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Effects of sudden failure of shoring elements in concrete building structures under construction

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ABSTRACT

The most frequently used technique to construct reinforced concrete (RC) building structures is the shoring or propping of successive floors, in which the slabs are supported by the shores until the concrete acquires sufficient strength. A significant number of structural failures have been reported during construction in recent years leading in some cases to the progressive collapse of the whole structure. The collapse often starts with the local failure of a single element which could be due to errors in design or construction and/or due to accidental events. Although this is a well-recognized problem, studies on the effects of local failure in the shoring elements on the integrity of the shoring-structure system have not been carried out in the past. In this work advanced numerical finite element models were carried out of a three-storey RC building and its shoring system. Four scenarios of local failure were considered: sudden removal of a (1) shore, (2) joist and (3) complete shore line; and (4) incorrect selection of shores. The results indicated that the structure-shoring system was able to develop alternative load paths without dynamic amplification effects due to the large stiffness and redundancy of the system without compromising the integrity of the structure but leading to significant damage in the concrete slabs. Design recommendations are also given based on the results from this study, which pretend to be the first study to focus on the structural response and damage of a building structure under construction after the sudden failure of one or more shores.

1. Introduction

Building reinforced concrete (RC) structures involves the use of temporary shoring or propping systems to support the slabs until the concrete is strong enough to support itself. Although there are many types of such systems, the one most commonly used is the shoring of successive floors [1,2], in which the shores distribute the weight of the newly poured slabs among the lower floors. The main components of this system are: shores (s), joists (j) and formwork boards (f) (see Fig. 1). Recovering shores from the lowest level enables the construction of a new upper floor without the need for additional shores. The most basic option of this system consists of the shoring/striking (SS) of individual floors when the slab is able to support its own weight plus the loads transmitted to it from above. Fig. 1 shows the construction phases and these operations in a building with three successively-shored floors.

In order to reduce the costs of this system even further, two other alternatives have been suggested that include an intermediate operation on each floor: clearing or partial striking (C) and re-shoring or back propping (R). The former involves removing more than 50% of the shoring material some days after the pouring of the slab in order to recover 50% of the shores (s) and joists (j) and 100% of the formwork boards (f). Re-shoring consists of removing all the shoring and formwork boards a few days after pouring when the slab is able to bear its own weight (with no or minimal cracking), and then re-install the shores to help support additional future loads. These two construction alternatives are shown in Fig. 1 for three successively-shored floors (Shoring/Clearing/Striking-SCS, and Shoring/Re-shoring/Striking-SRS).

The design philosophy of temporary structures differs significantly from permanent structures; in the former, the members are highly stressed during short period of time and they can be reused several times. Some of the latest simplified calculation methods that can be used to design these systems include those by Duan and Chen [3], Fang et al. [4], Calderón et al. [5] and Buitrago et al. [6,7]. There are commercial pressures to shorten construction cycles to reduce costs which introduce demand on simplicity of the connections and components. Stability has been traditionally identified as one of the main reasons for concern and codes for design (e.g. BS 5975:2008 + A1:2011 [8]) generally provide information to ensure sufficient bracing and

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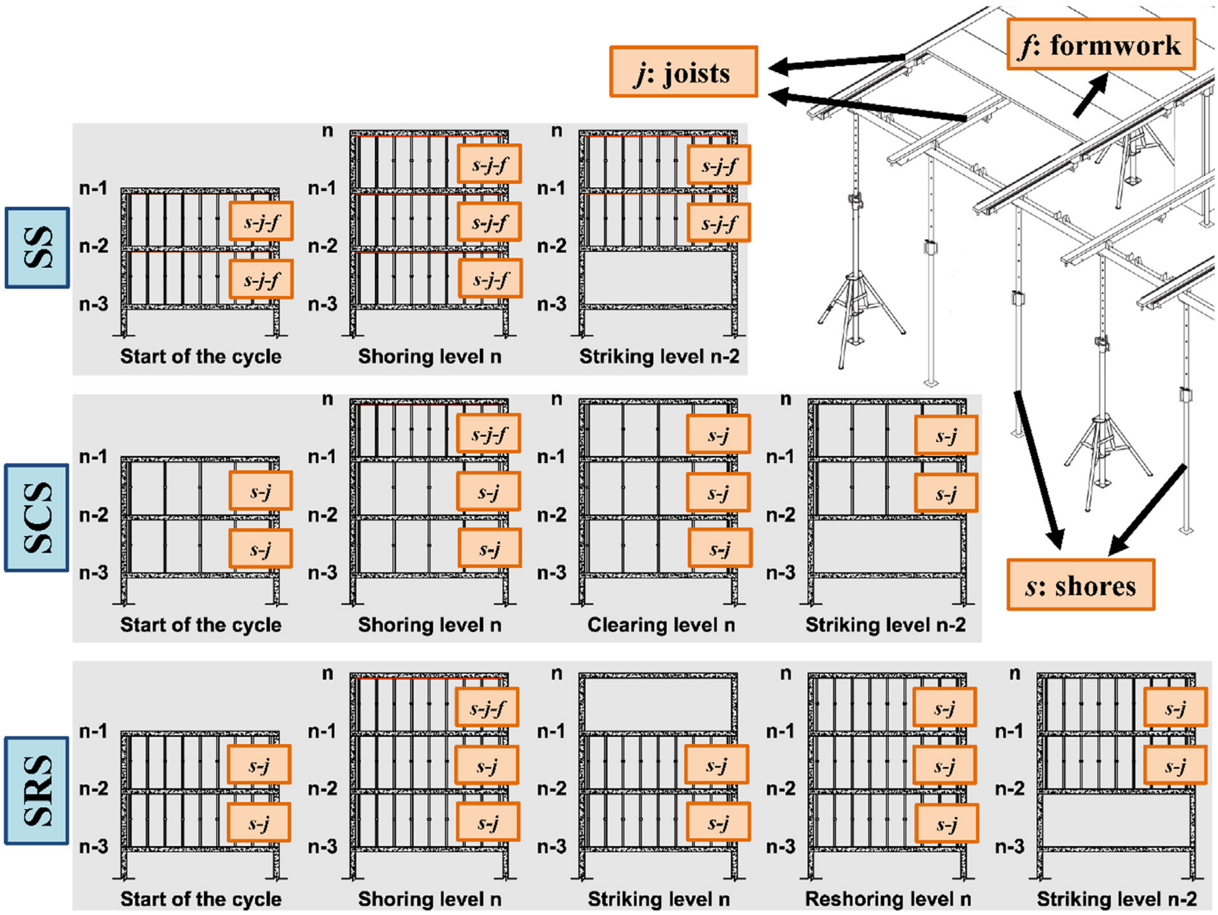

Fig. 1. Shoring system: components and construction processes.

lateral stability. Design guidelines for temporary works are now starting to introduce clauses to avoid progressive collapse with the idea that local failure of the temporary structures does not lead to failure of the whole structure [8]. This is a shift from traditional views in design practice where local failures in construction works were generally assumed to have negligible consequences compared to permanent works to an extent where collapse due to an accidental event could be acceptable if agreed with the client or relevant authority [9].

This variable tendency in design reflects that the risk of local failure of shoring systems (including its probability and consequences) is still not well understood. Due to the temporary nature of shoring systems the probability of local failure is higher and the consequences are lower compared to permanent structures. However, it is not well defined to what extent this is critical due to the lack of solid research in this area. According to a recent study by Buitrago et al. [10], shore failure is the principal cause of the collapse of buildings under construction and have caused loss of human lives, injuries and material losses. Such failures are mainly due to: loads higher than allowable design loads on the shores, improper shore installation or lack of shore bracing. In addition, other studies on building failures under construction [10–15] have shown that failure can also be due to inadequate design of the structure itself (i.e. insufficient anchorage length of reinforcement bars, insufficient reinforcement for flexure and punching shear or deficient detailing).

The numerical analyses of a RC building structure carried out in this work provide unique and novel evidence on the structural consequences of the structure-shoring system after the local failure of different shoring elements using the concept of notional member removal. This approach is commonly used for robustness analysis of permanent structures in research [16–24] and international codes [25–27]. This approach is based on the "sudden" removal of an element (scenario independent approach) to assess the capacity of the structure to redistribute the loads (alternative load path method) and to assess dynamic effects. Advanced dynamic analysis are unlikely to be carried out in design of shoring systems even in category 2 of design checks [8] which includes more complex designs. Therefore, simplified approaches using Dynamic Amplification Factors (DAF) will be needed for design. This work shows that the DAFs used for permanent structures are not directly applicable to structure-shoring systems due to their high redundancy and stiffness compared to traditional permanent structural steel or RC construction. Design recommendations are provided based on the analyses carried out in this work.

After the Introduction (Section 1), Section 2 describes the building structure considered in the study including loading and construction considerations for the design of the shoring system. Section 3 describes the finite element (FE) model used to assess the local failure scenarios and Section 4 presents the results for each scenario. Section 5 contains a discussion of the results together with some recommendations, and the main conclusions drawn from the work are given in Section 6.

2. Description of the building structure

The study in this work focused on a three-storey flat-slab RC building in which shoring was used to support the slabs and formwork. This section describes both the building structure and the shoring. The weight of the fresh concrete poured into the top formwork was uniformly distributed among the previously built slabs and the ground by means of the shores as shown in Fig. 2.