

Performance of Concrete Slabs with Different Reinforcing

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ABSTRACT: This paper describes a test programme at the University of Canterbury to evaluate the performance of elements of concrete slabs that are reinforced in different ways. The reinforcing includes steel fibre, brittle mesh, ductile mesh and two grades of reinforcing bars. The percentage of reinforcing varies. Shear and flexural tests are conducted. The work described is in the initial stages of testing, so this paper concentrates on the methodology for selecting the test types and parameters.

1 INTRODUCTION

In New Zealand buildings, significant cracks in concrete floors or slabs are not regarded as being acceptable. According to NZS 3101: Part2: 2006, Table C2.1, recommended maximum surface width of cracks at the serviceability limit state for interior environments, which is fully enclosed within a building (exposure classification of A1), is 0.4 mm. These cracks may occur due to shrinkage, creep and gravity loads in commercial construction. Examples of common commercial construction are given in Figure 1(a) and 1(b). These show a steel-deck-composite slab, and a hollow-core precast concrete slab construction. An example of a slab cracking is in Figure 2, in a NZ multi-storey building from 1980's construction.

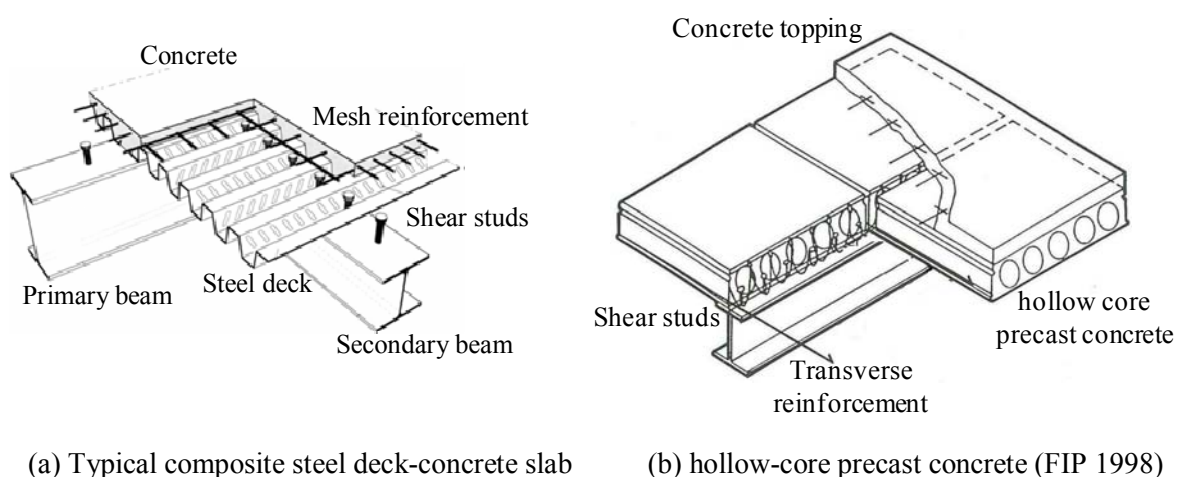


Figure 1. Schematic of flooring systems

In composite construction, in the primary beam (girder) application, tensile forces in the slab caused by secondary beam-end-rotation due to secondary beam deflection under load, shrinkage, and no deck negative bending strength transverse to the primary beam, all contribute to tendency to longitudinal

cracking (Chien & Ritche 1984), as shown in Figure 3. Therefore, there is a possibility of one large and undesirable crack, rather than several smaller cracks, if there is insufficient transverse reinforcement. There are also concerns about the ability of these slabs to resist high point loads, as well as to prevent longitudinal splitting.



Figure 2. Cracking in a composite slab over intermediate support (Photo courtesy: B. Galloway)

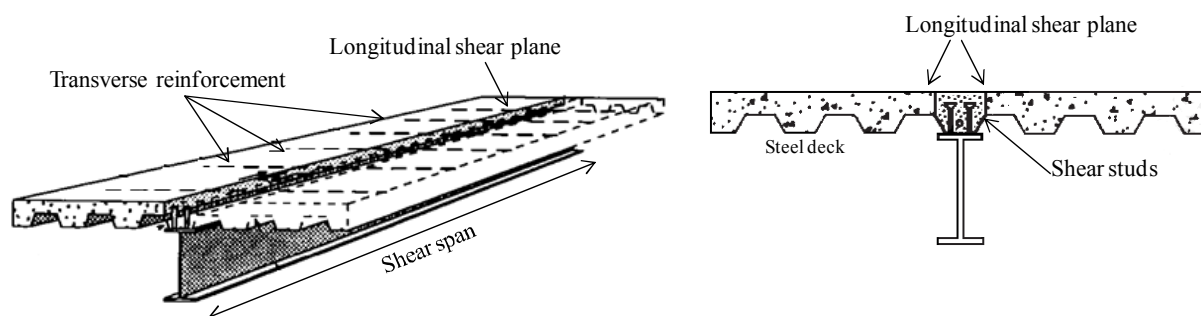


Figure 3. Potential longitudinal shear plane (NZS 3404:Part2: 1997, Figure C13.4.10)

In addition, concerns have been expressed about the ability of slabs with cracks to resist horizontal seismic loads. Furthermore, after the 2010 Darfield/Canterbury earthquake, many residential house floor slabs suffered damage. Much of this damage resulted from relative settlement and lateral spreading of different pours of concrete slabs on liquefiable soils as shown in Figure 5.

In most of these cases there was no reinforcement between these different residential floor slabs. While these houses met the NZS 3604 design criteria, the NZ Department of Building and Housing have issued guidance stating that more rigorous and stringent requirements should be used to ensure better performance of house foundations on poor soil. This was done even though the likelihood of an earthquake of similar magnitude in the lifetime of a structure is considered to be low.



Figure 4. Crack in slab after the 2010 Darfield/Canterbury earthquake

There has been significant discussion in the design community regarding the best way to ensure better performance for floors of buildings and houses. In particular, there are differing opinions about the efficiency of reinforcing floors in different ways. Some consultants state that brittle mesh should not be used (brittle meshes are the traditional New Zealand meshes, e.g. 665 and 662, these are classified as 500L according to AS/NZS 4671:2001). Others have stated that neither brittle nor ductile mesh (ductile mesh is made from hot rolled bar, rather than cold drawn wire, and provides a minimum uniform elongation of 15%) is effective, and others state that neither mesh nor rebar of any sort has any effect. To compound these arguments, the steel fibre suppliers are keen to see their products in more applications, possibly together with other reinforcement systems. The advantages of this are less likely to be structural, but may be in terms of factors such as improved fire resistance. Moreover, steel fibre reinforced concrete (SFRC) provides a time-saving benefit over conventional mesh reinforcing solutions by eliminating the need for delivery, storage, lifting and placing of the mesh in construction. Hence, the use of SFRC has gained popularity to replace nominal reinforcement in many applications, such as steel deck composite floors, ground-supported floors and pile-supported floors. For these reasons, it can be seen that it is necessary to understand the performance of concrete slabs in which flexural, shear or tension cracking may occur with different types of reinforcement.

This paper describes a project evaluating the behaviour of both un-cracked and pre-cracked concrete components with different types of reinforcing (steel fibre, mesh, and rebar) under shear and flexural testing. While the overall project is focused on solving the gravity issues, this part of the project is just as relevant to the current seismic issues. The project is currently in its initial stages, so the paper describes the test programme and the rational/methodology for selecting the specific tests, configurations and parameters.

2 TEST PROGRAM

2.1 Concrete and steel fibre

To evaluate the effect of the concrete compressive strength, two reference concrete mix designs were developed to achieve 30 MPa and 50 MPa after 28 days. One type of fibre (Dramix RC-80/60-BN), which is being used in common composite construction, was considered. Table 1 gives the properties of the steel fibre.

Six different dosages of fibre were considered, including plain concrete. Since the inclusion of fibres significantly affect the workability properties of fresh concrete, rheological testing has been carried out to achieve an optimum mix design for each dosage of fibre. Rheological tests were conducted using the BML viscometer machine. As a result, twelve mix designs were developed. The compositions of the mixes are summarized in Table 2. Locally available coarse aggregate (semi-crushed having maximum size of 13mm) and fine aggregate (natural river sand) were used in all concrete mixes.

Table 1. Properties of the steel fibre

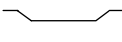
Length (mm)	Diameter (mm)	Aspect ratio (l/d)	Ultimate tensile strength (MPa)	Elastic modulus (GPa)	Density (kg/m ³)	Deformation	Shape
60	0.75	80	1050	200	7850	Hooked end	

Table 2. Mixture composition and properties of the concrete

28-day design strength (MPa)	Fibre Dosage (kg/m ³)	Fibre volume fraction (%)	w/c ratio	Water (kg/m ³)	Cement (kg/m ³)	Coarse aggregate (kg/m ³)	Sand (kg/m ³)
30	0	0	0.6	168	280	1100	868
	10	0.13		170	283	1080	877
	20	0.25		172	287	1040	906
	40	0.51		175	292	920	1007
	60	0.76		185	308	750	1129
	80	1.0		190	317	600	1252
50	0	0	0.42	167	398	1100	772
	10	0.13		169	402	1080	779
	20	0.25		172	410	1040	802
	40	0.51		175	417	920	901
	60	0.76		180	429	750	1041
	80	1.0		185	440	600	1161

2.2 Mesh and rebar

Three types of steel mesh, one ductile and two brittle, will be investigated. Properties provided by the manufacturer of the meshes, such as characteristics of ductility and strength are given in Table 3. Ductile mesh is being fabricated from hot rolled bar rather than cold drawn wire, and provides a minimum uniform elongation of 15% (AS/NZA 4671:2001), which satisfies the requirements of the concrete construction for seismic and structural purposes.

Table 3. Steel mesh nominal properties

Mesh	Diameter (mm)	Cross sectional area (mm ² /m)	Pitch (mm)	Lower Characteristic Value Yield stress (MPa)	Minimum 0.2% Proof Stress (MPa)	Uniform elongation (%)
665	5.3	147.1	150	500	485	1.5
662	7.1	263.9	150	500	485	1.5
DM170	7	171.1	225	390	-	15

To study the effect of reinforcement grade and bar diameter, two grades of reinforcing bars, and two different bar diameters are to be tested (Table 4).

Table 4. Rebar properties

Rebar	Grade	Diameter (mm)	Cross sectional area (mm ²)	Lower Characteristic Value Yield stress (MPa)	Uniform elongation %
D12	300-E	12	113.1	≥ 300	10
D16	300-E	16	201.06	≥ 300	10
D12	500-E	12	113.1	≥ 500	10
D16	500-E	16	201.06	≥ 500	10

2.3 Shear tests

There have been studies on the transfer of shear stress across a definite plane in reinforced concrete (Swamy et al. 1987; Mattock and Hawkins 1972; Mattock 1974; Walraven and Reinhardt 1981). These studies show that the development of tensile stresses created on the reinforcement, crossing the shear plane, through slippage and crack opening induces clamping forces between the crack faces (Swamy et al. 1987). Also, past studies have shown that fibres improve the shear performance of both normal-weight concrete and light-weight concrete (Higashiyama and Banthia 2008; Majdzadeh et al. 2006; Mirsayah and Banthia 2002; Valle and Buyukozturk 1993; Narayanan and Darwish 1987). However, although steel mesh is being used in composite floor construction and slab on grade, no published experimental data and evidence on the performance of this type of reinforcing in direct shear are available. Moreover, no systematic research could be found which compares the performance of steel mesh (ductile and brittle), steel fibres and rebar.

Among existing test methods for evaluating shear strength and shear toughness, Z-type push-off specimen (Figure 5(a)) has been widely used for both traditionally reinforced concrete and SFRC. This is also known as Hoffbeck-style test. It is not a standardized test procedure, and different specimen sizes have been used in past studies. For instance, Hoffbeck et al. (Hoffbeck et al. 1969) used specimens 546mm high with a cross section of 254mm by 127mm. Walraven and Reinhardt (Walraven and Reinhardt 1981) used 600mm high specimens with a cross section of 300mm by 120mm. Khaloo and Kim (Khaloo and Kim 1997) used 520 x 300 x 125 mm samples. Although using the Hoffbeck-style push-off specimen properties of SFRC could be measured in direct shear, the stress field in the specimen beyond cracking is highly complex, and stress conditions deviate significantly from being in pure shear (Mirsayah and Banthia 2002). Moreover, the specimen preparation is a cumbersome procedure if a large number of tests have to be carried out.

The Japanese Society of Civil Engineering (JSCE) has proposed a standard method (JSCE-G 553, 1999) (Figure 5(b)), which is a modified version of (JSCE-SF6, 1990). This standard is an improvement over the Hoffbeck-style specimens. During this test, the stress field remains substantially that of pure shear, and hence more reproducible shear response is obtained (Mirsayah and Banthia 2002). The specimen size in this method is 100 x 100 x 350 mm. It can be seen that the size of the JSCE test specimen is specifically design for SFRC and it does not provide enough space to accommodate reinforcement. In addition, since during the test procedure, the applied force creates two shear planes in the specimen, it would be difficult to have pre-cracked shear specimens to be tested.

Because of the deficiencies and complexities of the aforementioned shear test methods, it was decided to conduct the shear tests as per FIP (Federation Internationale de la Precontrainte) standard (Figure 5(c)). The size of the specimen in this method is 250 x 250 x 540 mm. In the FIP's developed test method, the interface is theoretically subjected to pure shear forces, and the occurrence of a bending moment owing to force eccentricities is minimized (Beushausen and Alexander 2007). These test samples are easy to construct.

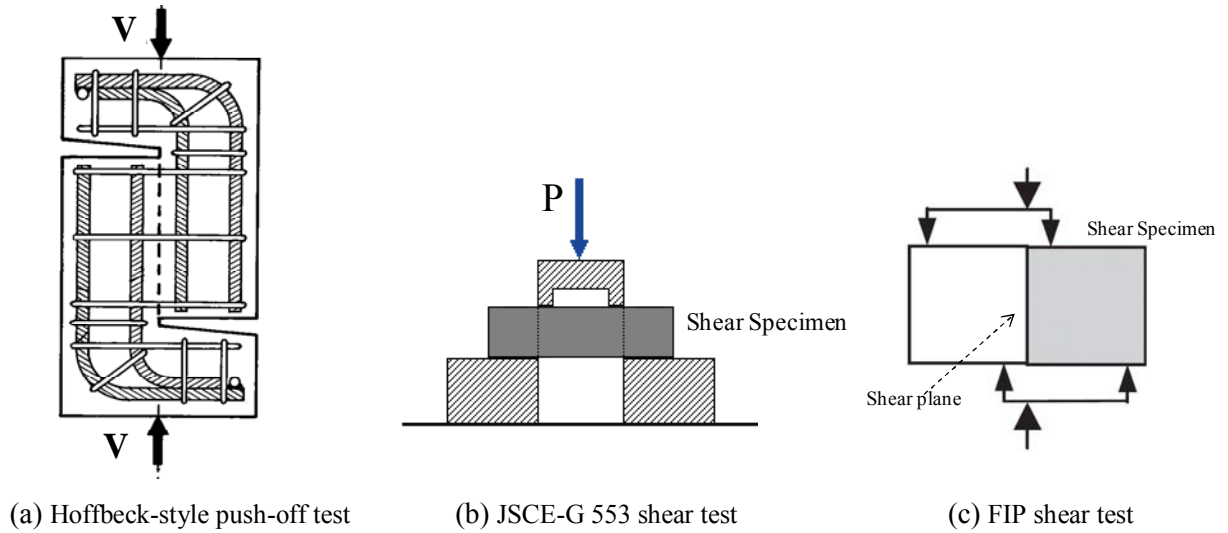


Figure 5. Schematic of shear tests

In the current research several series of specimens will be tested, in which the amount of reinforcement (ductile/brittle mesh- rebar and steel fibre) across the shear plane is variable. Different reinforcement ratios ranging from 0.1% to 0.4% for steel mesh, and 0.1% to 0.9% for rebar were considered. Three samples were cast for each configuration and are to be tested at age of 56 days.

Moreover, to investigate the effect of pre-cracking along the shear plane, prior to the shear test, some of the specimens will be pre-cracked first. Both crack width opening and slippage will be measured during the test. To investigate the effect of specimen size, 150 x 150 x 540 mm specimens were also cast for some of the SFRC mixes.

2.4 Flexural tests

Flexural tests will be conducted as per EN14651 standard (Figure 6). The test procedure provides for the determination of the limit of proportionality (LOP) and of a set of residual flexural tensile strength values. The tensile behaviour of SFRC is evaluated in terms of residual flexural tensile strength values determined from the load-crack mouth opening displacement curve or load-deflection curve obtained by applying a centre-point load on a simply supported notched prism (EN14651, 2005). This test is similar to the recommendations of RILEM TC-162 which is adopted in NZS3101:2006.

Three prismatic specimens of 150 x 150 mm² cross section and a length of 550 mm were cast for each mix of SFRC as shown in Table 2. Flexural specimens will be tested at age of 56 days. The notch at midspan will be produced on one of the faces perpendicular to the casting surface, using wet sawing. The width of the notch will be less than 5 mm, with a depth of 25 mm, leaving a section with a net depth of 125 mm at midspan. The tests will be carried out with closed-loop testing equipment, displacement or deflection controlled, not load controlled. This requires stiff equipment and high responsive system.

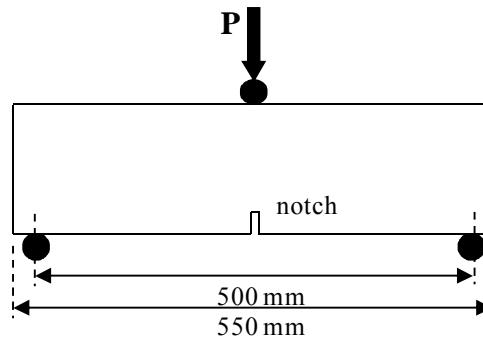


Figure 6. Schematic of EN14651 flexural tensile test

2.5 Other tests

For each SFRC mix, six concrete cylinders of 100 x 200 mm were cast, and will be tested at ages of 28 days and 56 days in accordance with ASTM-C39 standard test method to determine the compressive strength and elastic modulus. Moreover, three more cylinders were cast to determine the splitting tensile strength of each SFRC mix according to ASTM-C496 standard at an age of 28 days. Preparing and curing of concrete shrinkage specimens, and determination of the length changes of the specimens due to drying in air were conducted as per AS 1012.13-1992 for each SFRC mix.

3 INTERPRETATION OF RESULTS

When results are obtained, strengths (peak and unloading behaviour), crack widths, and number of cracks will be obtained for the different tests. This information will be useful in assessing whether or not a particular reinforcing will be appropriate in a particular situation.

If a new type of reinforcing is developed, or a different type of steel fibre that it not used in this test configuration, is used, then it is useful to be able to compare the relative performance or to establish equivalence with testing already performed with different configurations. This may be relatively easily conducted by performing both shear and flexural tests with the new reinforcing. The strength and the rate of unloading with displacement can be compared with test results of existing materials to establish equivalence.

4 CONCLUSIONS

This paper describes a test programme at the University of Canterbury to evaluate the performance of elements of concrete slab reinforced in different ways. The following are discussed:

1. The need for work on slab reinforcing is necessary to improve the behaviour of multi-storey and residential building construction.
2. The selection of test types for both shear and flexure.
3. The test parameters including specimen size, reinforcing types (steel fibre, brittle mesh, ductile mesh and two grades of reinforcing bars), reinforcing volumes and concrete properties.
4. The methodology to compare the behaviour of concrete reinforced in different ways.

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