UniServices
Auckland UniServices Limited

Testing of Cupolex® Flooring System

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a wholly owned company of

THE UNIVERSITY OF AUCKLAND

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1 Introduction

This report describes the testing of six concrete slabs by Auckland UniServices Limited. These slabs were constructed in the Civil Engineering Test Hall at the University of Auckland by Dempsey & Wood Civil Contractors Limited, using the Cupolex® aerated flooring system. Auckland UniServices Limited were contracted to conduct these tests by Cupolex Australasia Limited. The aim of these tests was to validate the strength of concrete floors constructed using the Cupolex® system so that such floors can be used to construct residential or garage floors in New Zealand. In order to meet the requirements of the New Zealand Loading Standard [1], garage floors are required to resist a point load of 13 kN. In accordance with NZS 4203:1992 [2] this point load was applied through a square load point with sides of 300 mm.

2 The Cupolex® aerated flooring system

Cupolex® is a proprietary aerated flooring system developed and patented by Pontarolo Engineering S.r.L. – San Vito al Tagliamento (PN) Italy. The system consists of modular plastic elements manufactured from recycled polypropylene. These modules come in a variety of sizes. All have a plan area of approximately 560 mm by 560 mm, and depths ranging from 50 mm to 500 mm. Figure 1 shows a sketch of a 260 mm deep Cupolex® module. The purpose of the product is to reduce the volume of concrete and the quantity of reinforcement required to create a floor, resulting in a cost saving for the client. To achieve this, multiple modules are placed in an overlapping grid pattern as shown in Figure 2.

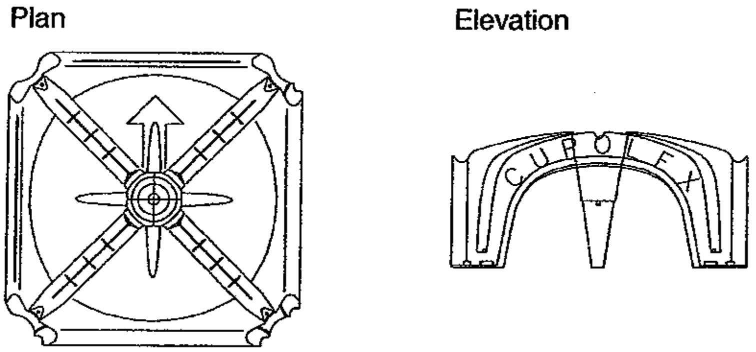


Figure 1. 260 series Cupolex® module

Where there is a need to interrupt the grid of Cupolex® modules such as at the edge of a floor, or around a column, specifically designed "Beton Stop®" modules are used to close off the open ends of the Cupolex® modules. Beton Stop® was also developed by Pontarolo Engineering, and its use is shown in Figure 3. A key feature of Beton Stop® is the ridges as seen in Figure 3. These allow flexibility in positioning the Beton Stop® module.

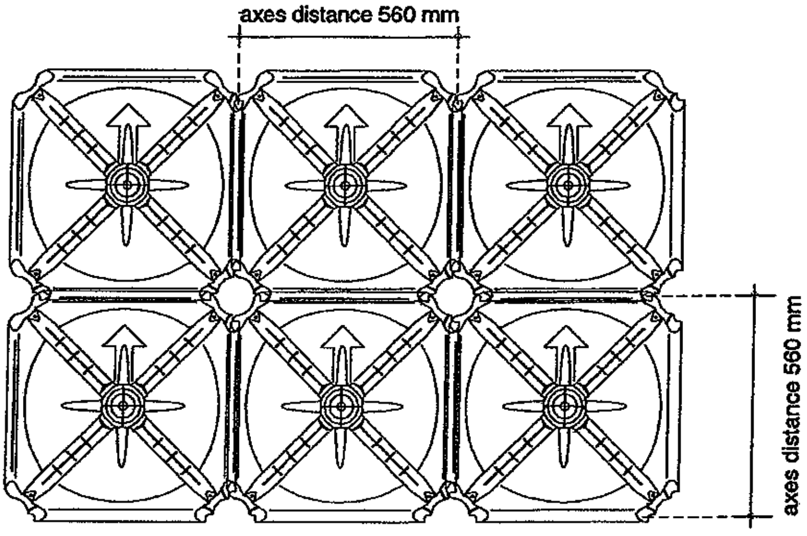


Figure 2. Grid arrangement of Cupolex® modules

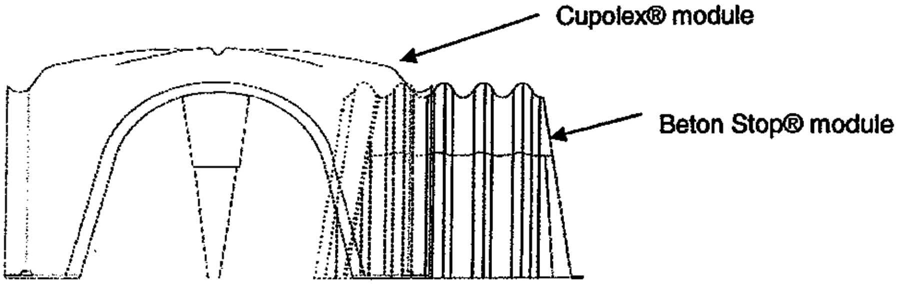


Figure 3. Use of Beton Stop® module to close open end of a Cupolex® module

3 *Test specimens*

Six flooring units were tested as part of this program. The floor units were 2,170 mm by 2,170 mm in plan, and had a total depth of 300 mm. Each unit contained nine 260 mm deep Cupolex® modules, arranged in a grid pattern as shown in Figure 2. Figure 4 shows a plan and a through-section of a typical test unit. Note that in the plan view the Cupolex® and Beton Stop® modules are not visible, since this is a top view. The outline of the 560 mm square grid on which the Cupolex® modules were aligned is shown, along with the specified extension of the Beton Stop® modules.

The six test specimens were divided into two groups. These were differentiated by the reinforcement used in the slab. Group N ("normal") were reinforced with only a single layer of 688 mesh in the top of the slab, while group G ("garage") were reinforced with the 668 mesh and an additional grid of D10 reinforcing bars, placed within the valleys between the Cupolex® modules (and thus at 560 mm centres). At the time of casting, the units were arbitrarily numbered N1-N3 and G1-G3. All units were mounted on a layer of polystyrene approximately 50 mm thick. This was intended to simulate the flexibility of a typical subgrade that a slab might be founded on in practice. In order to simulate the worst likely bearing conditions 50 mm was cut off the bottom of the central pillar of the Cupolex® module beneath the load point in each test unit. This accounted for the possibility of a Cupolex® module spanning an uneven surface or an area of soft ground, preventing effective force transfer through the pillar.

During construction of unit N3D (D for damaged) the central Cupolex® dome underneath the load point was split. It was decided to proceed while using the damaged Cupolex® module so that the effect of this damage on the strength of the slab could be investigated. The main effect of the split was to allow concrete to enter the hollow chamber underneath the central Cupolex® module as shown in Figure 5. The concrete that leaked through to the interior of the module formed a concrete strut, with a cross section bearing on the polystyrene of approximately 400 mm by 500 mm.

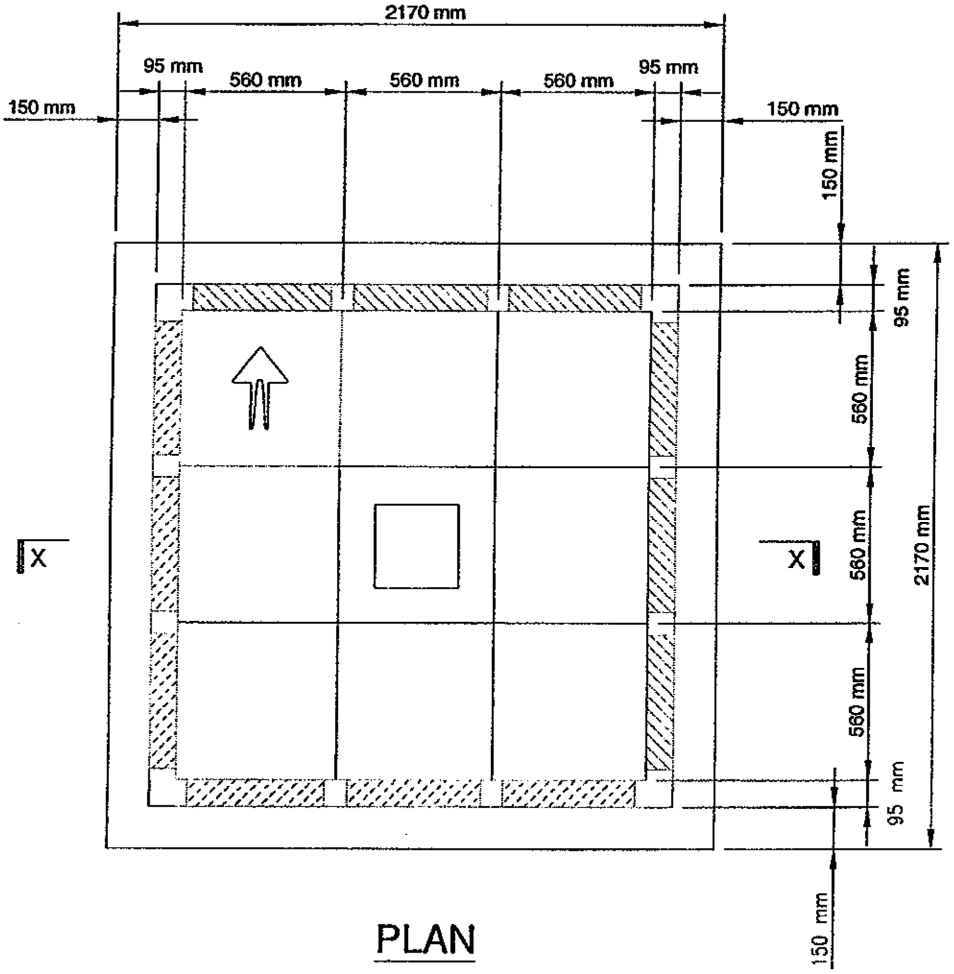
4 Test method

The test specimens were subjected to unidirectional loading. A concentrated force was applied at the load point (marked in Figure 4) by a single actuator with a capacity of 500 kN and a stroke of ±300 mm. The actuator reacted against a steel frame as shown in Figure 6. The force was applied to the slab through a steel bearing plate. For the first five tests conducted this plate was a square with sides of 300 mm (area 0.09 m^2). For the final test, of unit G3, the plate was reduced to a square with sides of 150 mm (area 0.0225 m^2). The applied force was measured by a load cell attached between the actuator and the bearing plate. The displacement of the load point was measured using a single portal gauge transducer. This was connected to the bearing plate and to a steel angle connected to the reaction frame.

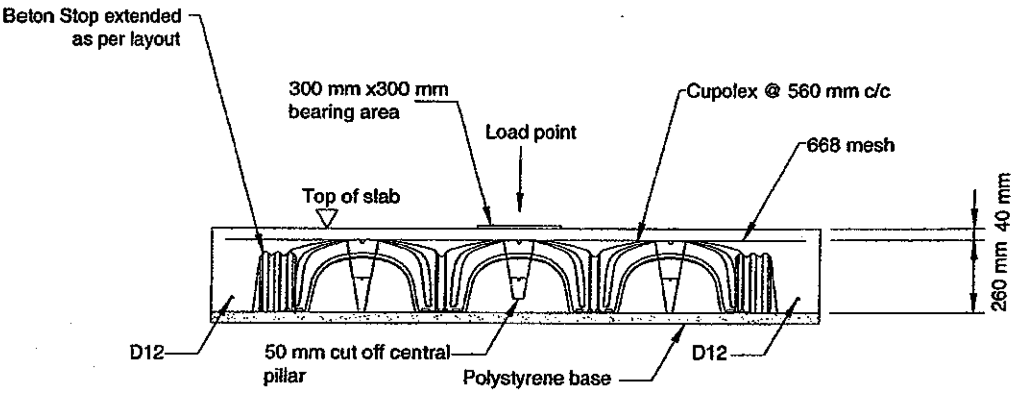
A variety of load histories were applied. These are listed below in the order that the units were tested.

N3D:	monotonic testing until failure
N1, N2, G3:	unidirectional cycles to 10, 20, 40 and 60 kN then to failure
G2:	unidirectional cycles to 10, 20, 40, 60, 75, 85, 95 and 105 kN then to failure
G1:	unidirectional cycles to 10, 20, 40, 60, 70, 80, 90, 100 and 110 kN then to failure

Unit N3D was tested monotonically to obtain an idea of when failure was likely to occur. It was assumed that this unit would be stronger than the other N units due to the solid concrete strut directly under the load point. Based on the results of this test it was decided to subject units N1, N2 and G3 to unidirectional cyclic loading as listed above. Based on the results obtained from testing unit G3 it was decided to increase the cyclic loads applied to unit G2. Finally, for unit G1 the potential for punching shear failure was tested by reducing the area of the bearing plate by a factor of four as previously mentioned.



PLAN



SECTION X-X

Figure 4. Cupolex® flooring system test specimen

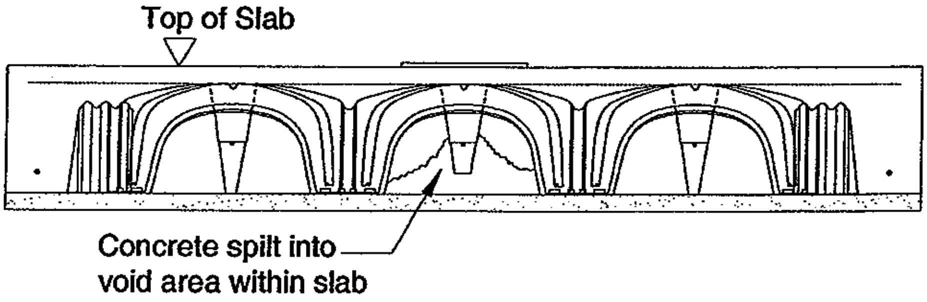


Figure 5. Effect of central Cupolex® module splitting during construction

At the time the concrete for the six test units was poured a large number of concrete cylinders were constructed. These were stored in a water bath, having a temperature that was matched to the internal temperature of the test units using the temperature matched curing system developed by Allied Concrete [3]. Cylinders were crushed at regular intervals by Allied Concrete to monitor the compressive strength of the concrete, and testing of the floor units commenced when the strength of the concrete reached 20 MPa. Units N1, N2 and N3D were tested on Friday 11th November 2005 and units G1, G2 and G3 were tested on Tuesday 15th November 2005.

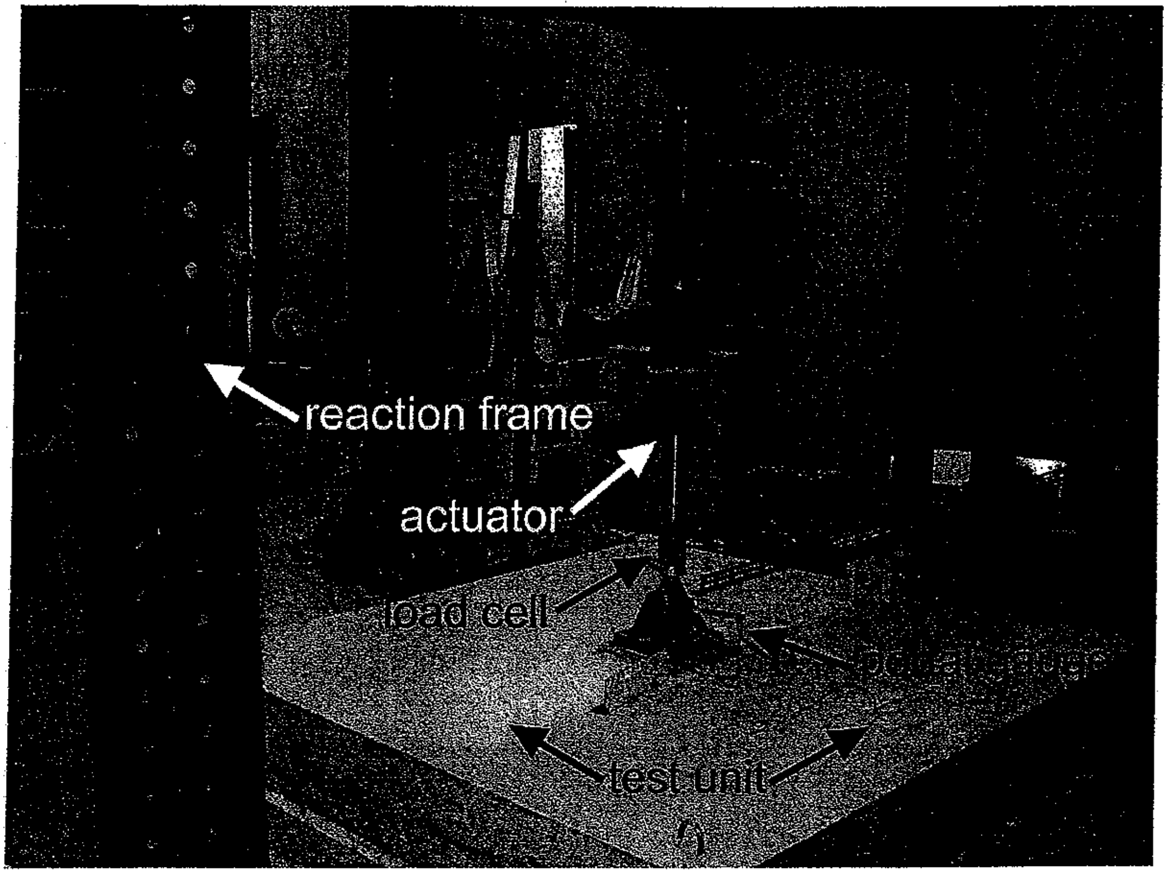


Figure 6. Test rig

5 *Experimental Results*

The force-displacement response of the six test units is discussed in this section. The responses of the six units are shown in Figure 7, Figure 8, Figure 9, Figure 10, Figure 11 and Figure 12.

Figure 7 shows that unit N1 sustained a load of approximately 90 kN without significant decrease in stiffness. Repeated loading did not affect the stiffness of the unit, and the slab behaved elastically when subjected to a force of 60 kN. If larger forces had been applied repeatedly it seems likely that elastic response would have been obtained for forces as large as 85 kN, based on the linear force-displacement response until this level.

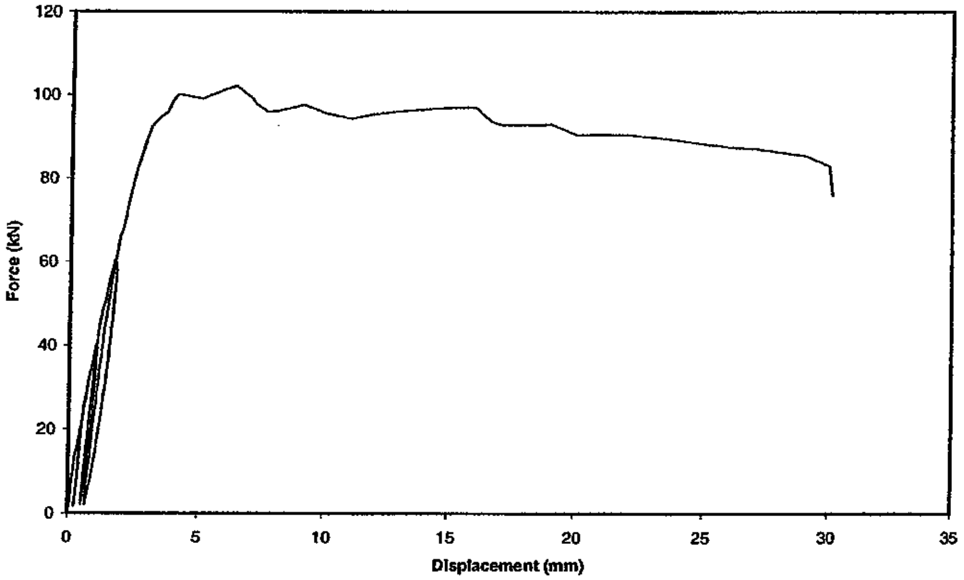


Figure 7. Force-displacement plot for unit N1

The response of N2 is not available since the displacement transducer malfunctioned during this test. Figure 8 shows the force applied to unit N2, as well as the force applied to N1 for comparison. This plot confirms the appearance at the time of testing that the behaviour of unit N2 was similar to that of N1.

As discussed previously, unit N3D was damaged during construction. This unit was subjected to a monotonic force, and its response can be seen in Figure 9. This unit was initially much stiffer than any of the other five units, due to the fact that there was a load path allowing the applied force to bear directly on the polystyrene base course. In contrast the load path of the other five units required the force to be resisted by beam action. Unit N3D developed a strength that was approximately 50% higher than units N1 and N2. The significant gain in strength from the point when the deformation was approximately 25 mm is a result of the increasing stiffness of the polystyrene in the bearing area as it compressed. The main conclusion drawn from this test was that in this case damage to the Cupolex® modules during construction did not negatively impact the performance of the finished floor.

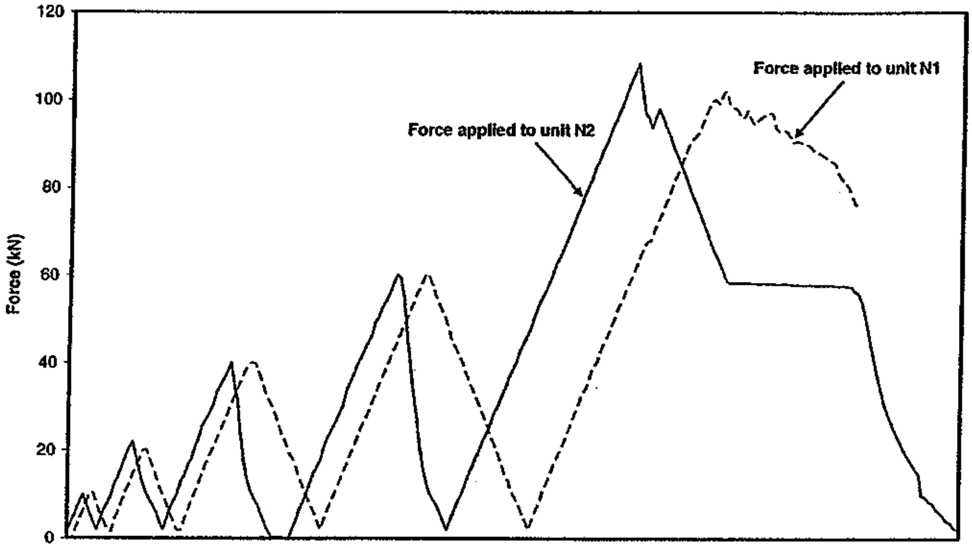


Figure 8. Plot of force applied to units N1 and N2 (displacement transducer malfunctioned)

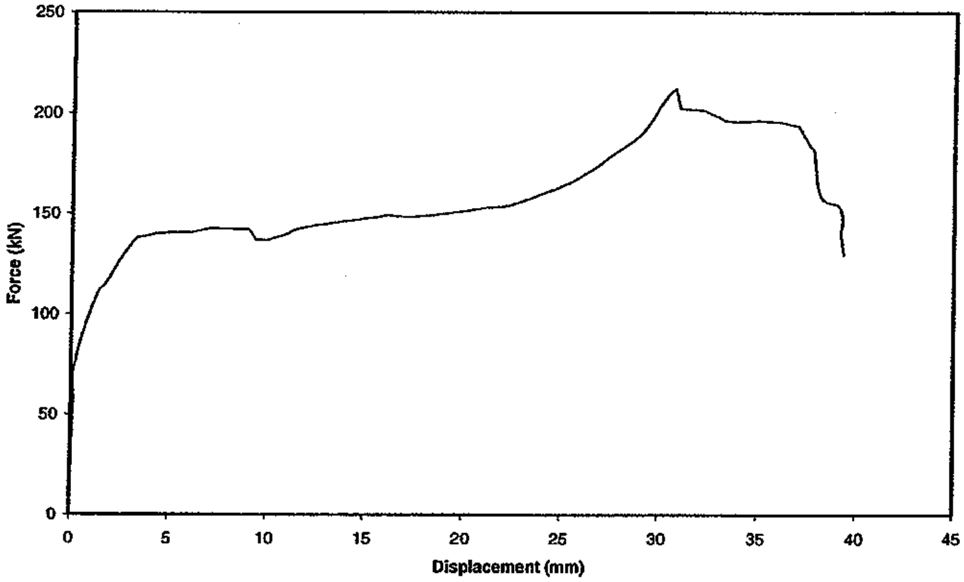


Figure 9. Force-displacement plot for unit N3 (damaged)

Units G1, G2 and G3 were all subjected to unidirectional cyclic loading. G3 was the first of these three units tested. It was loaded in the same way as N1 and N2. The response of the unit can be seen in Figure 12. Based on the strength of the unit G3, unit G2 was subjected to a greater number of load cycles before being tested to destruction as shown in Figure 11. A force of approximately

85 kN was applied to both units G2 and G3 before cracking occurred, and both units were able to carry a force of over 100 kN until the displacement of the load point was over 30 mm.

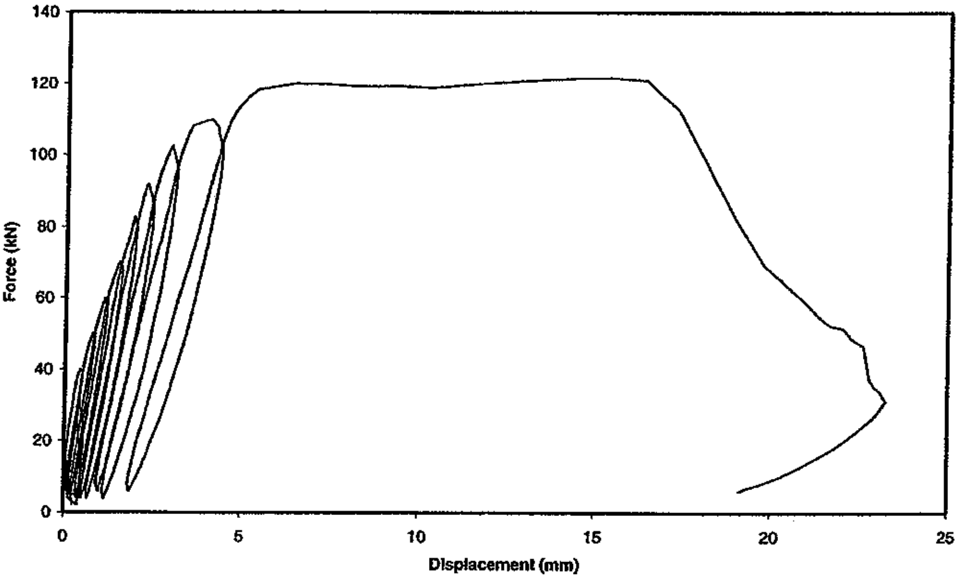


Figure 10. Force-displacement plot for unit G1 (150 mm by 150 mm load plate)

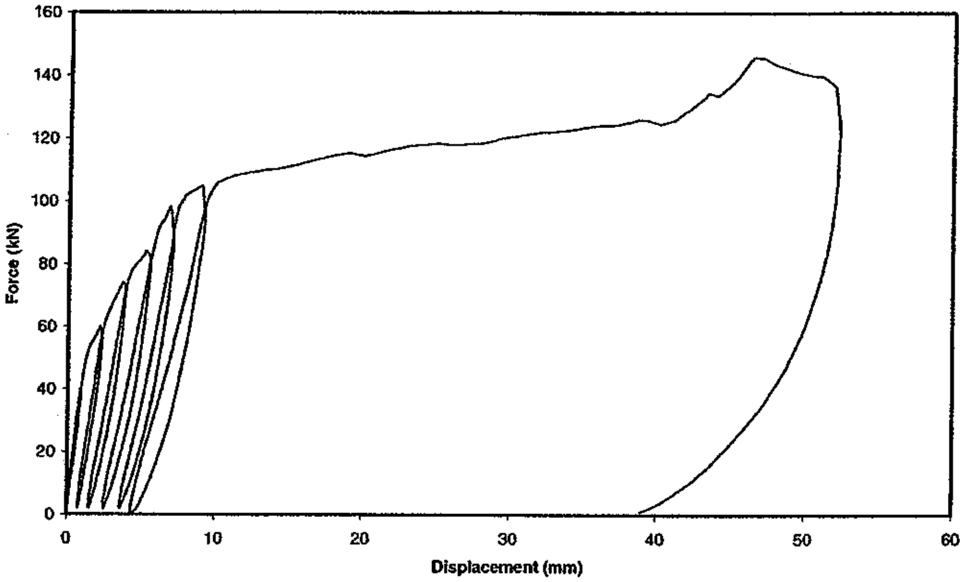


Figure 11. Force-displacement plot for unit G2

Due to the excellent performance of units G2 and G3 it was decided to reduce the size of the bearing plate from 300 mm by 300 mm to 150 mm by 150 mm for the final test. The results of this change can be seen in Figure 10, which shows the force-displacement response of unit G1. Despite the different loading arrangement, the performance of this unit was essentially identical to that of units G2 and G3.

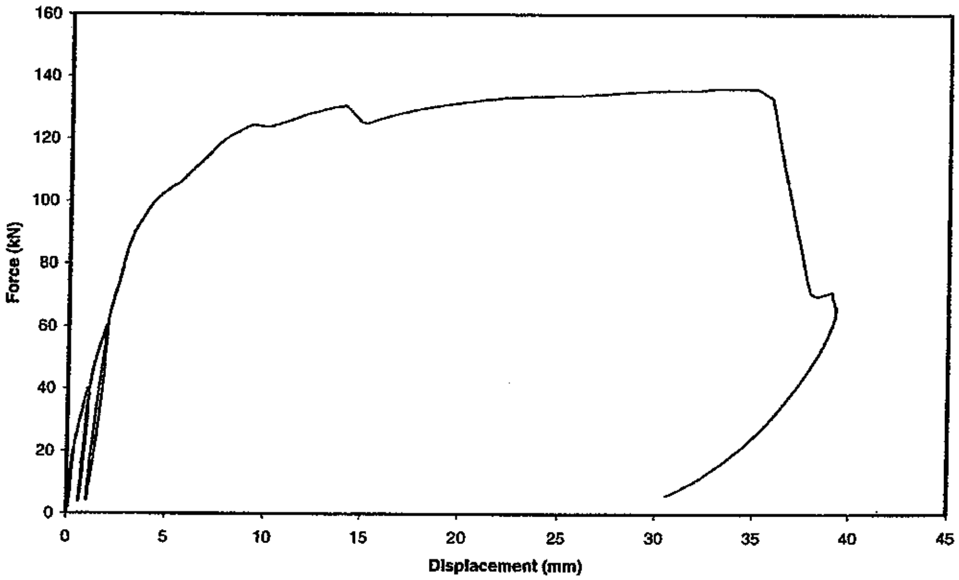


Figure 12. Force-displacement plot for unit G3

In order to aid comparison of the performance of the six test units, and to remove the influence of the different load histories, force-displacement envelopes have been plotted. These are shown in Figure 13. Also shown on this plot is the point load that a garage floor is required to carry in New Zealand [1]. No envelope could be plotted for unit N2 due to failure of the displacement transducer used.

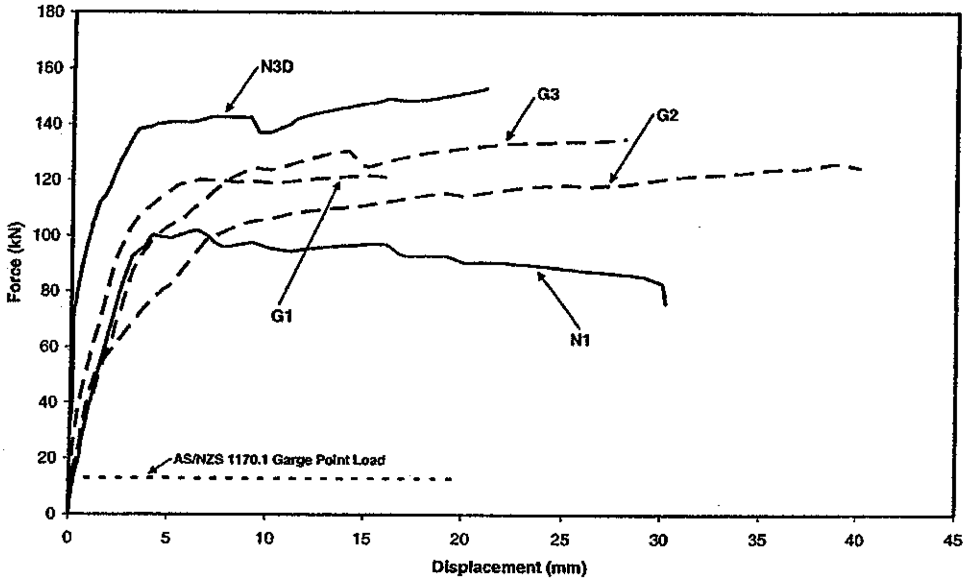


Figure 13. Force-displacement envelopes for units N1, N3D, G1, G2 and G3

Conclusions drawn from Figure 13 are that:

- all units significantly exceeded the required strength of 13 kN;

- the elastic stiffness of all units except for unit N3D was similar. The reduced apparent stiffness of unit G2 is probably a result of permanent deformation that remained upon unloading from each cycle, which most probably was a result of deformation in the polystyrene foundation;
- the deflection of the load point did not exceed 0.25 mm when a load of 13 kN was applied to the floor units;
- unit N3D was initially stiffer and developed a greater ultimate strength than other units, due to the presence of the aforementioned concrete strut under the load point.

6 Discussion of results

Despite the use of different load histories, bearing plates and reinforcement details, the performance of five of the six Cupolex® test units was similar. The only exception to this similarity was unit N3D, which was significantly stronger. The reason for this has been previously explained.

All other units had an elastic response until a force of approximately 80 kN was applied. At this force, internal cracking was judged to be occurring based on the sound emanating from the test specimens. When the applied force was approximately 90-100 kN, a roughly circular crack formed. For all test specimens the radius of this crack was approximately 700 mm (±25 mm), as shown in Figure 14. This crack followed a predictable path around the sub-floor support points. Following formation of this crack, the applied force remained approximately constant while displacement of the load point increased to 25 mm or more. The formation of this crack was taken to indicate the flooring system had failed.

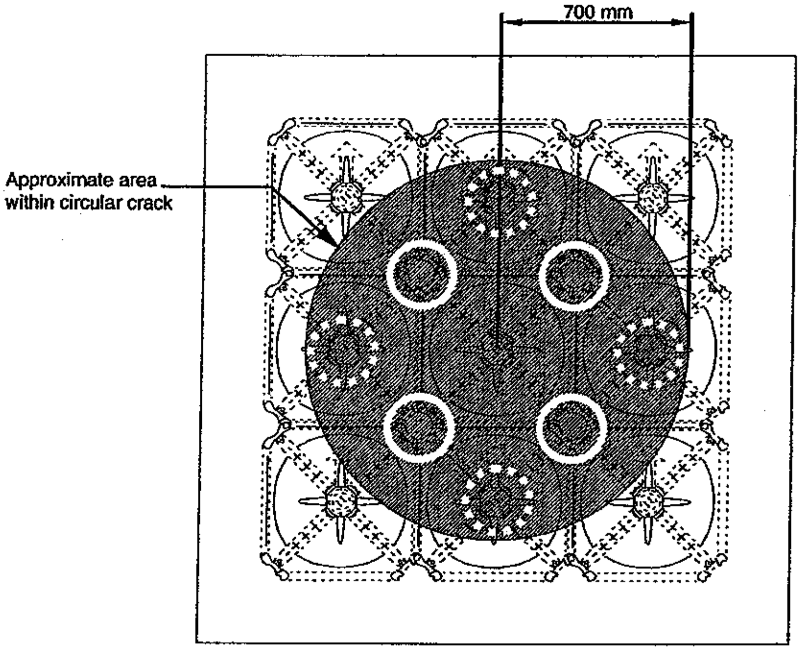


Figure 14. Location of primary crack leading to failure

Aside from the circular crack shown in Figure 14, the only other cracks that formed were splitting cracks from the edge of the slab running in to the circumference of the circular crack. These are shown in Figure 15. Note that the magnitude of these cracks has been exaggerated for clarity. In reality the cracks were up to approximately 1 mm wide at failure.

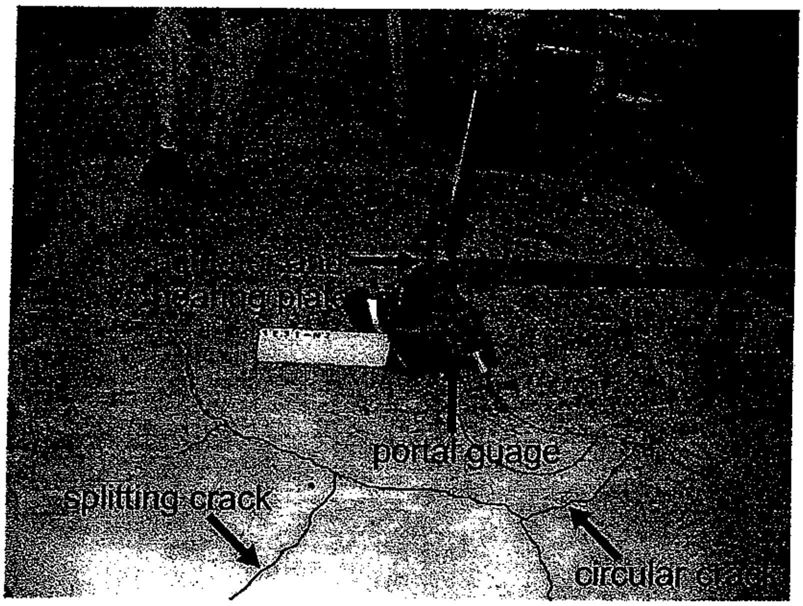


Figure 15. Photo showing crack formation

The diameter of the failure surface was reflected in the sub-floor deformations. Following testing the units were stood in an upright position and the polystyrene removed from the bottom of the unit (see Figure 16). This allowed inspection of the interior cavity of the unit, and also assessment of the deflection under each point that bore on the polystyrene by measuring the residual indentations (Figure 17).

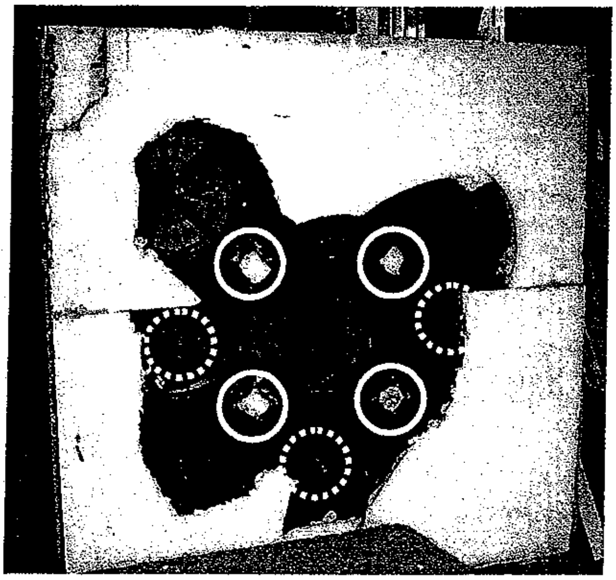


Figure 16. Test unit in upright position with foundation polystyrene removed

Figure 17. Removed foundation polystyrene showing indentations left by bearing pressure

The deflections under the intersection points of four Cupolex® modules (solid white circles in Figure 14 and Figure 16) and the central supports of four of the Cupolex® modules (dashed white circles in Figure 14 and Figure 16) were measured for several of the units. These measurements varied somewhat, but the deformations of the intersection points were consistently greater than the deformations under the central supports, which were further from the load point. The magnitudes of these deformations are shown in Figure 18. There was no apparent deformation beneath points lying outside the circumference of the circular crack. There did not appear to be a correlation between subfloor deformations and either load history or the area of the bearing plate.

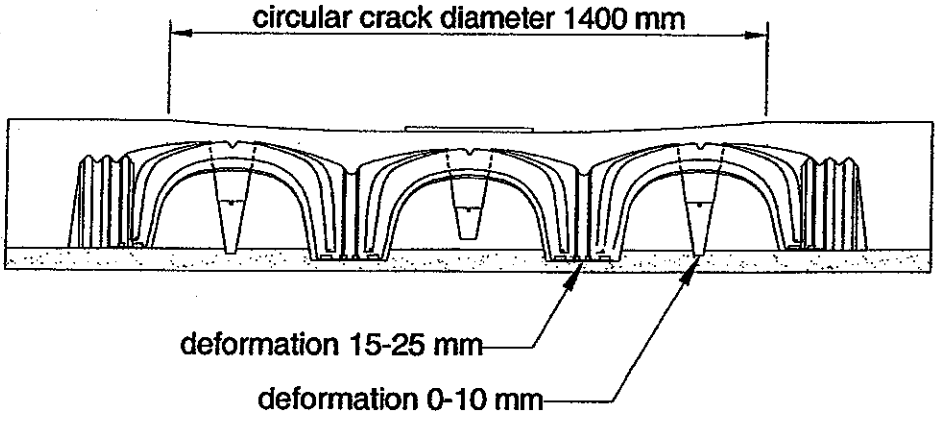


Figure 18. Cross section of slab showing magnitudes of deflection after failure

7 Conclusions

It can be concluded from these tests that:

- 300 mm thick floors constructed using 260 mm deep Cupolex® flooring modules can sustain the 13 kN point load required of garage floors by the New Zealand loadings standard [1] when this load is applied through a bearing plate with an area of either 0.09 m^2 or 0.0225 m^2;
- the deflection of the load point did not exceed 0.25 mm when a point load of 13 kN was applied;
- the floors tested responded elastically until a load of approximately 80 kN was applied;
- floors reinforced with 668 mesh and a square grid of D10 bars at 560 mm centres were able to sustain a larger maximum load than those reinforced with 668 mesh only;
- the square grid of D10 reinforcement did not affect the cracking performance of the slabs, and hence did not affect the service strength of the slabs;
- floor performance was not negatively affected by construction damage to the Cupolex® module directly underneath the load point.

References

1. AS/NZS 1170.1:2002 *Structural design actions, Part 1: Permanent, Imposed and Other Actions*. Standards New Zealand/Standards Australia: Wellington, New Zealand. 26p.
2. NZS 4203:1992 *Code of Practice for General Structural Design and Design Loadings for Buildings*. Standards New Zealand: Wellington, New Zealand. 134p.
3. Walker, T.H., Dallas, A., and Ingham, J.M. (2004). *Investigating Temperature Matched Curing for New Zealand Conditions. The New Zealand Concrete Industry Conference*. Queenstown, New Zealand: The New Zealand Concrete Society.