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Load limiters on shores: Design and experimental research

Manuel Buitrago*, Jose M. Adam, Pedro A. Calderón, Juan J. Moragues

ICITECH, Universitat Politècnica de València, Camino de Vera s/n, 46022 Valencia, Spain

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A B S T R A C T

When constructing reinforced concrete building structures, shores are normally used to transmit the loads from freshly poured slabs to lower floors. However, certain problems are involved in this process, including: (a) the loads on the shores may be higher than expected, which can lead to the collapse of the shoring system or even of the whole structure, and (b) the limited range of shore types in commercial catalogues, which often means that the shores used are oversized. This paper describes the study carried out on the development of a new load-limiter (LL) that can be fitted to shores to improve safety and reduce the cost of constructing building structures. The study shows that combining mechanical and civil engineering fields made it possible to produce a novel device that could revolutionise the shoring techniques at present in use. The method of designing and implementing the LLs involved: (a) the design of prototypes by using numerical simulations, (b) the use of the design of experiments technique, (c) an ambitious experimental campaign in which LL were tested, (d) the detailed simulation of the final design, and (e) the formulation of a simplified model that considers the behaviour of the shore-LL as a unit.

1. Introduction

The most frequently used method of constructing RC building structures is by shoring successive levels of floors to transmit the loads of the freshly poured slabs to the lower shored floors [1–3]. The temporary shoring system of each floor is composed of a series of elements: shores (or props), joists and formwork boards [4,5]. A scheme of this system is shown in Fig. 1, together with details of the different components of a type of shore most frequently used at the present time, although other types are available on the market. Shores are fitted in place by adjusting the inner metal tube to the required height by means of a pin. This pin is supported by a ring that transmits the load to an adjustable thread on the upper part of the outer tube. The adjustable thread allows the shore to be accurately adjusted to the exact height required.

Two of the current problems of this shoring system are: (a) the shores may be subjected to higher loads than they were designed to withstand, involving the risk of a collapse during construction [6–11], and (b) the manufacturers only produce a limited range of shores, which means builders, engineers and architects may be forced to use stronger shores than necessary to ensure structural safety. This paper proposes a novel solution to both these problems in the form of a mechanical device applied in the civil engineering field: the Load Limiter (LL) on shores (Patent number ES2636833). LLs on shores keep the loads applied to the shores below their allowable load. Firstly, this device will improve safety during construction while reducing the risk of collapses due to shore failure. Secondly, LLs also mean that lower strength (and cheaper) shores than those initially required can be used, since they limit the shore loads to values below their allowable load, which simplifies on-site handling because lighter shores can be used.

The technical and economic viability of the LLs was confirmed by numerical simulations [12], which achieved: (a) improved safety during construction, (b) reduced costs, and (c) better structural efficiency. The aim of the study was to determine the optimal LL design, production method, together with experimental tests and numerical simulations to check its behaviour. The essential requisites were defined as: (a) option of choosing the limit load, (b) it had to be re-usable, (c) at a reasonable cost, (d) with minimum effect on shore stiffness, (e) limit and maintain the design limit load of LLs, and (f) be easily adaptable to similar types of shores.

The paper is organized as follows: The LL design is described in Section 2 and a brief description of the production process is given in Section 3. Section 4 deals with the different tests carried out and an analysis of the results. Section 5 describes aspects of the numerical simulations, including validation of the models used and a simplified proposal to consider LL behaviour on shores in macro-scale numerical simulations. Finally, Section 6 contains the conclusions drawn from the study.

* Corresponding author.
E-mail address: mabuimo1@upv.es (M. Buitrago).

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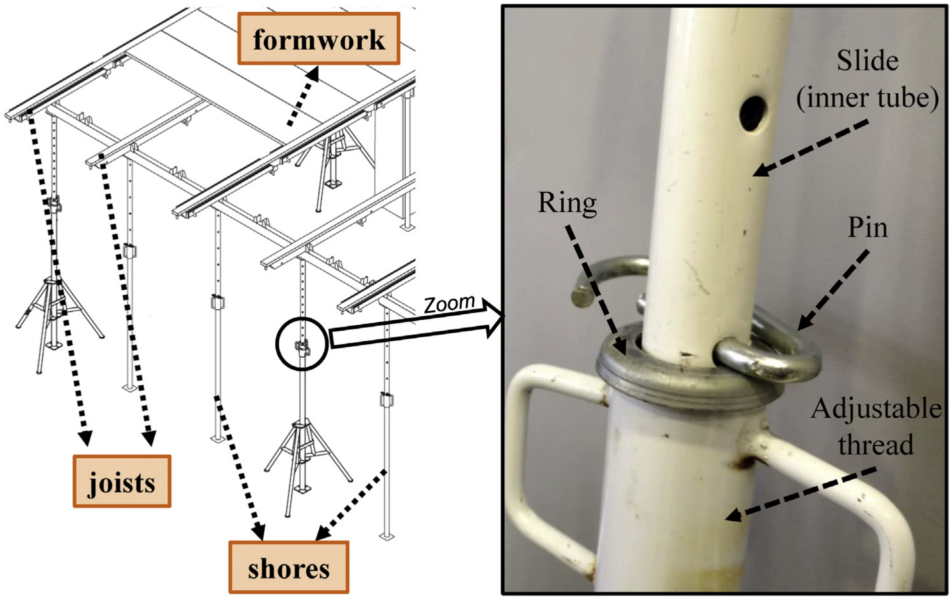

Fig. 1. Sketch of the shoring system and detail of a shore.

2. Design

Fig. 2 shows the desirable stress-strain behaviour of the shore-LL unit, used as the theoretical basis of the LL design.

A shore without a LL has a linear elastic behaviour until failure. This failure, by buckling of shore or yielding of the pin, is sudden [13] after which the shore can no longer support the loads it receives, which must be re-distributed through the slab around the neighbouring shores. A shore with an LL must show the same behaviour up to the limit load. However, after the limit load has been reached, and instead of a suddenly breaking and going out of service, the behaviour of a shore with an LL becomes perfectly plastic and keeps the load at its limit load, thus avoiding overloads. The plastic behaviour is limited below the maximum plastic strain or displacement value for safety reasons and to prevent excessive slab cracking. During the plastic behaviour in which the load remains at the limit load, only the excess load hypothetically received by the same shore without a LL must be re-distributed between slabs and the shoring system. After the LL reaches the maximum plastic deformation, the shore can assume a further load up to its ultimate load to make full use of its resistance.

2.1. First designs

One of the most difficult aspects was to transfer the theoretical behaviour described above to a LL with a reduced cost. Fig. 3 shows the initially defined ideal position for fitting the LLs to the shores, close to the thread. This position centralises shore operations, which was considered to be a vital aspect to easily install the LL and extend its application. The path of the load arriving at the shore can easily be interrupted between pin and ring to put the LL into position. After a number of iterations, the LL's conceptual design consisted of a frame-type structural system designed to yield at its defined limit load. Its failure mode is controlled by three plastic hinges, one in the centre and two in the upper corners, coinciding with the areas with the smallest cross-section (see Fig. 3b). Each LL is formed of two symmetrically fitted identical elements, as can be seen in the different design stages, which were designed with the help of ANSYS [14] numerical simulations (dealt with in detail in Section 2.2) for a shore taken as reference (see Fig. 1).

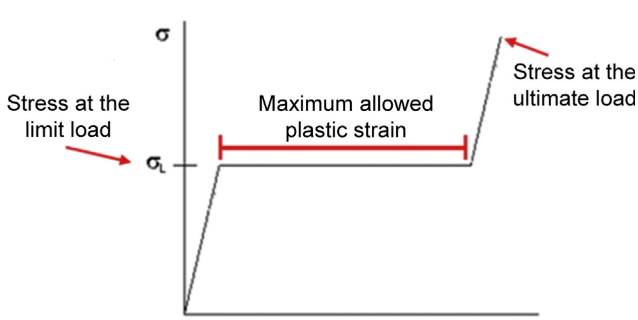

Fig. 2. Theoretical behaviour of load limiters.

Fig. 3c shows the first proposed design, having previously rejected the areas with reduced cross-sections to simplify LL manufacture since they are quite small (25 mm long × 10 mm wide) and the placement of three plastic hinges at the desired points (centre and upper corners) did not require reducing the element's cross-section. The appropriate thickness was chosen to give the LL high bending stiffness so as not to significantly reduce axial stiffness of the shore-LL unit. The improvement of the solution shown in Fig. 3c consisted of widening the support surface of the LLs on the rings (see Fig. 3d). The LLs were finally given a circular geometry to fit the shape of the shore and ring, at the same time improving the support conditions (see Fig. 3e). The first results obtained from the ANSYS models [14] were really promising and showed good bending stiffness in the elastic behaviour and plastic behaviour after reaching the limit load. Section 4 gives the results obtained from the experimental tests.

2.2. Different solutions

After analysing the results of the ANSYS simulations [14], a serious limitation was observed in the final design (Fig. 3e); it did not give control over the LL design limit load since the LL support could slide over the ring. A number of solutions were considered (see Fig. 4) aimed at eliminating the slip by including in the LLs: (a) tie rods (Fig. 4a), (b) confinement (Fig. 4b), or (c) confinement based on a stamped ring (Fig. 4c).

These three solutions were also simulated on ANSYS [14] to see how they worked. SOLID186 [14] type elements were used with 20 nodes and 3 degrees of freedom per node (displacements) to model the ring, LL and pin. In this design phase the steel was considered to have elastic