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Investigation of U-head rotational stiffness in formwork supporting scaffold systems

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ABSTRACT

In a steel supporting scaffold system, timber bearers impose a restraint on the rotation of scaffold U-head. This rotational restraint can be modelled by a rotational spring in structural analysis. To quantify the moment-rotation response of the U-head-timber bearer interface, a series of U-head sub-assembly tests were conducted, with a wide variation of parameters including applied load level, U-head configurations, and moisture content ratios of the timber bearers and joists. The relationship between the rotational stiffness and applied load is determined. A simplified procedure is proposed to implement this rotational restraint in nonlinear finite element analysis.

1. Introduction

Steel scaffolds are commonly used in reinforced concrete construction as shoring systems to support formwork. The common configurations of steel support scaffolds include standard door type and knee-braced door type modular systems, as well as stick type systems with cuplok or wedge-type joints (Fig. 1). They share common features. Steel scaffolds normally consist of standards (tubular columns), ledgers (beams), braces, and jacks. The bases of scaffolds consist of steel jacks which can be adjusted by a wing nut to accommodate irregularity of the ground. At the top of scaffolds adjustable shore extensions with U-head steel screw jacks are used to support timber bearers to ensure the leveling of the formwork, as demonstrated in Fig. 2.

Failures of reinforced concrete structures that occur during the construction phase are often traceable to the collapse of formwork supporting systems [1,2]. The economic and legal consequences of such structural failures can be disturbing. Numerous efforts have been made to investigate the structural performance of steel scaffolds both experimentally and numerically [3–12]. More recently, second-order inelastic structural analysis (advanced analysis) has been used to predict the behaviour and ultimate load carrying capacity of steel scaffold structures, including material and geometric nonlinearities, initial geometric imperfections, and semi-rigid joint details [13,14].

While the nonlinear effects such as gradual yielding and second-order effects are well understood and can be captured by nonlinear structural analysis software, current modelling of steel scaffolds often assumes highly idealised boundary conditions. Ref. [6] studied the effects of boundary conditions on the load carrying capacities of steel scaffold structures. Four types of idealised boundary conditions were considered, i.e., pinned-pinned, pinned-fixed, free-fixed, and free-pinned, in which the first and second terms refer to the boundary condition at the top and bottom of the scaffold, respectively. It was shown that the strength of a scaffold can be very sensitive to its boundary conditions. The study suggested that a more rational approach is to apply a translational spring and a rotational spring respectively to model the restraints at the top and bottom of the scaffolds. Ref. [15] suggested that if the scaffolding base is placed on a steel plate, the base can be modelled by a rotational spring (semi-rigid joint base). Based on laboratory test results, the bottom base stiffness was found to be 17.658 kN·m/rad. If the scaffolding base is placed on a concrete slab or wooden floor, then the bottom base can be considered as hinged.

In construction practice, horizontal formwork is often restrained externally in the horizontal direction by the partially completed permanent structure (see Fig. 1). Therefore, the scaffolding system has horizontal (translational) restraints at the top, which can be modelled by a translational spring [6]. If the form-

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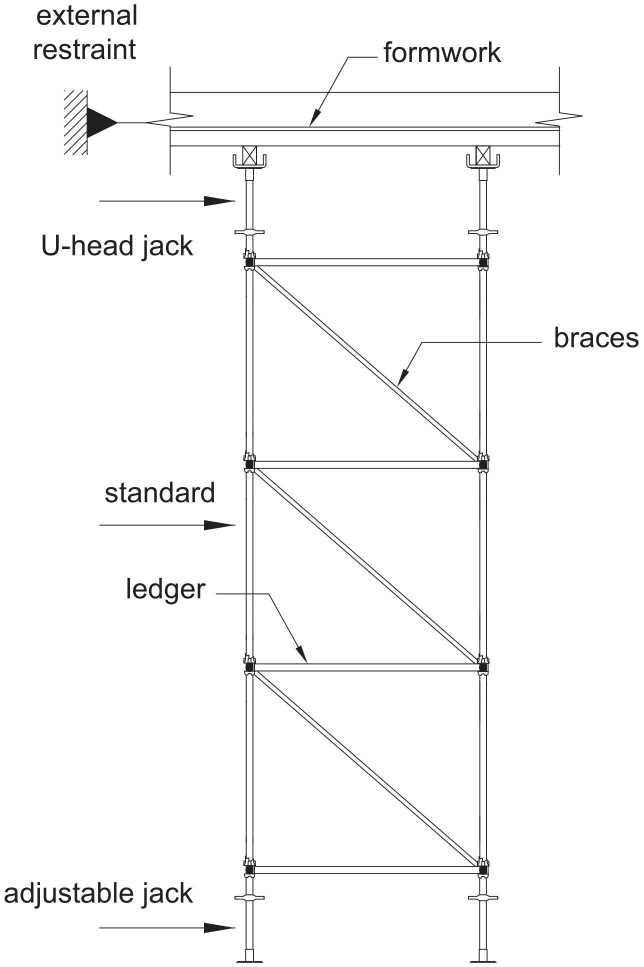

Fig. 1. A typical stick type steel scaffold system.

work is fully tied horizontally on sites, the top of the scaffold can be idealised as pinned support. In addition to the horizontal restraint, bearer beams generally also place a partial restraint on the rotation of the U-head (see Fig. 2). This partial rotational restraint can be modelled by an elastic rotational spring, whose rotational stiffness is denoted by k_r in this paper. (For simplicity, this rotational restraint is referred to as "U-head rotational stiffness".) Very little information is available on the value of k_r. In [13], k_r was assumed to be 40 kN·m/rad. This value was determined based on the calibration of finite element (FE) models with full-scale scaffolds load tests. As the calibration process involved the determination of a number of variables, it is unclear whether this rotational stiffness is a true representation of the restraints. Moreover, the rotational restraints provided by the timber bearer may depend on factors such as the applied load level, the configuration of the U-head, or even the moisture content ratio of the bearer. These factors were not considered in previous studies.

This paper presents a comprehensive experimental investigation into the rotational restraints on the U-head by timber bearers. A total of 41 U-head sub-assembly moment-rotation tests were conducted in the laboratory condition, using real timber formwork and steel scaffolding components that were provided by scaffolding industry. The experimental investigation was carried out with a wide variation of parameters including the applied load level, configuration of the U-head, and bearer moisture content.

2. U-head rotational stiffness

2.1. Test setup

Figs. 3 and 4 show the schematic and actual setup of the tests. The experiment was conducted on a full scale 1 × 1 bay grid of scaffolding with four U-heads. The square grid was 1.83 m × 1.83 m between U-heads. A load cell, shown in Fig. 5 was mounted beneath each U-head to record the axial force being applied on the U-head. The steel plate at the base of the U-head assembly shown in Fig. 5 was positioned on top of a pinned bearing which allowed rotation about an axis parallel to the timber bearers resting on the U-heads, as shown schematically in Fig. 3. LVL (Laminated Veneer Lumber) timber bearers were placed centrally on the U-head. The bearers were 3600 mm long × 150 mm high × 77 mm wide. LVL timber joists (3600 mm long × 95 mm high × 65 mm wide) were placed on top of the bearers at 500 mm centres, perpendicular to the bearers. Joists were equally spaced to ensure equal distribution of weight to each of the U-head components. A top layer of 17 mm plywood sheets was then laid across all joists as seen in Fig. 4. To model real construction conditions, the plywood was not mechanically fastened to the joists below, relying solely on the friction between the materials and the weight of concrete blocks applied on the plywood to stay in position.

The jack connecting the U-head to the upright (standard) is not included in the test set-up. Evidently, jack extension and eccentricity of the load applied at the U-head relative to the jack significantly affect the strength of the scaffold. They are required to be included in the structural model and analysis of the scaffold but are excluded from the tests reported herein as they are unrelated to the rotational stiffness between the U-head and bearer, and so that the rotational stiffness can be measured directly.

A hydraulic jack with customised extension exerts a vertical force (F in Fig. 3) via a loading frame to four U-head components. The U-heads were mounted on pivot plates that allow rotation to occur at the joint. The test frame was rigidly connected to the strong floor of the testing laboratory and a safety frame was erected underneath the test frame. The safety frame ensured that

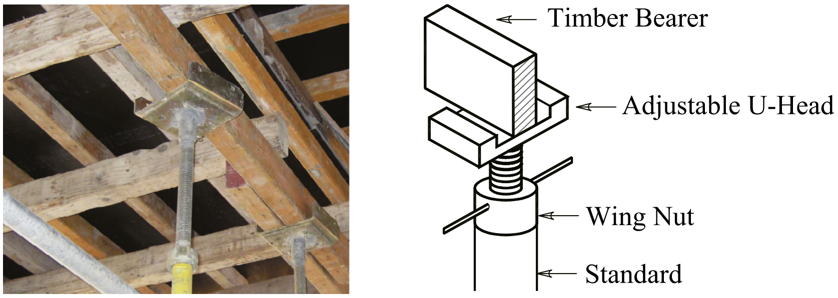

Fig. 2. Timber bearer supported by U-head jack.