Seismic Performance of Rib and Infill Floors

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ABSTRACT

Precast concrete rib and infill flooring is widely used in New Zealand. As with many precast floor systems, rib and infill floors can be vulnerable to damage during earthquake shaking, particularly floors without modern detailing (pre-NZS3101:2006). Movement during an earthquake can compromise the gravity load path for the floor, including a loss of seating or damage from rotational restraint. To date, limited experimental testing has been undertaken for rib and infill floors and the capacity proposed by current guidelines may be conservative for rib and infill systems. Given the prevalence of the floor system, it is important to understand the performance under seismic drift and likely failure modes.

This experimental testing program focused on identifying the structural drift that is likely to cause total or partial loss of gravity support for rib and infill floor systems without modern detailing.

Two specimens were developed based on standard detailing from the 1970-80's, with varied mesh and starter bar arrangements at the supports. Each test setup replicated one full bay in a concrete frame building. The specimens were tested under cyclic loading to investigate the drift capacity of the floor system, likely failure modes, and strain behaviour of the starter bar-mesh interface, and the results were compared to the empirical equations proposed by current guidelines.

1 INTRODUCTION

Precast concrete rib and infill flooring is widely used in New Zealand. The floor system consists of precast concrete ribs with a timber infill between ribs creating a permanent formwork for an in situ concrete topping. As with many precast floor systems, rib and infill floors can be vulnerable to damage during earthquake shaking that can compromise the gravity load path for the floor including a loss of seating and damage from rotational restraint at the end of units.

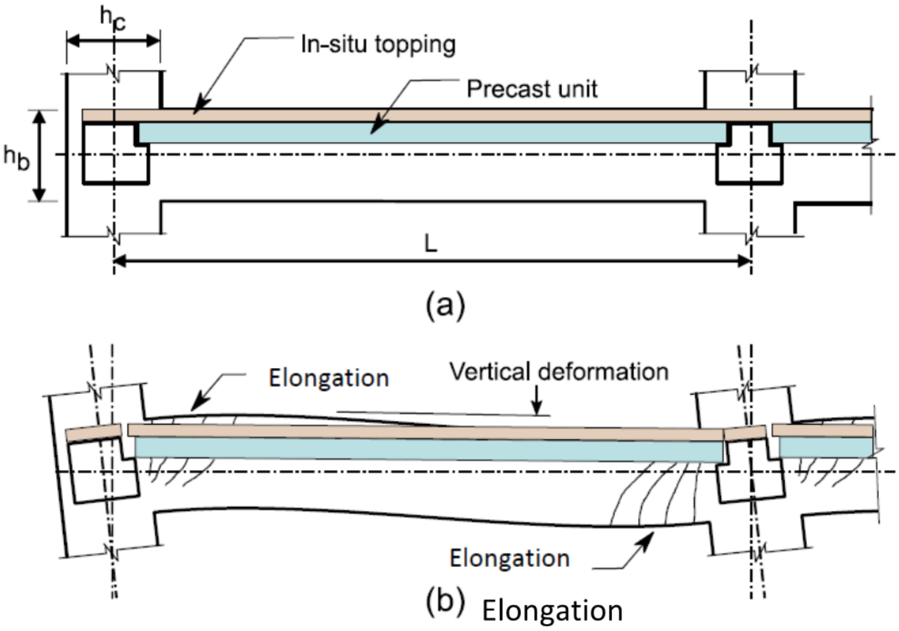

Figure 1: Precast floor behaviour under frame lateral loading [1]

Floor units typically sit on a support ledge, usually provided by the supporting beams, as is shown in Figure 1. Several factors can contribute to a loss of seating including displacement at the support ledge from frame or wall elongation, support beam rotation and spalling of both the unit and support ledge.

The in situ concrete topping acts as a diaphragm and is typically connected to support beams using starter bars. This arrangement can provide rotational restraint at the end of the units unless modern support detailing is provided including a post NZS3101:2006 detail with a low friction bearing strip or steel plate armouring of the corbel and/or precast floor. Rotational restraint at the end of units can result in damage to the end of the units which can compromise the gravity load path for the floor system.

Both a loss of seating and rotation of the support are a result of building drift. For buildings without modern support detailing, the limiting drift at failure of the precast floors is likely to be less than the limiting drift for the wall/frame system for the building, resulting in the expected performance of the precast floor governing the seismic rating of the building as a whole.

Assessing the drift capacity of precast floors, including rib and infill floors, is a challenging issue in the seismic assessment and retrofit of existing buildings. In New Zealand, the assessment of precast floor systems is carried out using The Seismic Assessment of Existing Buildings: Part C5 – Concrete Buildings [1].This guidelines provide recommendations on the assessment of rib and infill floors, including the drift capacity of the floors at positive or negative bending moment failure, loss of seating due to frame or wall elongation, support beam rotation and/or spalling of the unit and support beam. These recommendations are based on limited experimental testing for hollow core units and the proposed capacity may be conservative for rib and infill systems.

This paper presents an experimental test conducted to investigate the behaviour and evaluate the drift capacity of a conventional rib-and-infill floor system.

2 EXPERIMENTAL PROGRAM AND TEST SETUP

1.1 Specimen Configurations

The floor system used for the testing was based on a typical 1970's rib and infill floor system supported by a concrete frame building in Wellington.

For this test program, the column dimensions were 450x450, the dimensions of the support beam were 550(H)x350(W), and the dimensions of the parallel beam were 500(H)x450(W). All dimensions are in millimetres. The test setup included a horizontal actuator with a 165mm stroke which can produce more than a 5% drift ratio.

The floor system consisted of a 100 mm rib with 25 mm timber infill and a 65 mm topping slab. The rib detailing was consistent with that found in the 1970s building in Wellington.

The size of the mesh and reinforcing starter bars, and the mesh overlap with the starter bars were key parameters considered in this test program. To analyse the influence of the detailing, four specimens were proposed with the same detailing at each end. The starter bars were typically HD12 at 200 centres with a development length of 600mm to 1200mm. The topping mesh was 665 mesh (5.3mm bar @ 150 centres) with a lap with the starter bars ranging from 150mm to 600mm. These conditions are expected to cover most scenarios found in existing 1970s buildings . Figure 2 shows the precast rib detailing and topping reinforcement for the specimen.

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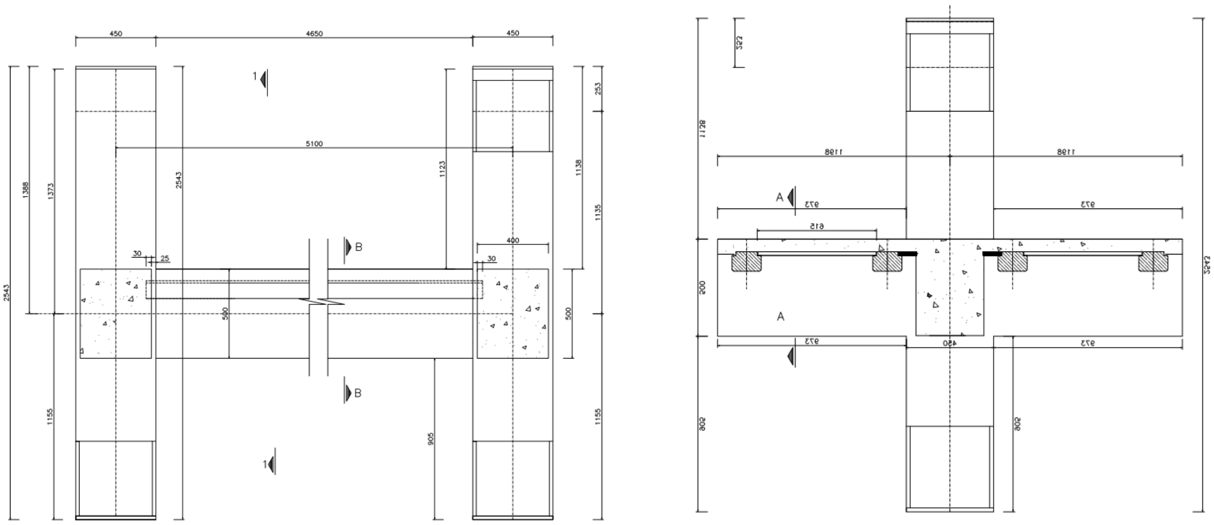
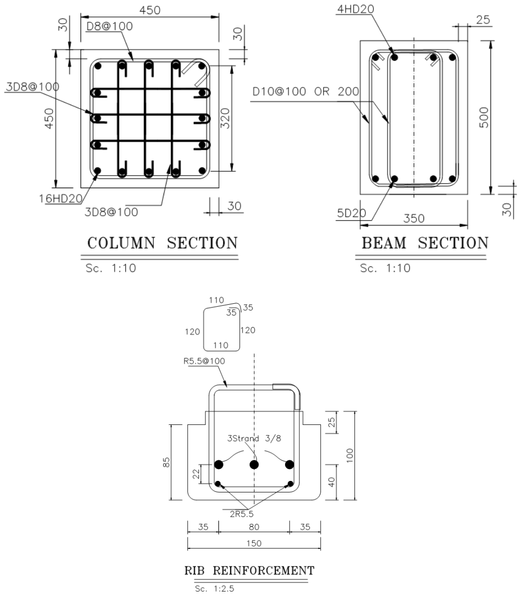
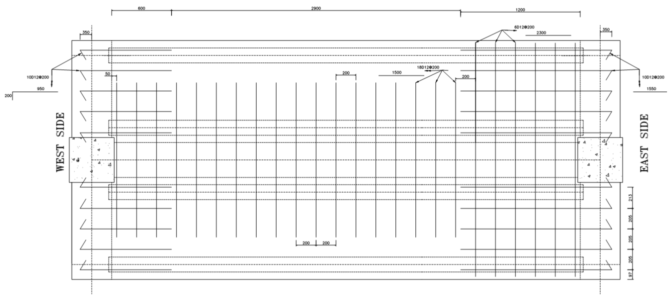


a) Longitudinal view

b) Section 1-1



c) **Columns, beam and ribs sections**



d) Topping reinforcement detail (mesh is not shown for clarity)

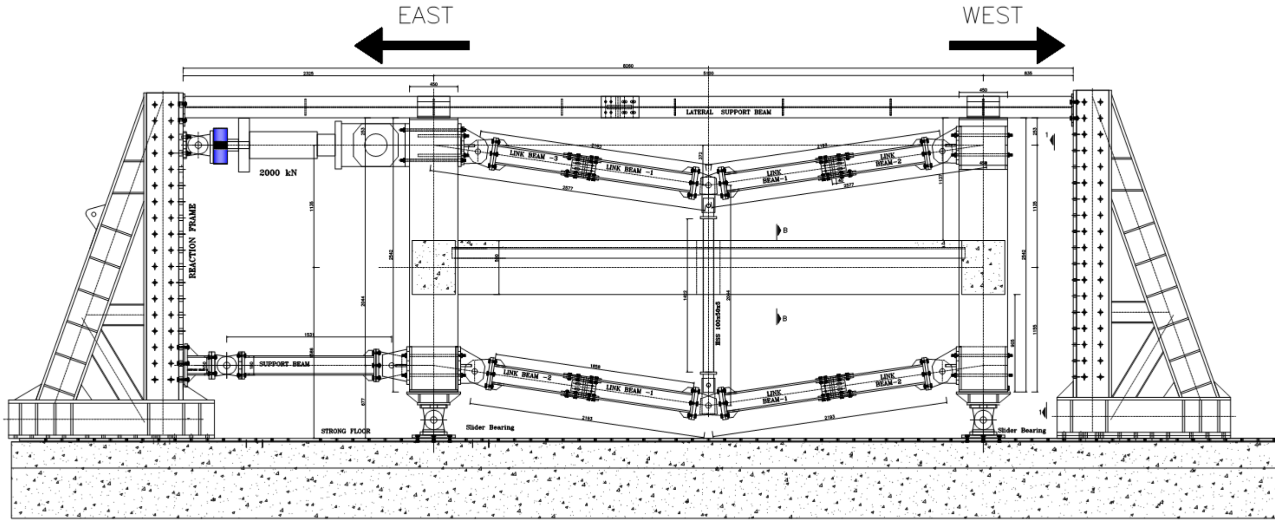
Figure 2: Specimen configuration

Figure 3 shows the specimen before concrete pouring.

Figure 3: Specimen before concrete pouring

1.2 Test setup, and Loading Protocol

The test setup consisted of a central concrete frame with cantilevered concrete beams supporting two precast concrete ribs either side of the central parallel beam, referred to as the east bay and west bays. This configuration was used for to capture elongation of the frame transferred to the rib support and rotation of the support beam. Figure 4 illustrates the general test setup along with a photograph of the test setup.



e) General test setup

b) Top view of the test setup

c) Underside view of the test setup

Figure 4: Test setup

The loading protocol was designed based on the recommendations in ACI 374.2R1 [2]. A reverse cyclic lateral loading was applied to the specimens using the horizontal actuator. Figure 5 shows the loading protocol based on ACI 374.2R-13. In this loading protocol, each step was two cycles up to 1% drift and 3 cycles above 1%.

Previous precast floor testing has found that a pulse type motion is critical for the governing failure modes of precast floors [3]. In order to account for this pulse type motion, the loading protocol started with a single cycle at 1% drift before continuing with the ACI 374.2R-13 protocol, ignoring the initial 1% pulse. The test continued until either failure of the precast floor unit or 5% drift (limited by actuator capacity).

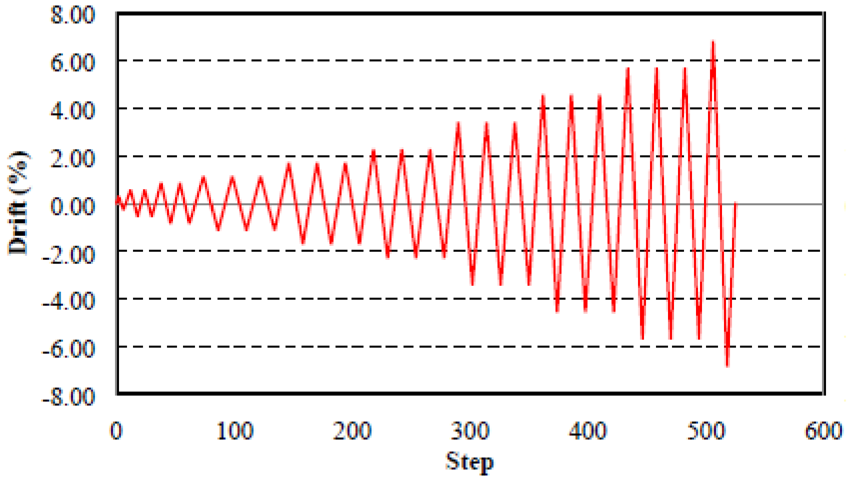


Figure 5: Loading protocol based on ACI 374.2R-13 [2].

3 TEST RESULTS

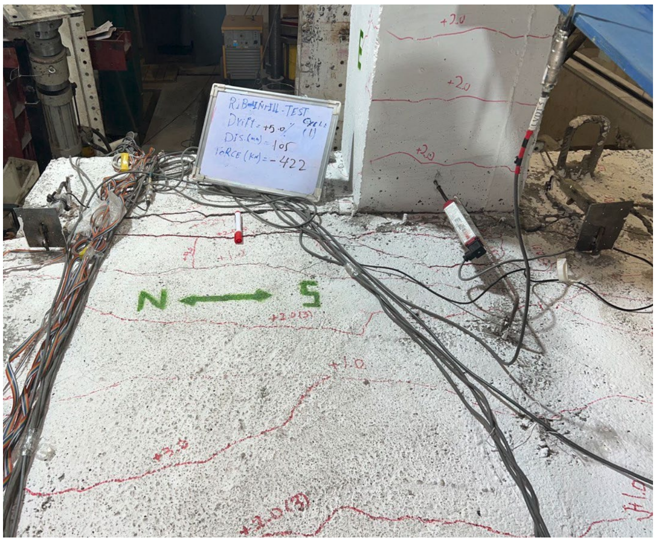
During testing, horizontal cracks formed at the intersection of the beam and topping on both ends of the specimen at a drift ratio of 0.25%. These cracks continued to widen throughout the test, reaching final widths of 17 mm at the east end and 12 mm at the west end during the last cycle, corresponding to 5% drift.

A second horizontal crack appeared at a drift ratio of 0.5%, approximately 100 mm from the interface crack at the east end, and continued to widen up to 8mm at 2% drift.

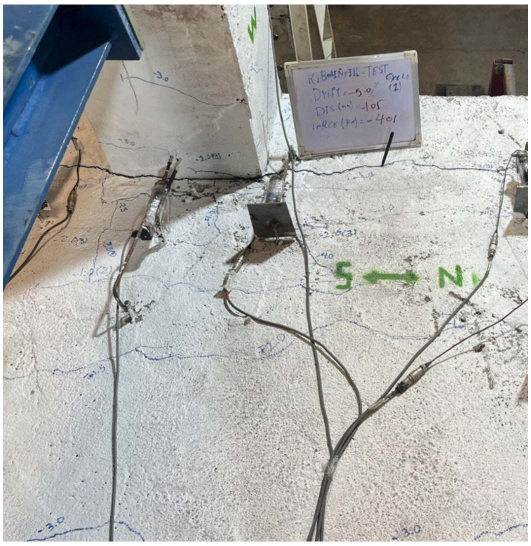
Cracks at the end of the starter bars emerged at a drift ratio of 1% and propagated, though they did not open significantly during the test.

Cracks formed on the ribs at 1% drift and continued to propagate up to 2% drift, but they did not widen during testing.

At 2% drift, crushing began at the ends of the ribs. By 4% drift, the ends of the ribs adjacent to the beam had completely lost seating. However, in spite of the complete loss of seating for precast units, collapse of the floor did not occur.



a) Cracks on the topping East end at the end of the test



b) Cracks on the topping West end

c) Underside the topping at East end

d) Underside the topping at West end

c) end of the rib at 4% drift

d) end of the rib at 5% drift

Figure 6: Cracks and damage pattern

4 CONCLUSION

An experimental testing program was conducted to investigate the seismic performance of an existing rib-and-infill floor system in a 1970s building in Wellington. The first test was performed without any additional loading on the floor system to examine the worst-case scenario for negative bending moment failure. The following preliminary conclusion are drawn from the results of the first test:

- Localized deformation concentrated at a crack at the interface of the beam and topping, which could lead to a loss of diaphragm integrity at the damaged support.
- Rib end damage began at approximately 2% drift, and by 5% drift, the ribs were fully unsupported. However, they did not collapse onto the supplementary seating angle.
- Dowel action of the starter bars effectively transferred shear forces from the ribs to the supporting beam.
- Cracks at the ends of the starter bars were observed but did not widen significantly during the test.

5 ACKNOWLEDGMENT

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6 REFRENCES

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