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Performance of precast concrete load-bearing panel structures in regions of low to moderate seismicity

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Abstract

The performance of jointed precast concrete load-bearing panel structures is evaluated using the capacity spectrum method for Australian seismic conditions which is typical of low to moderate seismicity regions. The critical element in the load path is the connection between the floor slab and the wall panel, and sub-assemblage tests are carried out in order to calibrate a finite element model for typical load displacement characteristics. The calibrated model is used to evaluate the performance of a full scale structure using the demand spectra given in the Australian code for various soil conditions. It is found that the seismic performance is inadequate under deep soil and very soft soil conditions for the structure detailed with deep embedment connections. In comparison for the structure with shallow embedment connections, local damage to the concrete topping slab would be expected for ground motions on shallow soil or very soft soil, but overall structural stability would be maintained for the ultimate limit state event.

Keywords: Precast structures; Seismic performance; Experimental; Earthquakes; Displacement demand

1. Introduction

Precast concrete load-bearing panel structures are currently a popular and economical structural system utilised in the residential and commercial international construction markets. These structures can be classified into two types: jointed and monolithic. In monolithic construction the precast concrete elements are joined by connections which possess stiffness, strength and ductility comparable to those of the precast concrete elements of the structure, and the design emulates the characteristics of a cast-in-place concrete structure. In contrast, jointed structures contain connection details which have significantly lower stiffness and strength properties than the precast concrete elements, and when the elastic limit of the structure is exceeded, ductility demand is concentrated in the connections between adjacent precast concrete members [1–3].

A jointed structure incorporating precast concrete load-bearing wall panels, flooring assemblies and roof units is considered in this study. Bearing walls carry in-plane vertical and horizontal loads, and transfer these loads to the foundation. The wall units and all other structural components are secured by connections which are completed on site. It is essential that these systems are able to transfer the necessary shear, tensile and compressive forces which may occur under any foreseeable loading conditions. The forces induced by earthquake ground motion in low-rise precast concrete load-bearing panel structures may dictate the strength and ductility requirements for these connections. The failure of the connections between adjacent wall panels is cited as a common cause of seismic damage [4]. Evaluation of the vulnerability of existing tilt-up construction is complicated by the lack of standard details for connections and the absence of a sound theoretical basis for many of the building code provisions related to tilt-up construction. Hawkins [4] noted that many tilt-up buildings in the US still contain connection details that are known to have performed badly in the 1971 San Fernando,

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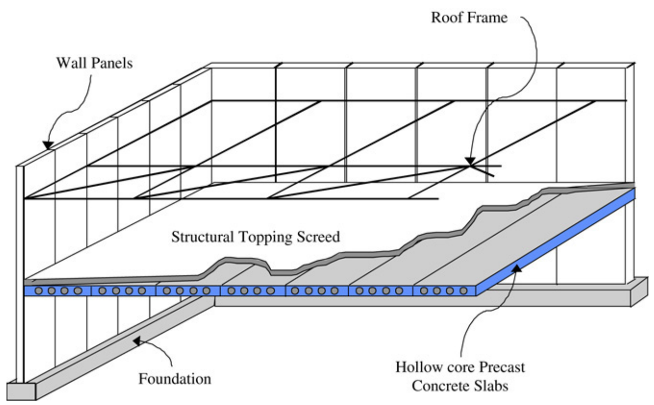

Fig. 1. Schematic diagram of typical jointed precast concrete load-bearing structure.

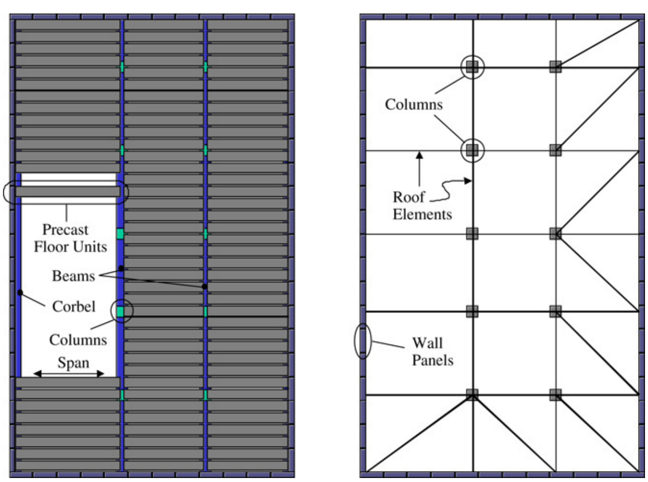

Fig. 2. Plan of structure showing structural elements and layout.

1987 Whittier Narrows and 1989 Loma Prieta earthquakes. Furthermore, without an analytical model that can accurately predict the seismic response of tilt-up construction, there is no basis for evaluating the required strength and toughness of the critical connections.

There are guidelines for the use of precast concrete in Australia [5,6], but there are currently no recommendations to specifically consider the design of precast concrete panel structures with regard to the Australian Standard for earthquake loads, AS 1170.4 [7,8]. In this paper, typical jointed precast concrete load-bearing panel structures are tested under cyclic load and their performance evaluated under earthquake loads typical of low to moderate seismicity regions.

2. Structural system

The selected structure is an office building that is constructed with typical low-rise precast concrete load-bearing panel details. The two-storey structure contains concrete foundations, load-bearing concrete panels around the perimeter, a first floor constructed from a precast concrete one-way spanning suspended slab and precast concrete beams, and a steel roof structure. The structure is 45.6 m by 28.8 m in plan and 8.6 m in height, as shown in Figs. 1 and 2.

2.1. *Configuration and description*

The precast concrete load-bearing panels constructed from 40 MPa concrete are 8.6 m tall, 2.4 m wide and 150 mm thick. They are reinforced with f92 mesh (f92 mesh consists of 9 mm diameter bars at 200 mm spacing with a yield stress of 500 MPa) placed centrally and six Y20 bars (Y20 bars are 20 mm deformed ductile reinforcement with a yield stress of 400 MPa and a fracture strain in the order of 15%) with 40 mm cover to the outside face of the panel. The additional reinforcement is provided to support the eccentric loads on the panels produced by the corbels on the panels that provide vertical support for the suspended slab and the panel to roof connections that are placed on the inside face of the panel. The suspended floor slab is a 300 mm hollow core prestressed one-way slab with a structural topping that spans the shorter dimension of the structure. The slab is completed with a structural topping screed poured on-site with f82 central mesh. The slab is supported on corbels at the end walls and on two inverted T-beams within the structure, giving a total of three spans. The first floor beams are supported by 300 mm by 600 mm precast concrete columns that contain six Y28 bars with R10 ties at 300 centres (R10 bars are 10 mm ductile plain steel rods with a yield stress of 250 MPa). The columns continue above the first floor suspended slab using $100 \times 100 \times 5.0$ square hollow section steel.

Three connections per panel tie the wall panel to the suspended floor slab to provide structural stability under lateral loads. There are typically no direct connections between adjacent panels; instead, structural continuity is provided by the connections between the wall panels and the suspended slab or the wall panel and the roof structure. The panels and the suspended slab are connected with Y16 connecting bars threaded into M16 ferrules cast into the wall panels (a 300 mm anchor bar passing through a hole machined into the ferrule provides anchorage for the ferrule). The Y16 connecting bars are 600 mm in length and are either cast into the structural topping screed to form a shallow embedment connection or, alternatively, the top of the precast slab may be cut out and filled with grout in the region of the bar to form a deep embedment connection, as illustrated in Fig. 3.

Two steel dowels are provided per panel to locate and connect the base of the panel to the foundation during erection. The dowel connections consist of R20 galvanised mild steel bars epoxy grouted 200 mm into the foundation beam and inserted 200 mm into 50 mm diameter grout tubes in the precast concrete panels. The tubes are located 300 mm from each end of the panels and filled with high strength grout after erection of the panels. The short ten bar diameter development length of the plain dowel bars results in bar slippage before yield of the bars.

The roof structure consists of beams to carry vertical gravity loads and a truss system designed to carry lateral loads. The main 410UB54 roof beams (410 mm deep universal beams with a self mass of 54 kg/m) span in the same direction as the floor slab and are supported by the wall panels at the ends and internal steel columns. The wall panels and the beams