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Original Research Article

Cyclic performance of reinforced legs in retrofitted transmission towers

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ABSTRACT

In Australia, thousands of aging steel transmission towers need upgrading in order to meet the demands of additional communication devices being placed on them and the increased wind loads according to newly revised design standards. One effective retrofitting approach to increase their load capacity is to attach a reinforcing member to the original leg member through a bolted cruciform connector. This paper addresses the structural behaviour of retrofitted tower leg members under dynamic loading conditions that replicate the in-service conditions due to wind loading on real towers. A series of experimental tests and FEM modelling were conducted. The experimental results and numerical models show that the bolt pretension continuously decreases with the increasing loading cycles and magnitudes, which further reduces the bolt-slip load in cruciform connectors. The bolt-slip phenomenon changes the load-sharing rate between original members and reinforcing members in retrofitted legs. The dynamic loading procedure reduces the structural stiffness of retrofitted leg members due to the surface smoothing and bolt pretension loss. A further parametric study shows an obvious reduction in load-carrying capacity of retrofitted leg segments under long term dynamic loading periods. In addition, retrofitted segments with splice connectors in original members are more sensitive to loading cycle numbers.

1. Introduction

Due to the additional communication devices being attached to them and upgraded design wind loads, current ageing transmission towers are potentially under designed. Due to economic efficiency and feasibility as well as environmental restrictions, retrofitting existing ageing towers is more practical than constructing new ones. In Australia, most steel lattice transmission towers are constructed by equal steel angle. One of the retrofitting approaches is to attach an equal steel angle to the original leg member through a bolted cruciform connector [1]. The assumption behind this retrofitting method is that the cruciform connectors are able to equally transfer loads between original and retrofitting members so that each member will be subjected to lower loads, while the retrofitted members have an increased load carrying capacity and structural stiffness. Based on this theoretical assumption, the retrofitting method has been practically applied in current ageing transmission towers (Fig. 1).

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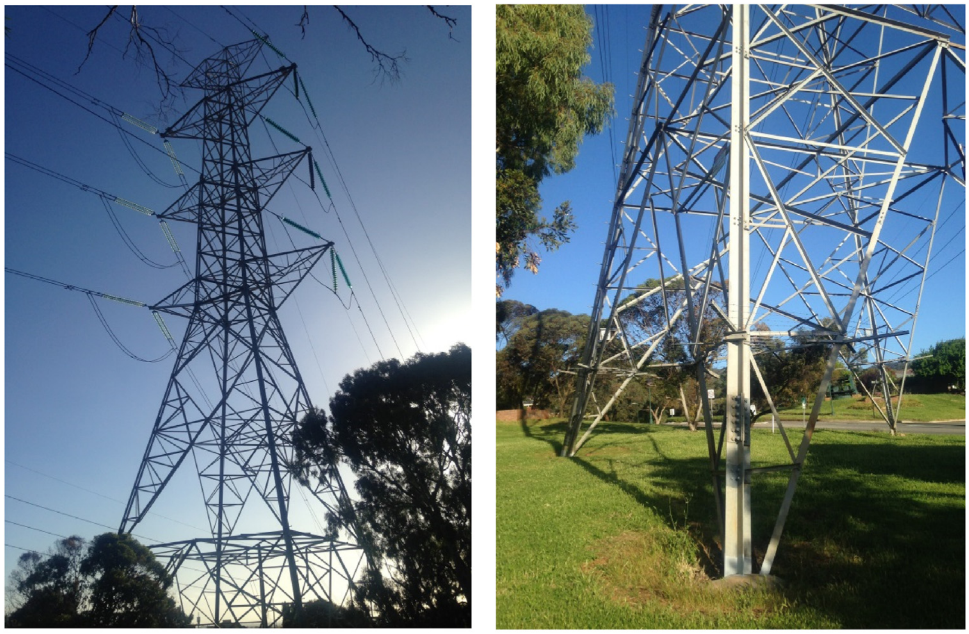

(a) Tower structure (b) Retrofitted leg members

Fig. 1 – An example of retrofitted tower structure in South Australia.

To study the effectiveness of the above retrofitted method, further researches have been conducted in recent years. The experimental studies and numerical simulations on retrofitted leg members verified the effectiveness of this type of connectors [2]. In addition, the effects of mid-span splice connectors in original members on the structural behaviour of reinforced leg members were also studied under monotonic loading conditions. Both numerical and experimental results showed that bolted cruciform and splice connectors played an important role in member strength calculation. In general, a softer splice connector resulted in a higher capacity through transferring more loads from original members to retrofitting members [3]. A series of monotonic tests on retrofitted tower structures showed that axial loads could be effectively transferred between original tower members and reinforcing members through the bolted-splice systems. Preloading (to replicate the fact that reinforcing members are applied to towers in situ that are already supporting axial loads) reduced the load sharing in reinforcing members in the early loading stage but did not have significant influence on the ultimate strength of the whole structure [4]. However, all research above focused on static analysis. There is still a research gap in dynamic analysis of retrofitted tower members.

With regard to bolted joints under cyclic loadings, many research studies were conducted on moment resistant joints in previous decades. Popov was one of the earliest researchers to examine bolted connections under repeating loads. Experimental work was carried out to investigate the ultimate limit state of steel frames under cyclic loads corresponding to the maximum load-carrying capacity of steel members and their connections [5]. Bernuzzi et al. presented simple design criteria for semi-rigid joints in seismic zones [6]. He et al. studied the buckling behaviour and shear lag phenomenon in beam-column joints under cyclic loads [7]. Iannon et al. investigated the ultimate behaviour and the governing parameters in frame joints [8]. All the above research was based on experimental tests. Recently, a semi-analytical model [9] and a 3D finite element model [10] were developed to simulate cyclic behaviour of beam-column joints based on initial geometry and material properties. For more complex cases, Nogueiro et al. studied the pinching effect on cyclic responses in bolted connections [11]. He et al. investigated the structural performance of hybrid joints between steel beam and concrete–filled steel tube columns. Design criteria for this type of joints were recommended based on scaled structural tests [12]. For practical applications in structural analysis, simplified numerical models were developed for steel-end plate connections [13] and partially restrained composite joints [14] based on their fundamental hysteretic properties.

However, these findings cannot be directly applied to steel transmission tower structures, since the transmission tower

Table 1 – Summary of test specimens and material properties.

Test specimen	Test specimen	Steel yield strength (MPa)	Steel ultimate strength (MPa)	Bolt grade	Bolt diameter (mm)	Nominal yield strength (MPa)	Torque (N m)
Retrofitted leg member (RL/NW)	RL/NW – A, B, C, D	300	330	8.8 M16	16	800	150
Retrofitted leg member (RL/W)	RL/W – E, F, G, H	300	330	8.8 M16	16	800	150

NW means without the middle splice connector; W means with the middle splice connector.