STEEL BEAM-TO-COLUMN BUILDING CONNECTIONS

W. F. CHEN

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Edited by

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Preface

Approximately 30–40% of the total construction cost of an average building which includes design, fabrication and erection is due to the structural system. Of these three items, fabrication and erection account for well over 75%. Thus, any saving in fabrication and erection can considerably reduce the cost of construction. It is evident, then, that the major remaining potential for economy in the fabrication and erection of structural steel buildings lies in the building connections, namely the beam-to-column connections. The use of steel beam-to-column connections is inherent in every structural steel building, whether one story or one hundred stories. Therefore, the beam-to-column connection, because of its importance to all construction, is significant both economically and structurally. Savings in connection cost as well as improved connection quality have an impact on all sizes of buildings, both small and large. Because of the repetitive nature of connections, even minor material or labor saving in one connection is compounded and expanded throughout the entire building.

Many designers have been plagued for years by efforts to assess the most recent research results on the stiffness, strength, ductility, and behavior of beam-to-column connections. There are many types of connections and varieties of types, and each has different rotational characteristics. For a design engineer, there are questions concerning the ability of such connections to furnish the stiffness required to maintain a structure within allowable drift limitations without resorting to integral or separate systems. To what extent will they provide needed damping under earthquake or wind motion? Unlike structures built in previous years where exterior masonry façades and interior block partitions provided rigidity not accounted for in design, buildings today do not always have such inherent stiffening elements. It is important, then, for a design engineer to understand the behavior of such connections, not only from the viewpoint of the connection as a structural element, but also from the viewpoint of the connection as a part of the complete structural system.

Since the behavior and design of beam-to-column connections are of major interest to many structural engineers, a significant amount of research has been done or is currently under way. Most of the past research on beam-to-column connections was performed on welded or riveted specimens. In recent years, most research has concentrated on fully welded fully continuous moment-resisting beam-to-column connections. This may be because welding offers the greatest opportunity for the full development of strength of the connected members. However, the economic advantages of less-than-full-capacity bolted connections and of connections employing combinations of welding and bolting to simplify on-site connections have been recognized lately. Extensive theoretical and experimental studies of the behavior of such connections have been made in recent years. As a result of these and allied developments, several practical methods for the design of such connections have been proposed. However, the engineers who need to study the basic theory or who need guidance in design often find it difficult to read, to relate, to locate or to use this open literature, recorded in various places and languages. It is the objective of this special issue of the *Journal of Constructional Steel Research* to provide a state-of-the-art summary of the recent experimental and theoretical studies undertaken to provide an understanding of the behavior, analysis and design of steel beam-to-column building connections and their effect upon the behavior of frames. Design rules and design procedures for these connections in Europe, Japan and USA are also given. These connections, of universal importance in earthquake, wind and hurricane loading, are also the source of a major fabrication expense. Savings from the *rapid* incorporation of recent research results to practicing engineers could be significant. This special issue attempts to achieve this goal in the case of steel beam-to-column building connections.

To this end, the special issue is organized into an introductory paper followed by three parts, each containing several separately written papers. The first part, 'Connections as Structural Elements', was coordinated by Professor H. Krawinkler, Stanford University. The coordinator for the second part, 'Connections in Frames', was Professor Gerstle, University of Colorado. Professor R. Bjorhovde of the University of Arizona assisted in coordinating the third part, 'Design Rules'. The general coordinator of the special issue was Professor W. F. Chen with assistance from Professor J. T. Gaunt of Purdue University.

The initial materials of this special issue grew out of five years of activities of the Task Committee on Beam-To-Columns Connections of the ASCE Committee on Structural Connections. The Task Committee, chaired by

Professor W. F. Chen, has invited several experts to write individual papers for the three parts of the special issue. The Guest Editor wishes to thank the authors for their efforts and cooperation in preparing this special issue.

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PART III—DESIGN RULES

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Introduction

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ABSTRACT

A brief historical review of the evolution of steel frame building construction is presented. Construction systems, wind bracing, connector types, concepts of connection behavior and the development of analysis and design methods are covered. Contemporary ideas regarding connection behavior, the requirements of a proper design, and classification of connections are then presented. Last, major themes of this publication (strength, deformation, ductility and connection predictability) are introduced.

1 PURPOSE AND SCOPE

This is a publication on the behavior and design of steel beam-to-column building connections and their effect on the behavior of frames. It is a state of the art report on current research, design procedures, and economic considerations. It is intended to be a practical guide to the use of research information and current knowledge of connection behavior.

The full range of connection behavior—from simple to rigid—is covered. Emphasis is on the conditions most commonly encountered in buildings: bolted and welded connections of frequently used types subjected to static or pseudo-static loading. There is also ample treatment of the effects of repeated loading and the problems of seismically loaded frames and their connections.

The subject can conveniently be divided into three parts:

(1) *Connections as structural elements.* The response of the components of a given connection (its bolts, welds, plates, shapes, stiffeners, and so forth) to a given set of forces.

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(2) *Connections in frames.* The effect of the connection on the stiffness and strength of the members joined and on the entire framework.
(3) *Design rules.* The ways in which understanding of connection behavior and the concerns of fabrication and erection are translated into working procedures for the production of safe, economical connections.

The three parts of the publication are organized according to these categories but it must be recognized that a complete division of interests is not possible. Suggestions and rules for proportioning will be found in all parts, and presentation of a particular design rule will often require an accompanying explanation of the behavioral condition it deals with. Also, a multi-authored work of this sort cannot be expected to have the unified point of view of a single author textbook. An effort has been made to avoid needless duplication, but it is inevitable that some topics will be treated in several chapters, with each contributor addressing them from his particular point of view. There is no intention to apologize for this for, indeed, it should be helpful to the readership for which the publication is intended: structural engineers with an understanding of connections who need an up-to-date source of informed views on the complex subject of beam-to-column connections.

Common concepts and definitions encountered in discussions of beam-to-column connections will be reviewed briefly in this chapter. Refinement and elaboration will come later. The aim of this introduction is to provide guidelines to assist the reader in keeping subsequent presentations in proper perspective.

The introduction will start with a short account of key stages in the development of the subject. These are of more than academic interest. As in all long-established branches of technology, there is found in current practice a residual influence of decisions made and directions taken long ago, before the underlying sciences were well understood. 'As the twig is bent so the tree is inclined', is a truism that applies just as well to technological as to human development. Not everything is the result of continuous, rational progress. Thorough understanding of what is done now requires an appreciation of history.

2 BACKGROUND

This account of how practice in the joining of beams to columns evolved and understanding of connection effects progressed will be limited to a few events that shaped later developments. Emphasis will be on the late nineteenth and early twentieth century. In many respects, these were the formative years of our subject.

2.1 Steel frame building construction

Concern for beam-to-column connections is concern for metal framed tier buildings. This is a structural form that originated in the industrial revolution of the late eighteenth century and has been evolving ever since. But many crucial developments took place in a well defined period of less than 30 years: from 1885 to 1913. This was the period from the opening of the first true skeleton frame office building—the Home Insurance Building in Chicago—to the completion of the building that convincingly demonstrated the full range of possibilities for tier buildings—the Woolworth Building in New York. These and a few other structures in Chicago and New York can be used to describe that era.

As originally constructed, the Home Insurance Building was 10 stories tall. Two stories were added in 1890, making the total height 164 feet (Fig. 1). In the words of the architect, Major Le Baron Jenny: 'As it was important in the Home Insurance Building to obtain a large number of small offices with an abundance of light, the piers between the windows were reduced to the minimum and the following system of construction was adopted:

'Iron was used in the skeleton of the entire building except the party walls and every piece of iron was protected from fire by masonry, excepting only some columns so situated as not to be dangerous if left exposed. A square iron column was built into each of the piers on the street front: All columns and mullions were continuous from the bottom plate to the top of the building. The girders carrying the I beams of the floors rested on brackets of the iron columns.

'Stone lintels must have short bearings on the piers, that there may be some movement without fracture. Every beam or girder that reaches a wall pier or column must be securely anchored thereto, every piece of iron that crosses another must be securely bolted thereto. It is also necessary to so attach the girders and the beams in their bearings that any moment will be transported entirely across the building at once without any previous slipping or taking up the slack.

'As the bolts do not accurately fill the holes, a clamp was introduced to pull the beams close together so that the least movement is felt at once over the whole beam.'[1]

Figure 2, drawn from measurements made when the building was demolished in 1931, illustrates these features.

Beam and column building construction using wrought or cast iron

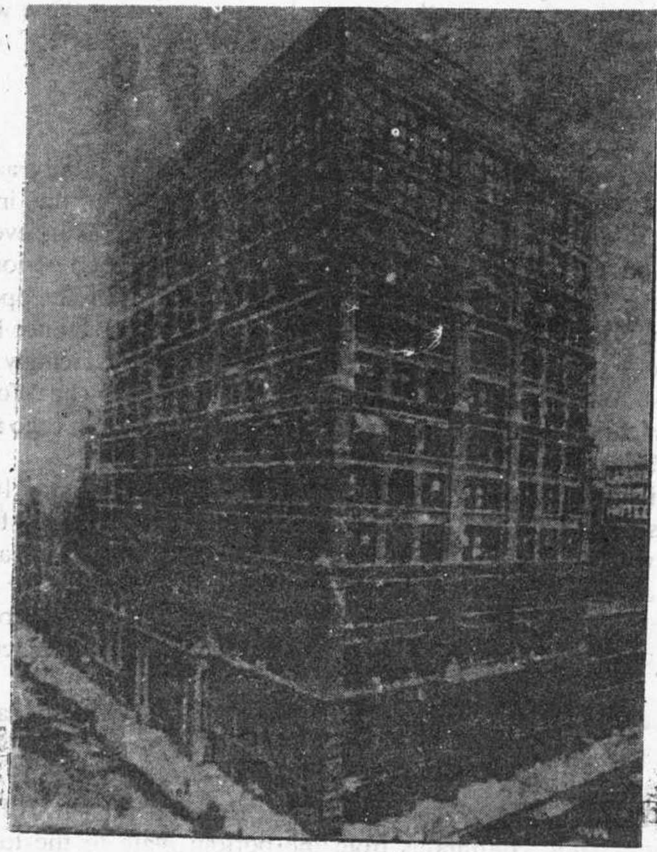


Fig. 1. The Home Insurance Building.[1]

members was in evidence long before the Home Insurance Building. In England, textile mills with internal cast iron frames had been built in the late 18th century and a multi-story industrial building with an internal iron structure was erected in 1801. Commercial buildings with complete cast iron facades appeared in the United States about 1850. The use of wrought iron I beams also started about that time. But Jenny's building, in which the walls were supported on a multi-story skeleton of metal beams and columns, was a true departure from previous structures, all of which had been hybrids of one form or another.

In its details, however, the Home Insurance Building seems primitive, even by the standards of the time (see Fig. 2). There is no sign of awareness of the member and connection types being used in existing wrought iron

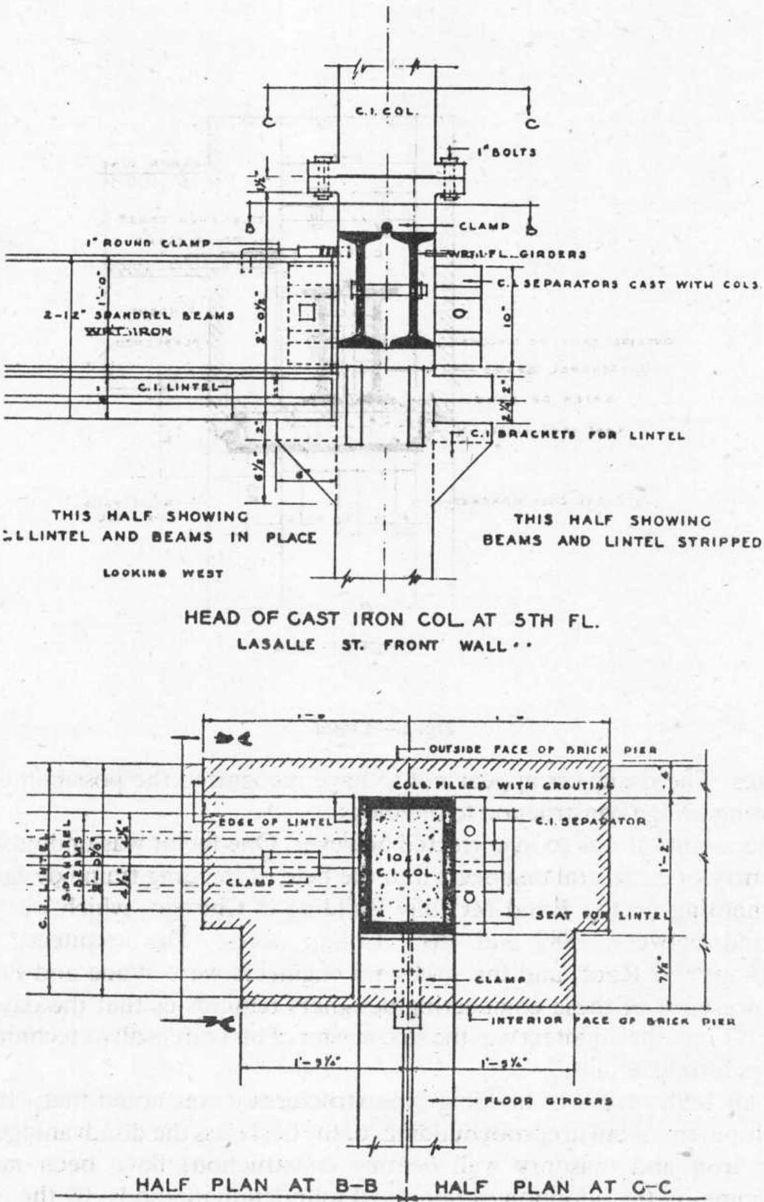
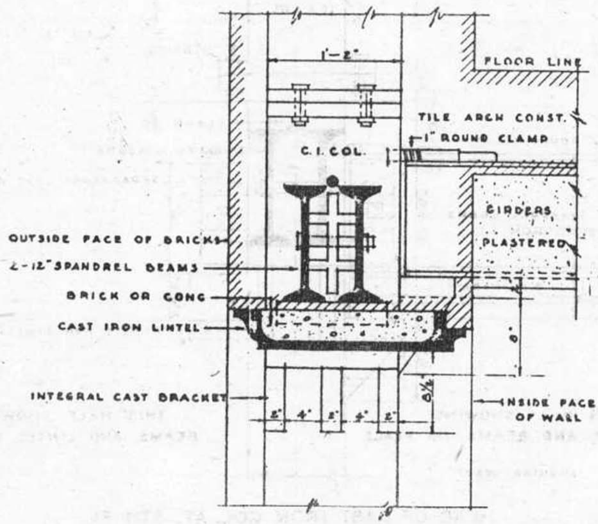


Fig. 2. Home Insurance Building detail.[1]



SECTION A-A

Fig. 2.—*Contd.*

bridges. The designers appear not to have recognized the possibilities for adapting bridge construction to buildings.

This situation was soon corrected however. One factor was undoubtedly the entry of structural engineers into the field of building frame design. In commenting on the Rand McNally Building in Chicago, which was constructed between 1889 and 1890, Condit notes: 'The architects were Burnham and Root, and the structural engineers were Wade and Purdy. The presence of these engineering designers reminds us that the day had passed when the architect was the sole master of his craft in all its technical as well as formal details.'[2]

In an 1898 review of building superstructures it was noted that: 'In the development of tall fireproof buildings of the best class the disadvantages (of older iron and masonry wall bearing construction) have been mainly overcome by the adoption of improved foundation methods, by the introduction of structural steel, by the adoption of the steel cage construction, by the mathematical analysis of all the different parts of the structure, and by the adoption of the principles and advanced practice of bridge engineering for the steel framework'.[3]

Steel beams had appeared on the market just in time to replace wrought iron from the sixth floor to the roof of the Home Insurance Building. But all of the other developments just quoted took place in the decade from 1885 to 1895.

The Reliance Building, a 14 story, 200 foot tall building in Chicago completed in 1894, illustrates the progress made during this period. Figure 3 is a photo of the completed building and Fig. 4 shows it under construction. The columns are of the Gray type: 4 pairs of angles connected by intermittent tie plates. A typical corner detail is shown in Fig. 5. Plate girders were used between all outside columns. The columns were made in two-story lengths with alternate columns being spliced at each story. The facing

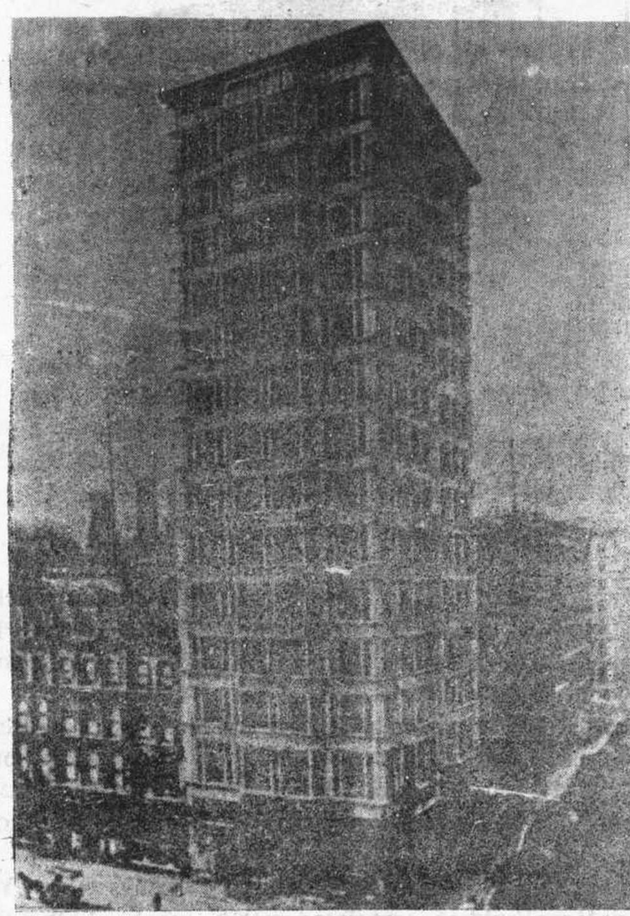


Fig. 3. The Reliance Building.[5]

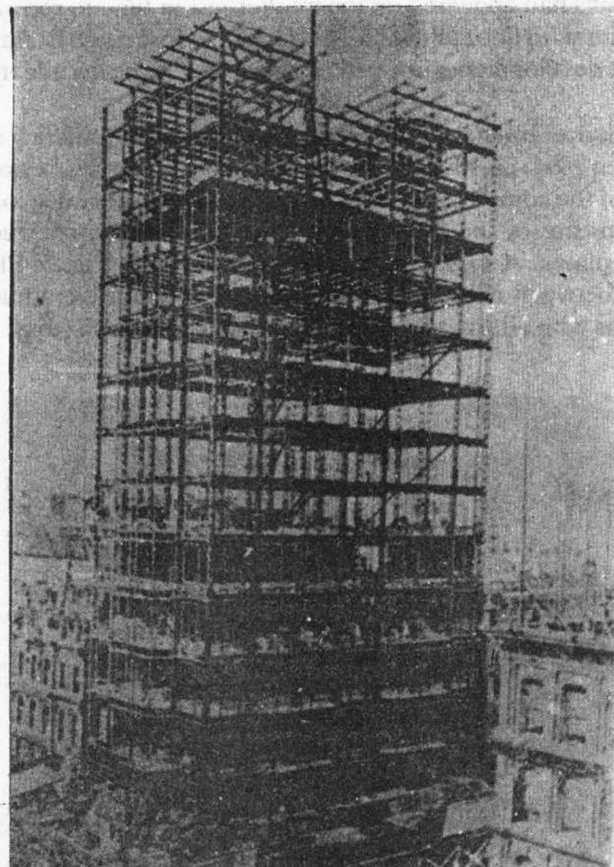


Fig. 4. The Reliance Building construction view.[5]

and fireproofing were of terra cotta, with some brick masonry back-up. The differences between the Reliance Building and the Home Insurance Building are graphic evidence of what was probably the most revolutionary decade in the history of building construction.

Skeleton construction started in Chicago but the scene of greatest activity soon shifted to New York. The attractiveness of a business location in lower Manhattan created a demand for tall buildings there. Unrestricted height regulations and excellent foundation conditions made it possible to meet the demand.

One of the early noteworthy examples of tall buildings in New York is the 33 story Park Row Building, completed in 1898 (Fig. 6). At that time it was stated that, 'The steel cage construction of office buildings had its genesis

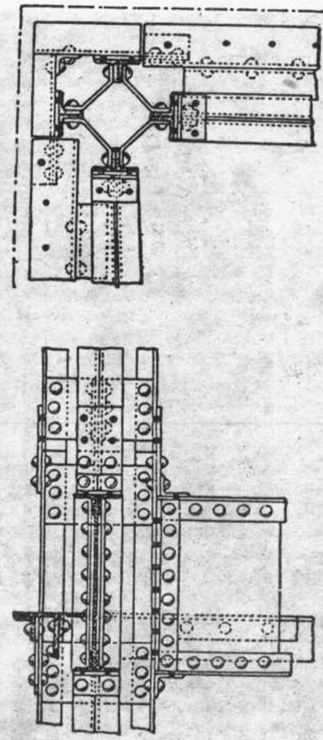


Fig. 5. Reliance Building detail.[5]

less than a score of years ago, and it may reasonably be assumed to have reached the zenith of its development, at least so far as height is concerned, in the building now under construction for the Ivins Syndicate on Park Row. From the head of its pile foundation to the top of the domes this structure will have the enormous height of 424½ feet, and it is probable that such a height will be rarely if ever hereafter found desirable and profitable for an office building.'[3]

Noted more for its height than its beauty, the Park Row Building did contain further evidence of the adoption of bridge engineering practices in building construction. This is illustrated by the intersection of a single web girder, a box girder, and a lattice girder with a box column at one corner of a court between two wings of the building (Fig. 7).

As shown by the beam-to-column connection in Fig. 8, detailing appears to have been even more advanced in the American Surety Building, a 21 story New York structure completed in 1895.

Progress continued in New York in the early 20th century with the