Precast reinforced concrete planks as structural members

Precast Reinforced Concrete Planks as Structural Members

Plaques en béton armé préfabriquées utilisées comme éléments de construction d'une structure

Vorgefertigte Stahlbetonplatten als tragende Bauteile

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SUMMARY

This paper investigates the differences in behaviour of «thin» precast reinforced simply supported concrete when subjected to static and impact loads. Many such planks have failed dramatically in practice. The causes and modes of failure are presented. The importance of detailing and the tensile strength of the concrete are discussed and practical guidelines are given for the design and detailing of such elements.

RÉSUMÉ

Cet article examine les différences de comportement des plaques minces en béton armé simplement appuyées, soumises à des charges statiques et à des chocs. Dans la pratique, nombreuses ont été les plaques qui se sont dramatiquement effondrées; ainsi, causes et modes de ruine sont présentés. Les détails constructifs, ainsi que la prise en compte de la résistance en traction du béton sont discutés; des directives pratiques sont données pour la conception et le détail de tels éléments.

ZUSAMMENFASSUNG

Dieser Artikel untersucht das unterschiedliche Verhalten von dünnen vorgefertigten Einfachplatten statischer und dynamischer Belastung. Viele von diesen Platten haben in der Praxis dramatisch versagt und die Ursachen des Versagens werden erläutert. Es wird die Bedeutung der Berechnungsführung und der Betonzugfestigkeit diskutiert und praktische Richtlinien für Entwurf und Detaillierung von solchen Bauteilen werden gegeben.

1. INTRODUCTION

This paper is based on work carried out for a thesis at the University of New South Wales in 1988 [1].

Precast reinforced concrete planks are used, in Australia, as structural members in three main areas:

a) Treads in steel stringer stairs. This is particularly common in stairs where the use of steel sections to frame the stair and "thin" concrete planks as treads reduces the imposed dead load on the whole structure and makes for ease of construction. Fig. 1 shows such a stair in a major hotel in Sydney, planks being of dimensions 2,200 x 280 x 70mm thick, spanning 1,350mm.

b) Planks in steel framed pedestrian footbridges.

c) Footway slabs which span over electrical services on roadbridges.

In each of these applications, the loading can be applied statically or dynamically as an impact load.

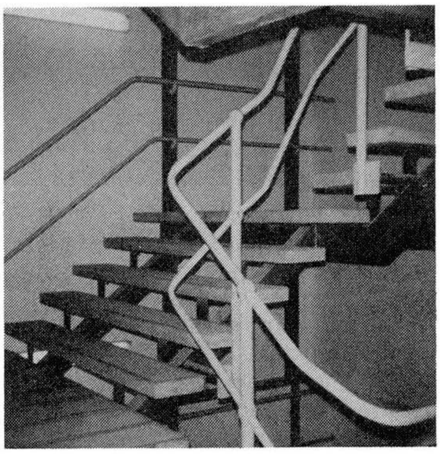


Fig. 1 Treads in a Hotel Fire Stair

Such planks are in common use and over the years many have failed dramatically in flexure due to incorrect analysis, design and/or detailing. With respect to analysis, much of the problem seems to have been, as stated by Breen [3], that designers have focused on "local section behaviour rather than the overall action."

The aim of the project was to study the behaviour in detail and produce practical recommendations for the design and detailing of such planks.

2. THE MODEL

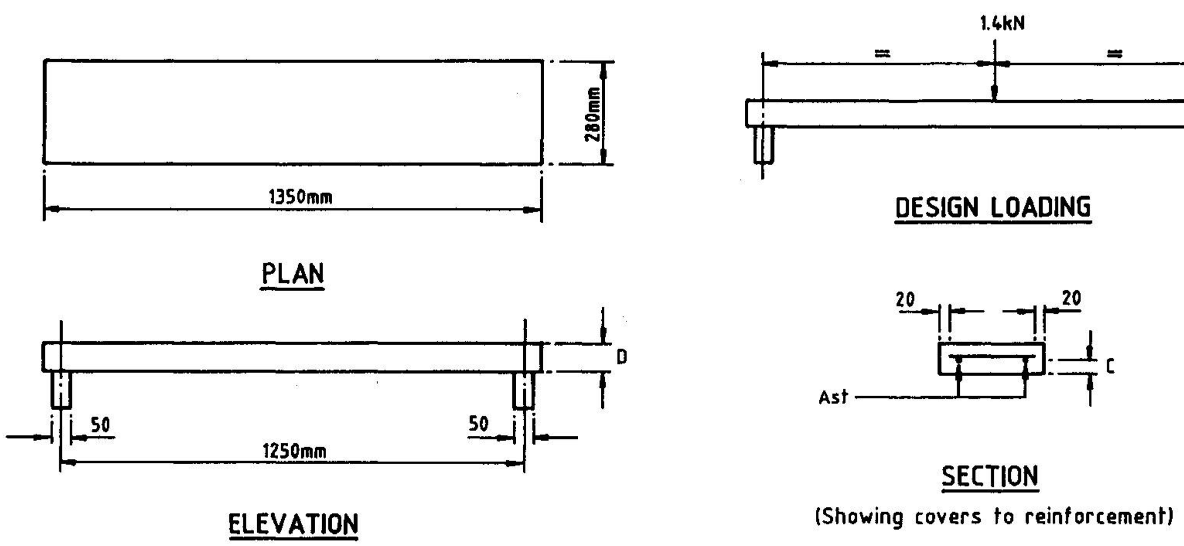
2.1 General

The planks tested in the laboratory are shown in Fig. 2. These test planks were designed using ultimate strength theory to the Australian Standard AS 3600 (Concrete Structures Code) [5]. The live load of 1.4 kN is for stair treads and is from AS 1170, Part 1 [5]. The dimensions and span are typical for such planks in practice.

The test plank thickness was varied to establish the importance of this dimension.

The position of the reinforcement in the cross-section was varied because it was considered that these planks fail in practice primarily due to the fact that "the dimensions of the precast treads are such that the reinforcement provided is near or at the neutral axis of the section and is therefore unutilised when the first loading occurs" [2].

The steel reinforcement used was welded wire fabric, which is common practice within Australia, and has a yield strength of 450 MPa. The concrete was of approximately 20 MPa compressive strength with 10mm aggregate and 80mm slump. No admixtures were used. The curing procedure adopted was typical of that used in practice by precast concrete manufacturers in Sydney.



Depth D (mm)	Cover c (mm)	Area of Tensile Reinforcement Ast (mm^2)
70	15	62.3
	25	62.3
60	15	62.3
	25	79.2
50	15	79.2
	20	100.5

Fig. 2 Plank Design Details

Two sets of planks were made, one for testing under static loads, the other under impact loads.

2.2 Static Loading

The main aim of the static loading was to study, under controlled laboratory conditions, the pre-cracking, cracking and post-cracking behaviour of the precast reinforced concrete planks. The applied load and the displacement under the load were measured and the resultant cracking patterns were observed and recorded (photographically) at various load stages throughout the testing procedure.

2.3 Impact Loading

For impact loading the same aim applied as for the static loading. The applied impact load, the maximum impact force absorbed by the plank and the displacement under the impact load were measured. The resultant cracking patterns were observed and recorded (photographically) at various loading stages throughout the testing procedure.

The type of loading used was repeated impact with increments of increasing mass. A load was 'dropped' onto the plank then raised to the required drop height with a further mass increment then being added before dropping the load again on to the plank. This modelled very realistically the type of repeated impact load such elements would undergo in practice (see Section 1).

The drop mass was increased in approximately 12.5kg increments with the masses being clamped together. The load was applied to the planks through a steel ring (120mm OD x 25mm) welded to the underside of the load carrier. This, it was believed, would model the load application through the sole or heel of a foot on a plank in service. The drop height was set at 300mm based on the real in service drop height when a person runs down a flight of stairs.

The two parameters of greatest importance in studying the impact behaviour of the planks were found to be:

Mass ratio: $\alpha = \dfrac{\text{mass of plank}}{\text{mass of striker}} = \dfrac{m_p}{m_s}$

and

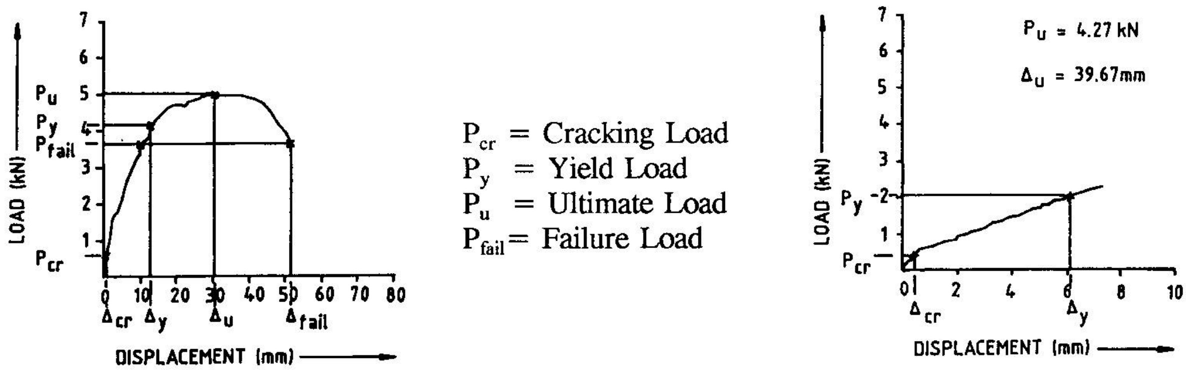
Dynamic Load Factor (DLF) $= \dfrac{y_i}{y_s}$

Where y_i = impact displacement due to load P
Where y_s = static displacement due to load P

3. EXPERIMENTAL RESULTS

3.1 Static Loading

The Load/Displacement plots for the 60mm thick planks are shown in Fig. 3. In the case of the plank with 15mm cover the plot resembled that of the stress/strain curve for the steel wire fabric, as expected for under-reinforced sections such as these where the behaviour of the tensile steel dominates behaviour of the cross-section. The behaviour of the plank with 25mm cover was entirely different. Here the reinforcement was near the centroid of the gross cross-section and due to the steel having very low stress, its behaviour did not dominate the behaviour of the cross section. The plot shows less ductility (than for 15mm cover) with a shorter linear relationship followed by sudden failure.

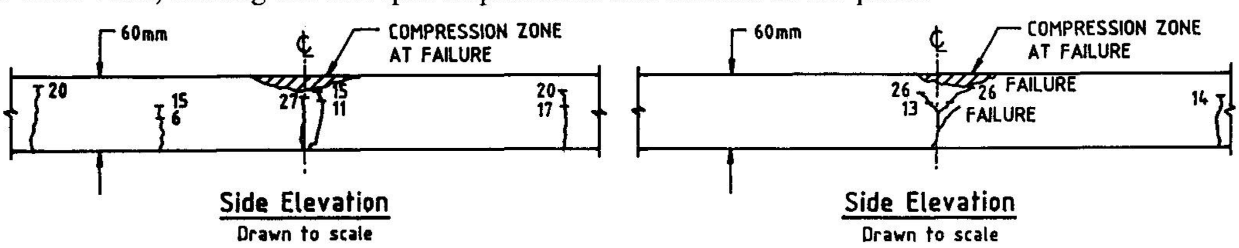


Cover = 15mm Cover = 25mm

f_c = 18 MPa, Thickness = 60mm

Fig. 3 Load/Displacement Plots - Static Loading

The cracking patterns for the 60mm thick planks are shown in Fig. 4. In the case of the plank with 15mm cover, the cracking was finer and more uniform, the cracks coincided with the positions of cross wires in the reinforcing fabric which caused crack initiation. In the case of the plank with 25mm cover, cracks occurred at mid-span with one or two major cracks which opened to as much as 6mm wide, causing the mid-span displacement and rotation of the plank.



15mm Cover 25mm Cover

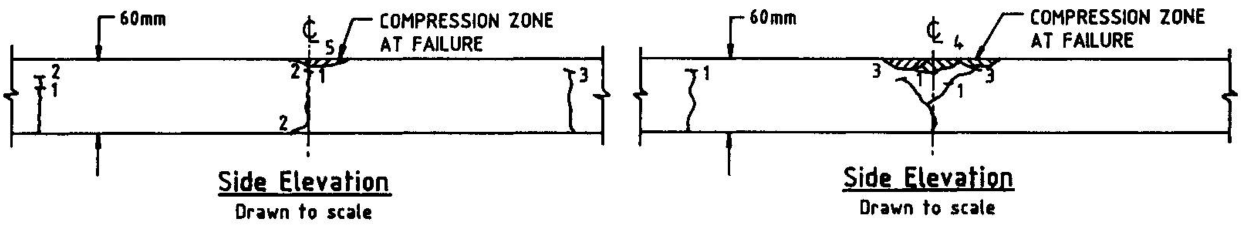
(numbers indicate loading stages)

Fig. 4 Cracking Patterns - Static Loading 60mm Thick Planks

3.2 Impact Loading

Generally, the behaviour of the planks with 15mm cover was similar to that for the planks with 25mm cover. The planks failed under the impact loading in a brittle manner. The failure was generally due to crushing of the concrete in the compression zone, which occurred more suddenly in the case of the more brittle planks with the reinforcement at mid-depth.

The cracking patterns for the 60mm thick planks are shown in Fig 5. The maximum crack widths which developed for the planks with reinforcement at mid-depth (25mm cover) were generally greater than for those with 15mm cover, the maximum being approximately 6mm as for the static loading. The planks with 25mm cover exhibited faster crack propagation and deeper crack penetration at an earlier load stage than did those with 15mm cover. This is because in the latter the tensile reinforcement had high stresses and was effective in controlling the formation and propagation of flexural cracks, being closer to the extreme tensile fibre of the concrete.



15mm Cover 25mm Cover

(numbers indicate loading stages)

Fig. 5 Cracking Patterns - Impact Loading 60mm Thick Planks

The Dynamic Load Factors (DLF) for the planks varied between 2.94 (50mm thick) and 8.40 (70mm thick). For each plank thickness, the value was higher for that with 25mm cover than 15mm cover.

4. CONCLUSION

4.1 Comparison Between Static and Impact Loadings

The loads required to cause cracking and failure under static loading were up to eight times higher than the cracking and failure loads observed under impact loading where the planks behaved in a very brittle manner. Generally, the planks with reinforcement at mid-depth exhibited more extensive cracking at the first load stage of the impact testing than did those with 15mm cover. This is due to the former being similar to a mass concrete element and therefore more brittle, with a faster rate of crack propagation.

For both the static and impact loadings, the ultimate load for the planks with reinforcement near mid-depth was approximately 85% of that for the planks with only 15mm cover.

In both types of loading, the displacements were generally reduced by placing the reinforcement at 15mm cover rather than at mid-depth.

As the mass ratio of the planks (α) decreases, the deformation or "lost" energy increases leading to more permanent deformation of the plank, less recovery (or restitution) and larger displacements. Thus, to reduce the energy loss and permanent deformation during impact, the plank mass should be kept as high as possible, as suggested by Grill [2]. The 50mm thick planks (the lowest mass ratio), generally behaved in an unstable manner and should be avoided in practice.

In relation to cracking, the cracks formed later and were better controlled by placing the reinforcement at only 15mm cover rather than at mid-depth, where the behaviour is similar to that for mass concrete where the tensile strength of the concrete is very important. As Hillerborg says, "...a crack may form which has a tendency to propagate, as cracks in their turn give rise to stress concentrations. If the crack propagation is not prevented the structure (or plank) will crack" [5].

4.2 Review of Current Design Loading Requirements

The precast reinforced concrete planks for this project were designed using the recommended loadings of the current Australian Standard for Dead and Live Loads (AS 1170, Part 1, 1989) [5]. However, under impact loading they failed at less than half of the service design load of 1.4kN.

Such planks undergo impact loads in practice (e.g., persons running down a flight of stairs or across a footbridge). The Authors recommend that loading codes recognise this by giving a range of impact factors (say 1.5 to 4.0) by which one would multiply the static load depending on whether the structure were a major or minor pedestrian facility (e.g., major entrance/escape stair in a large hotel or maintenance stair/footway).

4.3 Design Recommendations

1. Plank Thickness $\geq$ 60mm (irrespective of span).
2. Design Live Load at least twice the current value of 1.4kN concentrated (or 2.2kN/m) to take account of impact.
3. Reinforcement - diameter $\leq$ 0.1 x plank thickness.
   - pitch of main longitudinal wires and cross wires = 100mm.
4. Cover to Main Longitudinal Tensile Reinforcement $\leq$15mm; $\nless$ 10mm.
5. For planks in locations exposed to the weather; specify hot-dipped galvanised reinforcement.
6. Minimum 28 day Compressive Strength of Concrete = 25MPa - all locations.

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