Journal of Constructional Steel Research 78 (2012) 58–67

Contents lists available at SciVerse ScienceDirect

Journal of Constructional Steel Research

Experimental study on multi-panel retrofitted steel transmission towers

Julie E. Mills [a,*], Xing Ma [a], Yan Zhuge [b]

[a] School of Natural and Built Environments, University of South Australia, SA 5095, Australia
[b] Faculty of Engineering and Surveying, University of Southern Queensland, Qld 4300, Australia

ARTICLE INFO

Article history:
Received 26 February 2012
Accepted 7 June 2012
Available online 11 July 2012

Keywords:
Steel lattice tower
Transmission tower
Retrofitting
Load transfer lag
Preloading

ABSTRACT

Due to the increasing demands on power supply and telecommunication services, existing transmission towers are frequently being required to carry extra loads above their initial design limits. A range of methods have therefore been used to increase the capacity of existing towers by retrofitting them in some way. This paper addresses steel lattice transmission towers with main leg members retrofitted by steel angles through bolted double steel angle connectors, a method that is widely used in practice but to date with little experimental research to support it. Three unreinforced tower models and four groups of retrofitted tower models with and without preloading have been tested in the structural laboratories at the University of South Australia. The experimental results verify the effectiveness of the retrofitting method. Load sharing analysis shows that axial loads can be effectively transferred between original tower members and reinforcing members through the bolted-splice system. Preloading reduces the load sharing in reinforcing members in the early loading stage but does not have significant influence on the ultimate strength of the whole structure.

1. Introduction

Steel lattice towers have been used in the electrical industry for more than 100 years. Many of the towers that are currently in service were constructed over 20 years ago, and some can be 50 years old or more. The extent of such transmission lines is vast and the economic and social impacts of the failure of any towers that lead to outages of power are substantial. Due to current increasing demands of power supply and communication services, new conductors and other equipment are often required to be installed on existing towers. When the extra gravity and wind load from the newly installed equipment exceed the initial design capacity, the existing towers need to be upgraded. In some cases this is necessary even without any increased demand on the tower, just because the wind codes to which the towers were originally designed have been upgraded and the tower does not comply with current requirements.

Researchers have proposed quite a few techniques for upgrading existing/damaged steel moment frame structures [1–4]. In general, detailed case-by-case investigation is required for selecting a suitable retrofit method [5,6]. For steel frame structures, improving moment capacity for critical joints and members is usually one of the main tasks in the retrofitted design [7,8]. Upgrade of bracing systems is another economic way to improve the lateral resistance capacity of the whole structure [9–11]. However, much of this work on steel framed buildings has limited application for tower structures, since the focus for towers is primarily on improving the axial load capacity of tower legs.

Unlike steel building frame structures, retrofit studies on tower structures are relatively rare in the existing literature. Albermani et al. [12] and Kitipornchai and Albermani [13] proposed increasing the axial capacity by reducing the slenderness ratio of the main tower legs through adding a series of diaphragm bracing type structures at mid-height points. They developed a non-linear analysis technique that they calibrated against the failure of an existing tower and showed that considerable improvement in the compressive strength could be achieved using this method for towers with slender diagonal members.

For main tower leg members with slenderness ratios lower than 80, the failure is governed more by the squash capacity of the tower legs than the buckling behaviour. Such towers occur very frequently in practice. For these towers, a more effective retrofitting method is to reinforce the legs through attaching additional members, usually called “reinforcing members”, parallel to the existing legs from the base upward. This practice is not currently governed by any design standards and thus the effectiveness of the retrofit method needs to be investigated. In particular the following questions relating to this method need to be answered:

- What is the most effective connection method to use for the connector between the original and reinforcing members in terms of type, location and frequency?
- Is the reinforcing member immediately effective or is it necessary to provide reinforcing beyond the critical point in order to achieve the

* Corresponding author. Tel.: +61 8 83023073; fax: +61 8 83025082.
E-mail address: julie.mills@unisa.edu.au (J.E. Mills).

0143-974X/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jcsr.2012.06.004

desired load capacity increase at that point? (much like the development length required for steel reinforcing rods in concrete)
- What effect does bolt slip in connections have on the outcome?
- What effect does existing load being carried by the towers have on the final capacity, given that the retrofitting needs to take place whilst the towers remain in service?
- What is the overall effectiveness of the method in terms of increased load capacity?

These are the questions that have been examined through a series of experimental and computer modelling studies led by the authors in recent years, which are discussed in this paper.

2. Effectiveness of the connection method in reinforced towers — single panel tests

The principle behind the retrofitting method being investigated in this study is that the capacity of the main tower legs will be improved by increasing their cross-sectional area through attaching a reinforcing angle member to the existing tower angle leg member. An illustration of this type of method being installed in Australia is given in Fig. 1.

Since there are no published design or construction guidelines currently available to govern this method in practice, a wide variety of connection types and details are currently used. The assumption made by designers is that the reinforced leg becomes a 'compound member' and its load capacity is determined accordingly. However, the design code provisions for compound members are not satisfied in reality since the load is eccentrically applied through only the original member, some load is already present in the original member when the reinforcing member is attached, and the connection methods used do not necessarily comply with the code specifications.

In order to address the first question regarding the most effective connector type and spacing, Tongkasame et al. [14] conducted a series of one-panel tests, based on Temple et al.'s interconnector model for angle members [15]. These tests were designed to analyse the load transfer effect of bolted cleat connectors with three possible arrangements known as aligned, alternate and cruciform connections (Fig. 2). The study concluded that the cruciform arrangement provided the highest load transfer rate between the original tower member and the reinforcing member. Other important conclusions were that two connectors per panel were sufficient (three per panel provided little advantage), and that the first connector played a critical role in load transfer. The load transfer mechanism of the steel angle connector was further studied by Zhuge et al. [16] through a non-linear ABAQUS model and a simplified model.

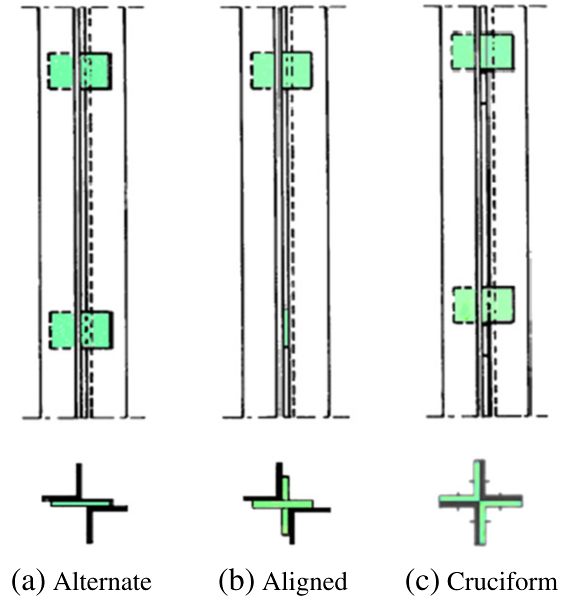

Fig. 2. Retrofitted one-panel angle leg with different connectors (after Temple et al. [15]).

The one-panel tests were able to demonstrate that the assumption, frequently made in practice, that full load transfer occurs immediately at the first connector and that the original and reinforcing members then carry half of the applied load after that point is demonstrably over optimistic. The tests showed that better load transfer is achieved if the first connector is particularly stiff (e.g. if it has a longer cleat and more bolts), but that full load transfer is not achieved until at least two connectors from the start of the reinforcing member [14]. However, it was important to extend the examination of this issue of 'load transfer lag' when reinforcement was extended over multiple panels and this formed one aim of the subsequent tests that are reported below.

3. Multi-panel tower scale model tests

3.1. Test set up

From 2008 to 2011, a series of tests have been conducted on a scale model of the lower panels of a simple transmission tower structure. In combined loading cases, the compressive tower legs in symmetrical

Fig. 1. An example of a reinforced tower leg installation underway in Australia (photo from Graham Brown, O'Donnell Griffin Pty Ltd).