Chapter 9

Conclusions and Recommendations

9.1 Background

The general conclusions and recommendations are given in this chapter. The conclusion is divided into four sections viz: conclusions from literature reviewed, effect of steel fiber content on concrete properties, slab tests and the comparison between theoretical and actual behaviour. General recommendations are given for further investigation.

9.2 Conclusions

9.2.1 Literature Reviewed

According to the literature, the following conclusions can be drawn:

- The hook-ended steel fibers are found to yield the best performance compared to the other types of the steel fibers. The addition of the steel fibers should follow a certain procedures to avoid the clumping and to achieve better distribution of these steel fibers. The addition of the steel fibers to concrete requires additional paste to produce a workable mix. Therefore and alteration is required to proportioning mix design procedure to compensate for the additional required paste. The practice of transporting, placing and finishing for the conventional concrete is applicable to the SFRC.
- The steel fiber reinforced concrete is found to improve the mechanical and the physical characteristics of the concrete. The steel fiber imparts an after cracking toughness due to the mechanism of the crack arrest, which hinder the development of cracks unless higher load values are applied. That toughness is responsible for that improvement in the engineering properties of the SFRC. The improvement is ranging between significant in some characteristics and insignificant in others depending on the steel fiber dosage and type.
- The improved engineering properties of the SFRC affect the properties of ground slabs as follows:
    - Improved performance capability due to the reduction or elimination of most of concrete distresses.

- Less thickness can be provided due to the higher flexural strength (compared to the plain concrete). The reduced section depth implies higher deflection values.
- Design methods for conventional concrete ground slabs can be used to design SFRC, the only alteration required is that, deflection should be taken into account in choosing the slab depth.
- Better economy for the SFRC ground slabs due to savings in materials, joint spacing and maintenance cost.

9.2.2 Effect of Steel Fiber Content on Properties of Concrete

The effect of the steel fiber dosage on workability, compressive strength, modulus of rupture, modulus of elasticity and toughness as investigated in this program can be summarized as follows:

- The workability is less sensitive to low steel fiber dosages and the sensitivity increases with the increase of the dosage.
- Steel fibers content up to 30kg/m^3 has the following influence:
  - Negligible influence on the compressive strength at 7 and 28 days.
  - Insignificant influence to the MOR.
  - Slight increase to E-modulus.
  - Increase the first crack strength by about 25%.
  - Significant influence on the toughness.

9.2.3 Slab Test

The investigation on two *full-scale slabs* loaded at interior edge and corners and subjected to static load revealed the following:

- Keeping in mind that the SFRC slab is 16.6% thinner, the plain concrete slab has slightly higher load capacity and slightly less deflection compared to the SFRC slab.
- In comparison to plain concrete slab, a reduction of about 16.6% is possible for ground slabs using hook-ended steel fibers with dosages as low as 15 kg/m^3.
- The structural advantage for SFRC indicated by steel fiber manufacturer was found to slightly over-estimate that strength of the SFRC.

The investigation conducted on *core specimens* taken from the full-scale slabs and tested at 90 days is summarized as follows:

- Strength variation among steel fiber cores is less than that for plain concrete. The SFRC seems to have a higher consistency than plain concrete.
- SFRC cores had a gradual or slow failure mechanism compared to plain concrete cores.
- The gain of strength for the SFRC is higher than that for plain concrete.
- The actual and potential compressive strength of the SFRC might be estimated from core specimen using conversion formulas developed for plain concrete.

The investigation performed on *sawn beam specimens* taken from the full-scale slabs and tested at 90 days might be summarized as follows:

- The flexural strength of the SFRC beams was greater than that of plain concrete beams.
- The Japanese method (JSCE-SF4) is found to be more realistic to interpret and calculate the toughness of the SFRC than the American method (ASTM C: 1018).
- Gradual type of failure is obtained for the SFRC beams (unlike plain concrete).
- The modulus of elasticity for SFRC can satisfactorily be calculated using data from third-point loading test.
- The flexural strength of SFRC might be obtained from cube compressive strength using formula similar to that used for plain concrete. The flexural strength of both SFRC and plain concrete is slightly over estimated by the formula.

9.2.4 Comparison Between Theory and Practice

- Huge differences were found between measured load capacity and calculated load using Westergaard and Meyerhof models while less difference was obtained by using the models given by Falkner et al and Shentu et al.
- Westergaard model is found not suitable for the SFRC slabs because it does not take the after cracking strength into account.

- Falkner et al and Shentu et al do consider the after cracking strength but do not calculate edge and corner loads. One of Shentu et al model inputs is the direct tensile strength, which is difficult to assess.
- Based on the result of this investigation, none of the four modes is found suitable to apply for ground slabs.

9.3 Recommendations

- The effects of the fiber dosage on fatigue characteristics, impact strength, shear strength, shrinkage, creep, thermal properties and durability require further investigation.
- Further research to study the influence of fiber contents higher than 30 kg/m^3 is required.
- Slabs similar to those investigated in this research can further be tested for cyclic loading. The static or semi-static load can only simulate few cases of the ground slab loadings such as racking or platforms on industrial floors. Cyclic load is seen to be better simulating the other type of ground slabs loading. Behaviour of slabs test with cyclic loading application might differ significantly from those with the semi-static loading. Much improvement might be realized by adding the steel fiber to concrete if the cyclic load is considered.
- Future investigations on slabs should consider the dimension of the slabs and corner and edge conditions. Larger slabs dimensions are recommended.
- The load transfer characteristics and joint efficiency for the SFRC ground slabs can also be evaluated.
- Due to the fact that the SFRC has a higher flexural strength (taking the after crack strength into account) less slab depth can be provided compared to plain concrete. The SFRC slabs therefore yields higher deflection values which might lead to failure of the underlying layers either due to densification or/and the shearing of these layers. Further test are recommended to investigate the deflection characteristics of the steel fiber reinforced concrete and establish a correlation that consider the following aspects:
  - The effect of the slab thickness on deflection.
  - The effect of the steel fiber dosage on the slab thickness (higher

dosage imply higher design flexural strength and thus less slab depth)

- The effect of the modulus of foundation reaction (higher K-value implies less deflection if all other factors remain constant).

The correlation should consider the maximum or allowable deformation that can be withstood by the foundation layers without densification and shearing (for different K-values there should be different deformation characteristics for the specific foundation).

- Although the Japanese method (JSCE-SF4) for interpreting and calculating the toughness of the SFRC has been used in this investigation, it's application on ground slabs should further be investigated. Ground slabs have different deformation characteristics due to the either complete support or/and partial support. Correlation between the allowable ground slabs deflection and the free deflection from beams specimens should be established. The toughness of the SFRC to be used for ground slabs can be calculated at that deflection.
- The gain of strength associated with the SFRC should be investigated. The hydration of the cement in concrete mixes increases the strength of the concrete. With time additional strength develops an additional bond between the steel fibers and the paste, which imply more strength. That strength can be explained by the additional stresses required to pull out or to break the steel fibers. Therefore the assessment of that strength gain might be beneficial for thickness designs of ground slabs and eventually affect the whole economy of that specific pavement, especially for pavements that doesn't require an early opening for the traffic.
- Further investigations are required by using larger slabs to further assess Meyerhof formula.
- Theoretical formula to assess the plastic deflection is required.
- Finite element analysis can be performed and the correlation between theoretical and practical results can then be investigated.