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Behaviour and Design of Connections for Demountable Steel and Composite Structures

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ABSTRACT

This paper provides an overview of demountable connections and elements for steel and composite structures. Demountable connections are generally assembled from prefabricated structural members which can be reused after dismantling. This paper investigates innovative connections which enable steel and concrete framed structures to be made demountable. Demountable connections considered in this paper include beam-beam connections, column-column connections and beam-slab connectors. The finite element models for the nonlinear inelastic analysis of coped beams, column-column connections and composite beams are developed based on nonlinear finite element analysis techniques using the commercial finite element program, ABAQUS. The behaviours for coped steel beams and composite beams are then compared with the corresponding experimental results. The finite element models are used to investigate the effects of material and geometric properties on the behaviour of demountable connections. The finite element models can efficiently predict the plastic damage in the coped steel beam used in beam-beam connections. It is demonstrated that the coped beam can be made demountable up to a load of about 50% of the ultimate load which is greater than typical service loads. The computational results indicate that increasing the sleeve length and reinforcement ratio increases the stiffness and ultimate tensile strength of demountable column-column connections.

1. Introduction

The concepts of demountable buildings and prefabricated construction can be traced back two millennia to the bible [1]. More recently in Australia, the Green Building Council of Australia has provided guidelines for best practice in the use of structural steel and concrete in construction projects. Furthermore, more recent discussion has centred on construction and demolition waste where demountable buildings which allow for the reuse of materials. Current estimates in Australia have determined that approximately 40% of landfill waste can be directly attributed to building and construction. Methods for lowering this rate can be achieved through changes in construction materials, methods of construction and demolition. This paper presents the concept of innovative connectors between steel and concrete elements that allow structures to be made demountable. Current Australian practice in steel building construction encourage steps that structural designers can take to maximise the potential for re-using steel buildings including using bolted connections in preference to welded joints and ensuring easy access to connections [2]. Recent examples of this concept include the Olympic Stadium project in Sydney completed in 2000 (Fig. 1). The end stands of this stadium were made demountable using innovative blind bolts and the structural steel was then reused to upgrade the Wollongong Stadium 80 km south of Sydney. In addition to the economic and environmental benefits that are promoted by demountable buildings, the proper design of connections that ensures buildings are able to be systematically disassembled also promotes safety in design.

The concept of demountable structures changes the traditional construction technology paradigm which often does not consider the reuse of structural members at the end of their service life. Demountable structures are generally able to be easily erected and dismantled, and are capable of adaption to different situations. Structural steel is one of the most promising materials for allowing structures to be made demountable. Bolted connections can also be utilised to promote demountability in commercial composite buildings. The erection procedures can be used in the reverse order for the efficient dismantling of demountable structures. For example, temporary supports used to erect the structure can be utilised for dismantling the structures. This procedure may prevent structural members from being bent, distorted or overstressed during dismantling. The deformation in a structural member may occur during its service life. The deformed members can be clearly marked for identification after dismantling a structure. These members could be repaired before reusing them. Demountable

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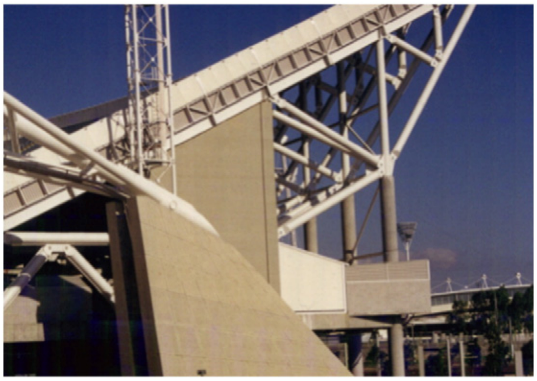

Fig. 1. Olympic stadium Sydney, Australia.

structures are generally limited to short-term use such as travelling shows, carnival structures and school classrooms. However, they have not been implemented in larger structures for long-term use. This paper presents the details of specific connections which may permit steel and steel-concrete framed structures to be made demountable.

One of the major practical/technical impediments of the reuse of steel is the ability to render structures demountable and thus this paper highlights the development of innovative connectors for both beams and columns that promotes the concepts of demountability. Therefore, this paper explores the behaviour of bolted-connectors for composite beams and columns which allow structures to be made demountable. Demountable connections considered in this paper include the following:

- Beam-beam connections,
- Column-column connections; and
- Beam-slab connectors.

Finite element analysis is conducted to compare demountable structural elements with traditional structural elements. The deterioration rate of structural steels over their lifespan should be considered in the structural design for reusing the components. New structures with reused steel could potentially be unsafe without accounting for the deterioration rate into the project design. Advanced structural health monitoring methods could provide information about the strains and deformations over a demountable structure's life.

2. Beam-beam connections

2.1. Basic concept

The web-side plates are used for connecting the primary beams to secondary beams in the structural steel framed connections. Fig. 2 depicts a beam-beam connection using web side plates. The web-side plates are either cut from Grade 250 plate. The steel beam is generally cut and the holes are drilled in the coped region. These manufacturing operations should comply with the limitations of maximum tolerance given in Section 14 of Australian Standard AS 4100-1998 [3], Eurocode 3 [4], Canadian Standard CSA-S16-09 [5], American Standard AISC-LRFD [6], and Japanese Standard AIJ [7]. The bolt hole diameter is maintained 2 mm larger than the nominal bolt diameter. The bolts, M20 or M24, can be utilised in the web-side plate beam-beam connection with a minimum of 2 bolt rows to a maximum of 9 bolt rows and a maximum of 2 columns of bolts. The web-side plates are welded to the primary beam web with 6 mm or 8 mm fillet welds including the minimum fillet weld size of $0.75t_i$, in which t_i represents the web-side plate thickness. The fillet weld should be continued on both sides of the plate but not continued across the top and bottom of the web side plate. A minimum 20 mm clearance is allowed between the primary steel beams and coped secondary steel beams as shown in Fig. 2. The requirement for the design model of the steel connections was specified in Clause 9.1.3 of AS4100-1998 [3]. The design method, capacity tables and detailing parameters for the web side plate beam-beam connections commonly used in Australia are given by Hogan and Munter [8]. This paper extends the design guidelines developed by Hogan and Munter [8] to predict the demountable behaviour of coped steel beams used in steel beam-beam connections.

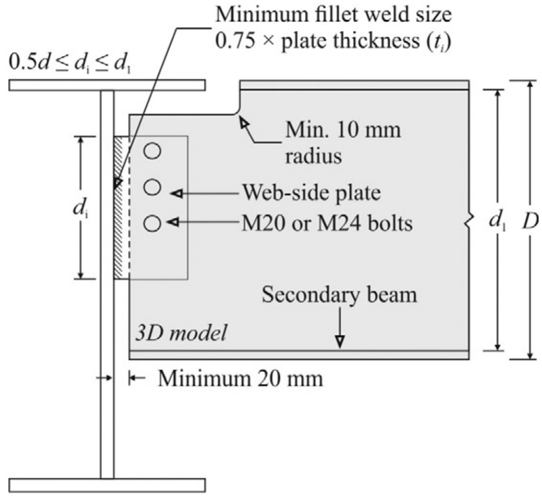

Fig. 2. Beam-beam connection with web-side plates.

When the coped beams are restrained by lateral torsional buckling, the following geometric conditions must be satisfied for the single web coped beam [8]:

$$d_c = \le 0.5D \tag{1}$$

$$c\begin{cases} D & \text{for } \dfrac{D}{t_{wb}} \le \dfrac{900}{\sqrt{f_{yw}}} \\ \dfrac{730 \times 10^6 D}{\sqrt{\left(f_{yw}\right)^3 \left(\frac{D}{t_{wb}}\right)^3}} & \text{for } \dfrac{D}{t_{wb}} > \dfrac{900}{\sqrt{f_{yw}}} \end{cases} \tag{2}$$

in which D denotes the beam depth, d_c represents the cope depth, c is the cope length, t_{wb} is the thickness of the secondary beam web and f_{yw} denotes the yield strength of the secondary beam web.

2.2. Finite element analysis

The finite element program, ABAQUS [9], was employed to study the demountable behaviour of coped steel beams used in the web side plate beam-beam connections. The object oriented Python script was developed for the finite element analysis. The developed Python script was utilised to automate the simulation including the creation of the finite element model, assigning of materials, creation of analysis procedure, application of loads, assigning of boundary conditions and collection of the results from the final analysis. The user-defined Python script incrementally generates many finite element models for the parametric study [10].

Steel beams are generally not perfectly straight but have small initial geometric imperfections, which are induced during the manufacturing and construction processes. These initial geometric imperfections may reduce the stiffness and ultimate strengths of coped steel beams. The initial geometric imperfections are generally assigned by perturbations in the steel beam. An imperfection was defined as the linear superposition of buckling modes which are used as input in the subsequent static analysis to assign an imperfection in the coped steel beam by adding the predicted buckling modes to the real geometry. The first buckling mode, as shown in Fig. 3, was assumed to define the model critical