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# Upgrading steel I-beams using local post-tensioning

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ABSTRACT

This paper investigates the behaviour of steel beams upgraded using locally pre-stressed reinforcing steel bars. The reinforcing bars were welded to the beam's flange or web at both ends and tensioned using a manual screw jack to increase the load-carrying capacity and stiffness of the beam. In total, seven beams were upgraded and tested under three-point bending, using different configurations of reinforcing steel. Results showed that the level of pre-stress, the type of local prestress (internal or external) and the diameter of rebars used significantly affected the beams' stiffness and their ultimate load-carrying capacity. The results obtained in this study were compared to those of other methods used for upgrading steel beams.



## 1. Introduction

Many steel bridges are rendered structurally inadequate with aging of the structure and the increase of traffic loads [6,10,12,23,29]. Replacement of these structures is costly and will interrupt traffic. Therefore, different structural repairing techniques and strengthening mechanism have been used [7,9,11,19].

Among these repairing and upgrading methods, bolting or welding of steel plates to existing steel beams is one of the most widely used techniques [9,26]. However there are issues related to this method. For example, the added plates increase the self-weight of the structure. In addition, the welding or bolting process may introduce new stress concentrations in the repaired region, causing a reduction of structural fatigue life [5,7,9,13,18,21]. Another strengthening method involves applying carbon-fibre reinforced polymer (CFRP), adding plates or sheets bonded to the web or soffit of steel beams. Benefits are light weight, good durability and ease of handling of FRP materials [18,26], and this method appeared to be efficient in increasing the load carrying capacity of the existing beams [8,9,11,13,26].

In addition to these methods, external prestressed tendons have been used to strengthen existing composite steel–concrete beam structures [1–4,17,20,27,30,31]. This technique involves welding end anchorages and using conventional high-strength post-tensioning cables. Results proved that the initial force in the tendon and its eccentricity significantly affect the strength and stiffness of tested beams [28]. Furthermore, this type of strengthening leads to a 25% increase in load carrying capacity in some cases [15].

As an alternative to the above mentioned methods, applying prestressing in a localised region within a steel beam is cited in the literature for strengthening existing steel bridges and repairing severely damaged steel I-beams [22,25]. This method increases the stiffness and the load carrying capacity of the steel structural member through adding reinforcing steel bars to a segment of the beam. Prestress is achieved by elevating the steel bars from the soffit of the steel beam by using a manual screw jack that generates a tensile force in the steel bars. Due to the low cost and the ease of operation, this method is also used to prestress concrete beams [24,25].

This paper presents an experimental study incorporating the local prestress method to strengthen and upgrade steel I-beams. The aims of this study are to investigate the behaviour of the locally prestressed steel beams in three point bending and to examine the effect of the prestress levels on the rigidity and the load carrying capacity of steel I-beams. Results are compared with those of beams strengthened with other strengthening methods.

## 2. The local prestress process

### 2.1. Description

The main concept of the local prestress process is to increase the load carrying capacity of a regular steel I-beam by attaching additional reinforcing bars. The reinforcing bars are then tensioned using a manual screw jack.

In this study two bars were attached symmetrically on either side of the beam. Two types of local prestress were: internal and external, shown in Figs. 4 and 5 respectively, differentiated by whether the bars are attached to the web or external flange surface.

Fig. 1 shows the installation sequence for the internal local prestress type. In this type, the bars were welded to the beam's web at both ends as illustrated in Fig. 1. Fig. 2 shows the manual screw jack. The bars were pulled to reach the required tensile stresses then a rigid support was

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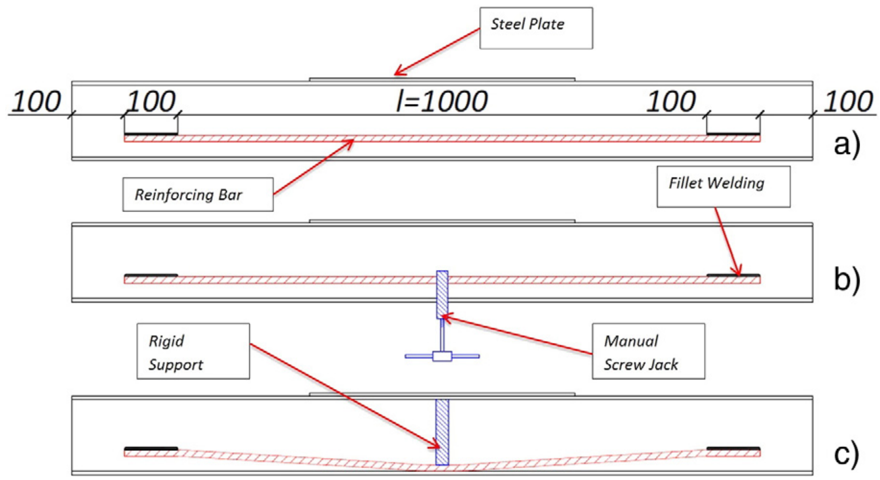


**Fig. 1.** The process of pre-stress: (a) welding the bars (on both sides), (b) pulling the bars using a manual screw jack, and (c) fixing the bars in place using a rigid support.

inserted between the mid-span of each steel bar and the bottom surface of the top flange to maintain the stresses in the bars. After the rigid supports (or stiffeners) are fixed in place, the manual jack is released and removed. The tensile force in the rebar generates a reverse bending moment in the mid-span cross section that results in an increase of the load carrying capacity [24,25].

In the external local prestress type, the bars were welded to the beam's tensile flange and they were pulled to reach the required tensile strength using a steel plate and a bolt (Fig. 3).

In addition to the prestress bars, identical steel plates with dimensions of 500 × 75 × 6 mm were welded to the centre of the compressive flange of all tested beams, to simulate any additional member attached or welded to these beams in a real roof system (such as a concrete slab in composite beams or a roof top plate).

*2.2. Theory*

Based on the elastic stress–strain relationship ($E = \sigma/\varepsilon$) the jacking distance *f*, defined in Fig. 6, was calculated using Eq. (1), derived in [25].

$$f = l\sqrt{\frac{\sigma}{2E}}, \tag{1}$$

where

$\sigma$ the value of prestressing (less than or equal to 500 MPa, the yield strength of the reinforcing bar)
$l$ The length of reinforcement bar (excluding the welding areas),
$E$ Young's modulus of steel.

The tensile force *N* within the reinforcement bars that was generated by the pre-stressing process can then be calculated by the tensile stress and the reinforcing bar cross-sectional area:

$$N = \sigma A. \tag{2}$$

Fig. 6. shows the jacking force, *F*, and the tensile force, *N*, within a strengthened steel beam after the process of pre-stress. The jacking force *F*, required to generate the tensioning force *N*, can be calculated using Eq. (3), derived in [25], when a displacement is applied in the centre of the reinforcing bar:

$$F = N\sqrt{\frac{8\sigma}{E}} \tag{3}$$

Different pre-stressing forces were applied on each beam in order to highlight the effect of the tensioning force on the beam's overall stiffness and load-carrying capacity. The differences in tensioning levels (force *N*) were achieved by varying the diameter of reinforcing bar (12 mm, 16 mm and 20 mm were used).

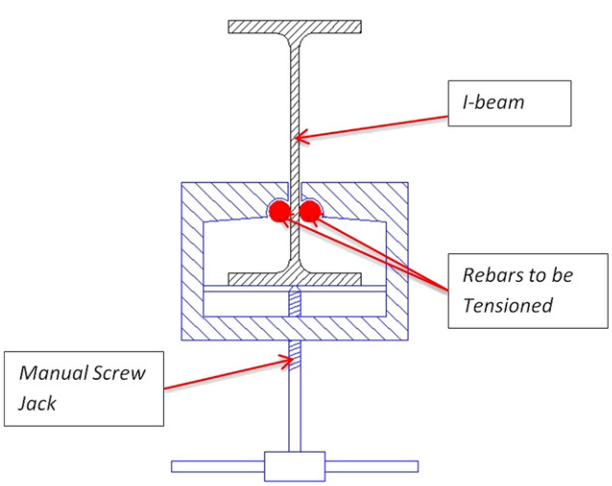


**Fig. 2.** Detailed drawing of the manual screw jack.

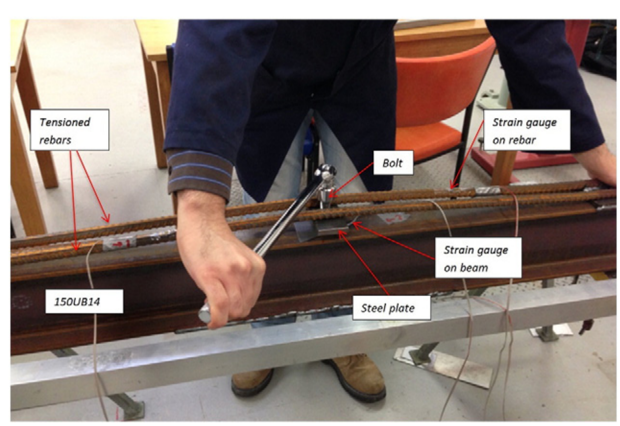


**Fig. 3.** The process of pre-stressing an upgraded beam using external prestressing (B16-E-2).