat concrete floor. 10mm thick mortar was used as the binder. The ratio of the mortar mix used in this study was 4.75 (kg/m^3) : 1.8 (kg/m^3) : 27.25

(kg/m^3) : 4.28 (kg/m^3) cement: lime: sand: water. After construction the hollow prisms were left undisturbed for five days.

On the sixth day the hollow core space was filled with grout material (ordinary concrete and steel fibre reinforced concrete). Grout was filled into each of the hollow cores of the concrete block unit of dimension 149mm X 65mm. As mentioned earlier the grout in four specimens was compacted by manual rodding method and the remaining four were compacted by needle vibration method. All the grout filled prisms were cured under plastic cover and left undisturbed for 28 days.

Testing of Masonry Prisms

After 28 days of curing, the concrete block prisms were removed from the plastic sheet cover and Demec gauges with 150mm gauge length were fixed on the broader face of the prism along the axial and lateral directions. Demec gauge points (Figure-1) were located in such a way that the gauge length run across the mortar joint in the axial direction to measure the strain effect during axial loading.

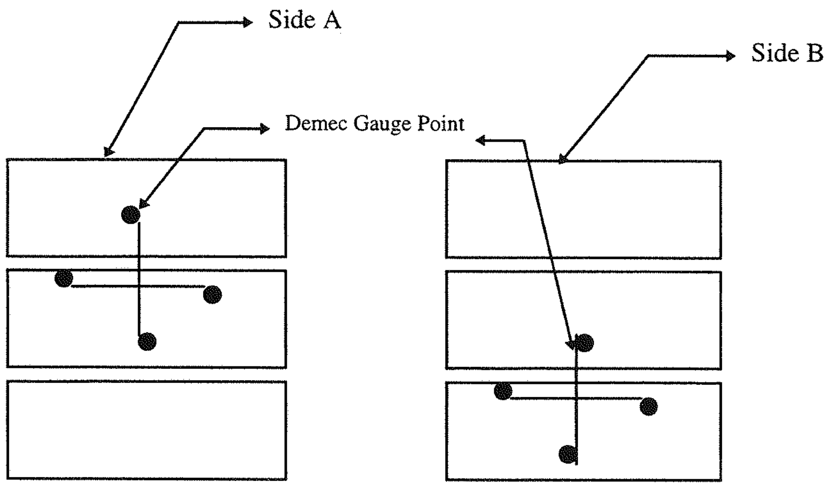

Figure-1 Strain Measurement in Masonry Prisms

All masonry prisms were tested in an Avery compression Testing machine of 1800kN capacity. Plywood capping of 4 mm thick was used between the bearing surfaces of the prism and machine platens. A constant rate of stress equivalent to approximately 12 MPa/min was applied in all the tests. Demec gauge readings were taken approximately at 150 kN load intervals. The strain measurements were discontinued at the load of 1050kN. The axial load was increased until each prism failed.

Failure of Masonry Prism

Figure-2 shows the typical failure of masonry prisms. There was not much difference between the failure mode of the concrete masonry prisms either for the type of grout fill (normal and steel fibre reinforced grouts) or for the different compaction methods (manual rodding or needle vibration). Even though the prisms showed notable cracks on their outer shells at the ultimate load, they did not fail explosively. All cracks ran predominantly parallel to the direction of loading,

Steel fibre reinforced concrete grout compacted by needle vibration method gave the highest compressive strength. The compressive strength results of prisms filled with normal concrete grout and steel fibre reinforced grout under different compaction methods are shown in Table-2.

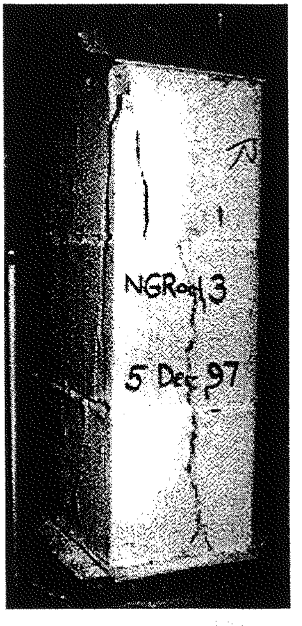

Figure-2 Failure Mode of Masonry Prisms

Table-2 Compressive strength of prisms at ultimate load of failure

Prism number	Axial stress(MPa)		Axial stress(MPa)	
	NG-ROD	NG-NEEDLE	SFG-ROD	SFG-NEEDLE
1	18.65	18.80	18.76	20.31
2	19.80	19.97	18.89	18.80
3	18.16	18.19	18.76	20.38
4	18.83	19.15	18.00	19.50
AVERAGE	18.86	19.03	18.60	19.75
Std. DEVIATION	0.69	0.74	0.41	0.75
Co. of VARIATION	0.04	0.04	0.02	0.04

In Table-2, NG stands for "natural grout (ordinary concrete grout)" and SFG stands for "steel fibre reinforced concrete grout". "ROD and "NEEDLE" stands for the two methods of compaction namely 'manual rodding' and 'needle vibration' respectively.

Effect of Method of Compaction and effect of steel fibre

Compressive strength of the masonry filled with ordinary concrete grout is not much affected by the method of compaction of the grout. It was observed that less than one percentage increase occurred between the manual rodding and needle vibration method of compaction for this type of masonry. However for needle vibrated steel fibre reinforced concrete grout, there was an increase of 6.2% in compressive strength compared to the SFG grout compacted by manual rodding. This shows that SFG requires more compacting effort to attain sufficient bond between the particles. This was also reported in Bako's [1] research work. For both NG and SFG specimens, the maximum compressive strength was obtained by the needle compaction method.

It was noted that there was a 4% increase in compressive strength of SFG compacted by needle compared to the compressive strength of NG compacted by needle vibration. Therefore this preliminary study shows that the addition of steel fibre in concrete grout mix minimises the lateral expansion of grout.

The strength ratio between the hollow full bedded prism and steel fibre reinforced grout (confined grout) was calculated and compared with the ratio obtained by other researchers in the past. The strength ratio values obtained from other researchers Kumar [9], Kumar and Dhanasekar [10] and Dhanasekar et al [5] are given in Table-3.

From Table-3 it was observed that the confinement of grout by adding steel fibre reinforcement gave the highest value of 83.3% of compressive strength of hollow masonry blocks. This could be because fibre reinforcement was distributed more or less uniformly throughout the grout mix and therefore minimised the expansion of the grout in all direction.

Table-3 The compressive strength ratio between hollow full bedded masonry prisms and the masonry prisms with confined grout

Group No	Specimen ID	No.of Specimens	Mean Strength (MPa)	ratio between hollow prisms and confined grouted prisms
1	Hollow masonry blocks(FBP)	4	23.7	83.3%
	Grouted- Steel fibre confined (This Research)	4	19.75	
2	Hollow masonry blocks(FBP)	10	35.7	52.4%
	Grouted-transverse triangular ties (Kumar [8])	5	18.7	
3	Hollow masonry blocks(FBP)	8	20.1	69.2%
	Grouted- fine wire-mesh- confined (Dhanasekar et al[4])	6	13.9	
4	Hollow masonry blocks(FBP)	8	20.1	74%
	Grouted-welded wire mesh- t confined(Dhanasekar et al[4])	6	14.9	

Lateral Strain Variation

By minimising the lateral expansion of grout one can maximise the strength of the prism. The variation of lateral strain with the axial stress is plotted in Figure-3.

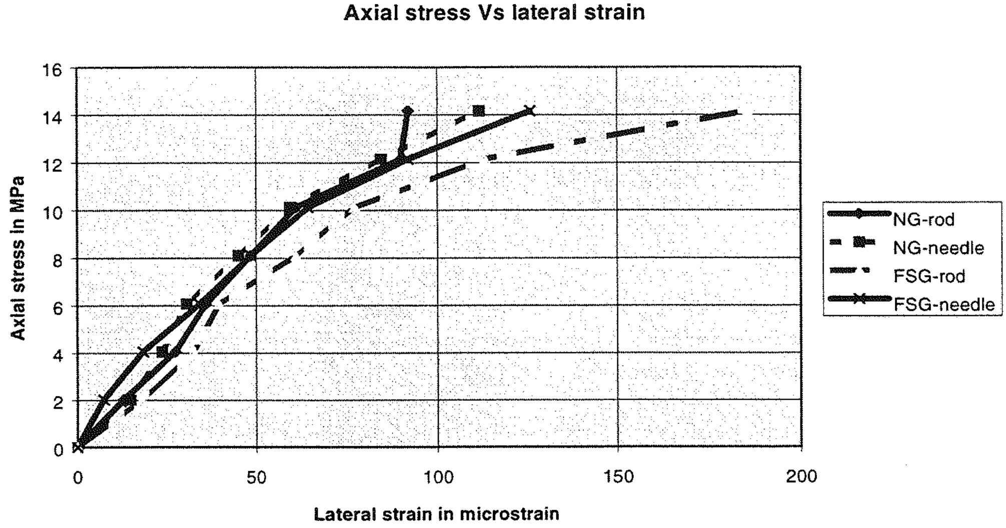

Figure-3 Lateral Strain Variation for the Prisms

Each line shown in Figure-3 is the average of the readings of three prisms. It should also be noted that on each prism strain measurement was taken on both broader faces. Even though the location of these strain measurements on the opposite faces did not correspond to each other exactly (Refer Figure-1), no significant difference in the measured lateral strains was evident.

In Figure-3 axial stress in MPa is plotted on the Y-axis and the average lateral strain in microstrain is plotted on the X-axis. It is observed from Figure-3 that the compaction methods do not exhibit significant sensitivity for masonry filled with ordinary concrete grout. However somewhat significant difference in lateral strain is evident between the two methods of compaction for the masonry filled with steel fibre reinforced grout (SFG). SFG compacted by manual rodding exhibited higher lateral strain compared to the needle vibration case. This further illustrates that compaction by manual rodding is not suitable for steel fibre reinforced grout.

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CONCLUSIONS

From the test results of the pilot study with 16 masonry prisms filled with ordinary concrete and steel fibre reinforced concrete grouts it was concluded that:

a) the addition of steel fibre in the grout mix increases the strength of concrete masonry prisms;

b) the increase in strength is the effect of reduction in lateral expansion of the grout fill;

c) the manual rodding compaction method is not suitable for steel fibre reinforced concrete grout; needle vibration is required to be performed to achieve the benefits of the SFG; and

d) SFG filled concrete masonry appears to outperform other forms of confinement tried by other researchers, namely, the triangular ties (Kumar [9]), and the fine wire mesh and welded wire mesh (Dhanasekar et al [5]).

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