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Recent Developments in Welded Multi-Storey Steel Skeletons in Canada

Progrès récents dans les ouvrages canadiens à ossature métallique soudée à plusieurs étages

Neuere Entwicklungen in geschweißten, mehrstöckigen Stahlskelettbauten in Kanada

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1. Introduction

Welded steel structures can have no claim to novelty now, after some thirty years of experience in both Europe and America with a multitude of examples of successful welded constructions. The recent developments relating to welded rigid-frame multi-storey skeleton structures described in this paper do, however, represent a significant development in the application of welding to steel construction.

The paper traces the development of welded multi-storey steel skeletons in Canada over a period of some ten years during which a full transition from simple flexible construction to butt-welded all-rigid construction has been accomplished. The progress is illustrated by a series of examples representing each significant step forward. It happens that all the examples chosen are of structures in Toronto, though in fact the progress described is typical of that found in all parts of Canada.

This progress has been made in particularly favourable circumstances, since vigorous commercial activity in Canada, particularly in Toronto, has led to the construction of many multi-storey buildings. This stimulating atmosphere, bringing with it great capital expenditures, has not however prevented keen competition in the development of more economic forms of building construction. What is most significant then, perhaps, is that this development of welded multi-storey building skeletons has been fostered most of all by considerations of overall construction economy.

It should be noted that the discussion is limited strictly to multi-storey skeleton steel frames, and no reference is made to other types of building structures or bridges, etc. Important developments in welded construction have been made in many fields of application during the period of time covered by this paper, but it seems best to limit the present commentary to the single field of simple beam and column structures.

2. The Role of the Canadian Welding Bureau

The progress described in the following section represents the fruit of the efforts of many architects, engineers, designers and fabricators. The key that unlocked the door to this accomplishment was provided by the Canadian Welding Bureau.

Before and during the recent war the need developed for a nationwide authority to develop and control welding activities in order to better ensure safety and satisfaction. With increased commercial activity after the war, it became of urgent importance that Canadian welding codes of national scope, specifically suited to Canadian industry, should be developed. Older industrial nations were already plagued with a multiplicity of standards. It seemed important to forestall and eliminate the possibility of any such development and confusion in Canada. Accordingly, at the request of industry, codes were drafted by representative committees formed by the Canadian Standards Association and the Canadian Welding Bureau itself was established in 1947 as a division of the Association to administer the codes.

The Bureau is a non-profit organization. It is self-sustaining and receives no government funds either directly or indirectly. Furthermore, the Bureau does *not* possess or exercise any legal or mandatory authority. Revenues are derived in part from testing services, from educational fees, and through the support of sustaining corporate members.

The principle duties of the Canadian Welding Bureau are: (1) to test and subsequently to certify those fabricators who are able to meet the applicable C.S.A. Standards, (2) to assist the Canadian Standards Association in providing the necessary codes and standards governing all phases of welding, and (3) to list those fabricators and contractors certified by the Bureau. Other services provided by the Bureau relate to welding standards, testing, training and education, and documentation.

Of greatest interest and importance is the Bureau's role in qualifying fabricators. In this activity the Bureau does not qualify individual welders, but rather an entire fabricating or contracting organization in relation to its complete personnel and equipment. In particular the fabricator or contractor is required to demonstrate to the Bureau that he employs or retains the services of: (1) engineering personnel competent to design welded fabrications and to specify and control the welding procedure used, (2) supervisory staff capable of directing and maintaining the proper welding procedure and quality, and (3) a staff of qualified welding operators. The fabricator or contractor must also show that he possesses or has access to: (1) plant equipment capable of properly preparing material for welding, etc., (2) welding equipment conforming to C.S.A. Standards, (3) facilities to maintain the welding and auxiliary equipment in good condition, (4) auxiliary equipment necessary for supplementary operations such as chipping, grinding, pre-heating, etc., (5) other auxiliary equipment for heat treatment, X-ray and flaw detection as required, and (6) physical testing equipment suitable for carrying out the tests specified.

It is clear then that the function and responsibility of the Canadian Welding Bureau comprises the approval not only of inanimate objects such as machines and electrodes, but the approval and assessment of the competency of individuals, including operators, supervisors and engineering personnel. Although this might appear at first an impossible assignment, it has proved not too difficult and both in principle and operation has met with a large measure of acceptance and success.

Government departments, owners, engineers, architects and other authorities have been quick to recognize the Bureau's qualification standards as a means of specifying and insuring sound, safe welding and relieving them of duties and responsibilities of which they themselves are not capable. It has led to a degree of confidence that was formerly lacking and has, as a consequence, greatly increased the use of welding not only in the field of structures but in allied fabrications. Owners, users, fabricators and welding equipment and electrode manufacturers have all benefited and are, as a consequence, supporters of the scheme both in principal and financially.

3. Examples

a) Sick Children's Hospital (1949)

The first significant application of welding to multi-storey steel skeleton construction came soon after the establishment of the Canadian Welding Bureau. The Hospital for Sick Children was to be constructed in an area close to existing hospitals and a welded structure was chosen to avoid the distress that would have been otherwise caused by the noise of riveting hammers. In applying welding to this structure no attempt was made to secure continuity in the frame except in resisting wind moments. The structural design was thus in fact identical to that of a riveted frame.

The frame followed the normal pattern for hospital construction consisting of a series of three parallel wings, each comprising up to nine floors, with wards set on either side of a central corridor, the three wings being joined by other similar sections along the main axis of the building. A general view of the completed steel work is shown in fig. 1. The framing was of simple beam and column construction, with the only unusual feature being that many of the beams had spandrel-type connections, with their webs lying in the plane of the column flanges. Beams were supported by means of simple seat and top

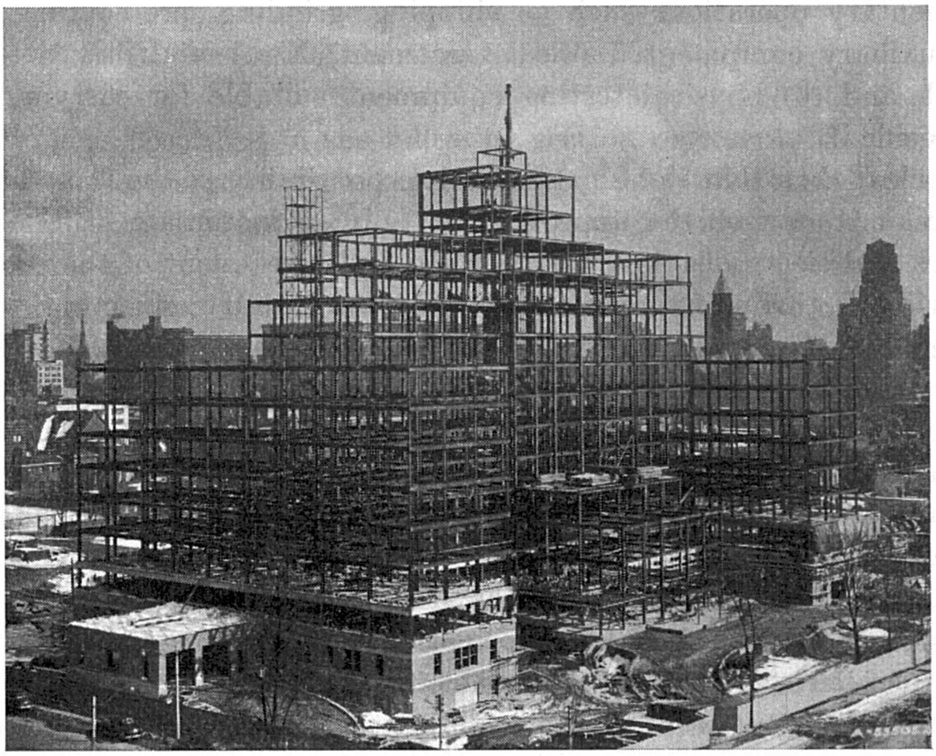

Fig. 1. General View of Completed Steel Work for Sick Children's Hospital (1949).

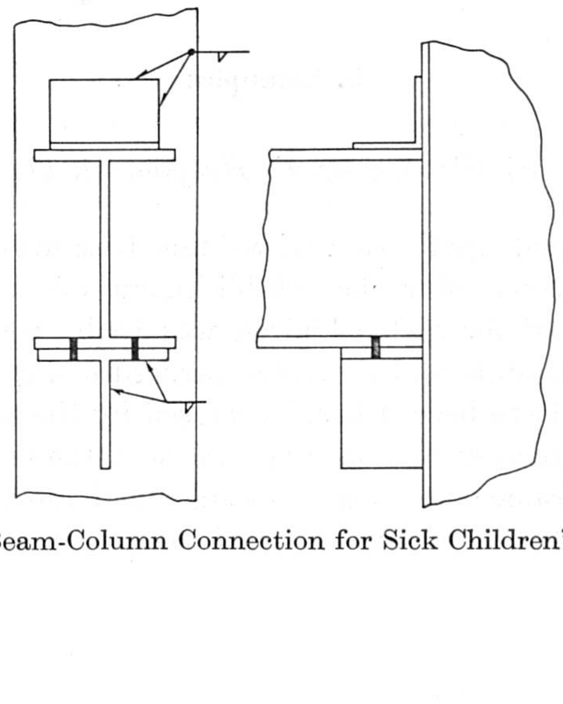

Fig. 2. Detail of Beam-Column Connection for Sick Children's Hospital (1959).

clip connections such as shown in fig. 2. In the case of lighter reactions an unstiffened seat angle was used instead of the tee-section. In most connections then, all welding was done in the shop with field connections completed with erection bolts. Wind connections and column splices were, however, field welded.

Although this structure could not be claimed as an example of ideal welded construction, it did represent good practice and in fact led to considerable economies through such features as the avoidance of holes in many members and the accordingly simplified fabrication. GOVAN and FERGUSON were the architects, and GORDON and WALLACE the engineers. The 2,400 tons of steel in the building were fabricated by a group of seven contractors because of the prevailing severe shortage of steel.

b) *Hydro-Electric Engineering Building (1952)*

Following the example of welded construction in hospitals, a number of buildings were erected using welding with simple flexible connections. This procedure involved no significant change in the conventional design practices that had been developed for riveted construction and led to certain economies and advantages even without the development of continuity in the frame. The next significant development in the construction of welded skeletons was a fully-rigid structure built for an office building for the Hydro-Electric Power Commission. The use of a rigid welded structure in this instance did not stem from thoughts of economy or experimentation, but rather was employed as a

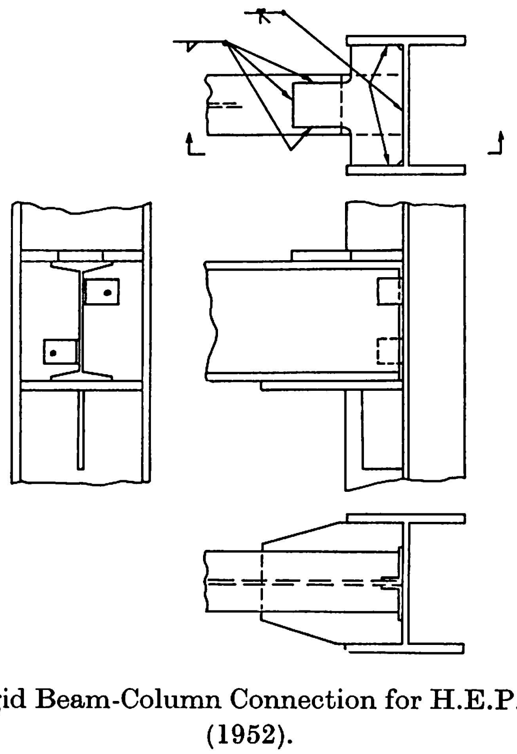

Fig. 3. Detail of Fully Rigid Beam-Column Connection for H.E.P.C. Engineering Building (1952).

result of engineering considerations arising out of unfavourable foundation conditions.

This structure, which was six stories high and 115 feet by 130 feet in plan, was of all-welded construction, with all primary connections designed for full rigidity. Typical connection details are shown in fig. 3, and it should be noted that detail metal is used to transfer load at all connections. ("Detail metal" is a term to describe the plates and angles etc. used to carry primary loads in connections). Such a style of joint of course facilitates fitting up, but obviously increases the cost of welding since in each joint the load must be transferred first into the connection plate and then on to the next member. It should be noted that no other examples of fully-rigid structures in which detail metal is widely used are to be found in the later examples described in this paper. The experience with this structure showed clearly that it was feasible to obtain full rigidity with practical techniques, but that, importantly, the result was not economically attractive.

The building was designed by the staff of the Power Commission, and the steelwork was fabricated and erected by the Dominion Bridge Company Ltd.

c) 484 Avenue Road Apartment Building (1955)

Following first applications of welding in hospital construction, where no continuity was attempted, and with some indication that fully rigid frame-

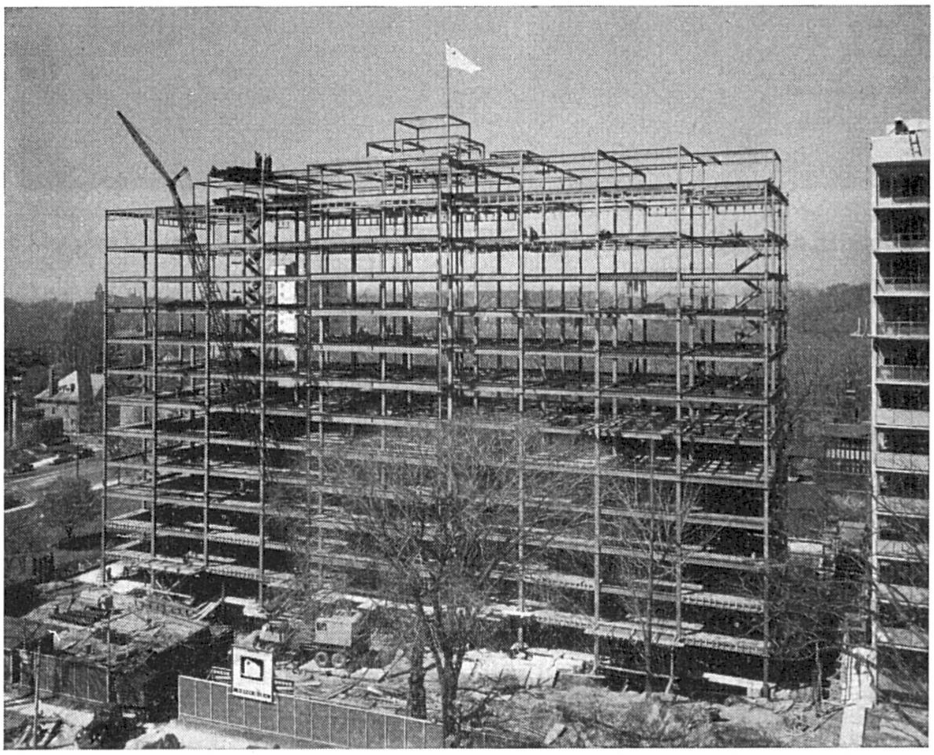

Fig. 4. General View of Completed Steel Work for Apartment Building at 484 Avenue Road, Toronto (1955).

works were not economical, engineers began to take advantage of welding in providing partial continuity in structural frameworks. Commencing about 1952 and carrying on very commonly until about 1956, a large number of semi-rigid structural frames were fabricated in Toronto. The case cited here is a typical example of these structures. This building, fourteen stories high and intended for luxury apartments, has a long and rather slender aspect, as shown in fig. 4.

The semi-rigid connection, accomplished with connecting plates having a section less than that of the flanges of the beams and girders of the main frame (see fig. 5) provides a considerable degree of restraint without the difficulty of a full moment connection. Semi-rigid framing offers significant advantages in reducing bending moments in beams and girders, and obviously illustrates a compromise between the economies offered by continuity and the cost of fully rigid connections.

As may be seen, the connection, though fairly complex on first appearance, is carefully arranged for simple field fabrication with all field welding done in the down-hand position. The loose top plates allow for irregularities in fitting lengths of beams and girders between columns.

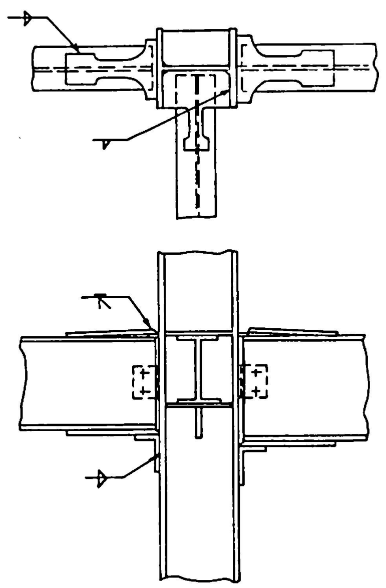

Fig. 5. Detail of Semi-Rigid Beam-Column Connection for Apartment Building at 484 Avenue Road, Toronto (1955).

Structures such as this were first built with the semi-rigid framing in one direction only — to take care of wind moments and provide a degree of continuity in the weak direction of the building. Later, as seen in this case, the semi-rigid connection was applied throughout. For this building the architects were Bregmann and Hamann, and the engineers Farkas and Barron. The frame was fabricated and erected by the Standard Iron Works Limited.

d) Imperial Oil Building (1955)

By 1955 welding was well established, and as shown in the previous example, was being used with considerable success in multi-storey skeletons with semi-rigid framing. The advantages in fully rigid construction were of course clearly evident by this time, although the difficulties arising in the field with fabrication of large skeletons for full rigidity were still apparently critical. Several significant advances were made in the design and construction of a twenty-storey office block for the Imperial Oil Company Ltd. Most important amongst these advances were the use of direct butt-welded connections between girder flanges and the columns, and the use of heavy boxed columns.

A typical girder-column connection is shown in fig. 6. It should be noted that the flanges of the beams are directly welded to the column using vee-prepared ends on the beam flanges, together with a coping hole at the bottom of the girder web. Web shears are directly accommodated by vertical fillet welds as shown in the sketch, and also seen are the temporary clip angles used during erection. The column, a 16″ WF 320 section boxed with two-inch cover plates is also shown in the sketch.

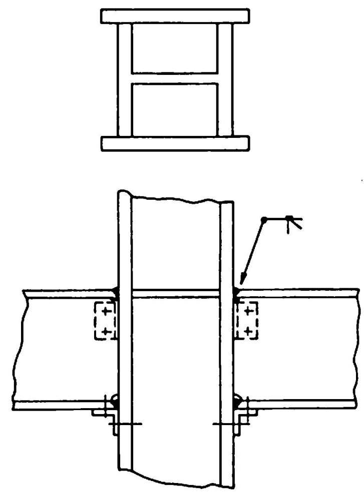

Fig. 6. Detail of Rigid Butt-Welded Beam-Column Connection in Imperial Oil Building (1955).

Rigid connections as described were used in the weak axis of the building, and semi-rigid connections with loose top plates were used in the other direction. The columns comprised heavy broad-flange sections with 2 to 4 inch plates welded across the flange tips. These long welds were accomplished using automatic equipment. It should be noted that column splices were also accomplished by direct butt welding, with two operators working simultaneously on the connection.

The architects were MATHERS and HOLDENBY and the engineers were WALLACE and CARRUTHERS. The steel structure was fabricated by the Bridge and Tank Company Ltd. of Hamilton.

e) Shell Tower (1956)

A special structure provided an opportunity to apply further refinements in fabrication techniques. The Shell Tower, though not a building, is in fact a multi-storey skeleton twelve stories high, one bay deep and three bays wide. It was the first multi-storey skeleton erected with fully rigid framing in both principal directions, yet entirely without "detail metal". The need for a clean simple structure is evident from the view in fig. 7 showing the completed tower with the steel framing entirely exposed.

The relatively small cross-section of the tower simplified the fabricating problem to a certain extent in that errors did not tend to accumulate as would have been the case in a large multi-bay structure. The accomplishment was none the less significant as revealed in the photograph which shows the connections

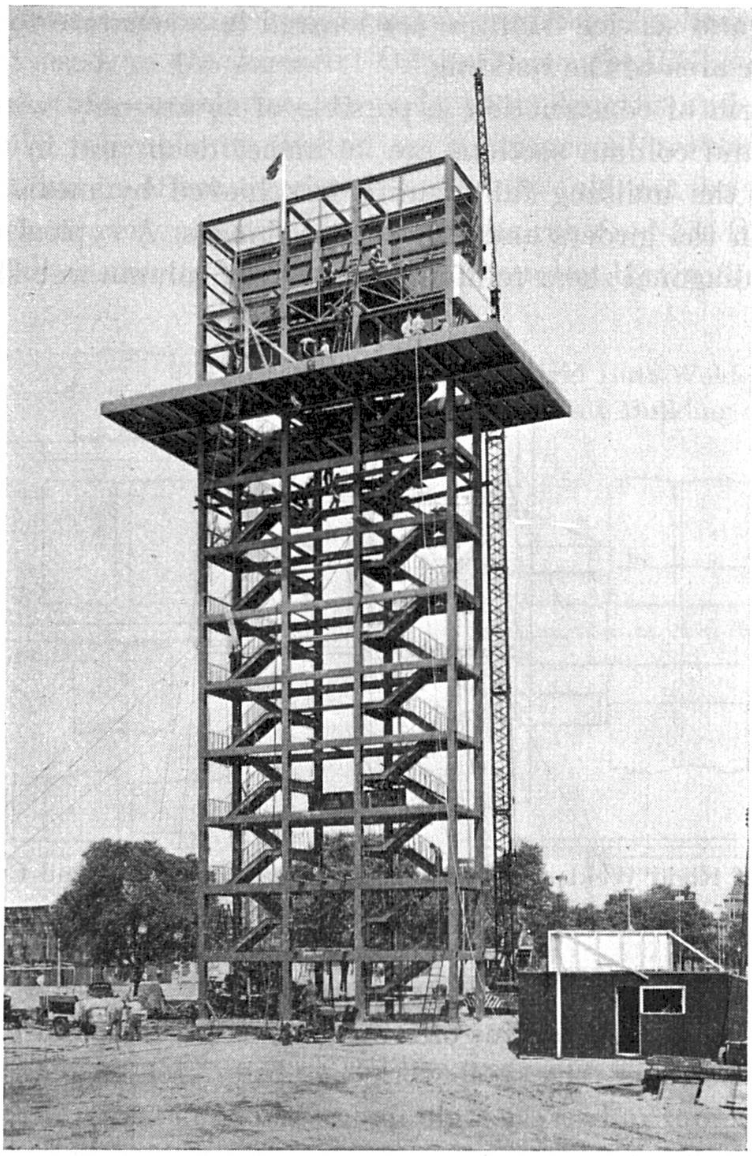

Fig. 7. General View of Completed Steel Work for Shell Oil Tower (1956).

clearly. The great care taken in the fabrication is evidenced by the fact that exposed weld metal was ground flush for the sake of appearance.

The tower, a striking addition to the skyline of the Exhibition Grounds, was designed by G. A. ROBB, and the engineers were WALLACE and CARRUTHERS. The tower was fabricated and created by the Disher Steel Company.

f) Union Carbide Building (1958)

In efforts to develop more usable floor space in tall office buildings, column spaces tend to be opened out, until as in the case of the Union Carbide Building the entire floor is left free of columns. In this building a clear floor area 62 feet by 212 feet is provided by means of rigid frame construction in which the exterior columns stand outside the walls of the building, and the main girders span unsupported from column to column across the full width of the building. All elevators and service facilities are located in a separate tower outside the principal floor area of the building.

Such a form of construction is possible of course only with welding. The main girder and column sections are 36 inches deep, and in the direction of the width of the building full rigidity is achieved by means of direct butt welds between the girders and the column flanges. A typical detail is shown in fig. 8. The diagonal shear reinforcement in the column web should be noted.

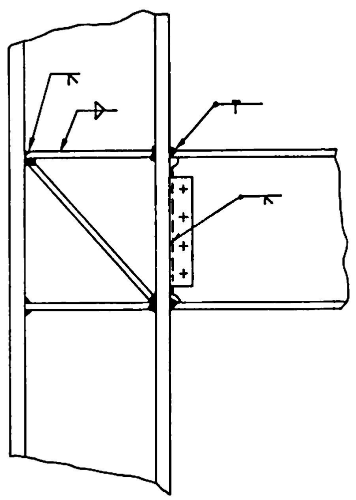

Fig. 8. Detail of Rigid Welded Connection Between 36″ Beams and Columns for Union Carbide Building (1958).

In the original design of the structure, rigidity was to be achieved in the longitudinal direction by means of reinforced concrete spandrel girders. In the construction, however, the steel work was fully erected before the spandrels were inserted, and only very light longitudinal flexural members were used for temporary bracing. During a severe storm the framework collapsed, fortunately without injury or loss of life. The structure has since been reerected according to the original design, save that shallow steel trusses were used for longitudinal bracing.

SHORE and MOFFAT were architects and engineers, and the Dominion Bridge Company Limited fabricated and erected the steelwork.

g) Sun Life Building (1959)

The final significant step in the development of welded construction that had started ten years before came with the construction of an all-welded all-rigid 17-storey office building. All the benefits of the experience gained before was brought to bear on this structure where full rigidity was achieved with direct butt welds between columns and flexural members, and even secondary floor beams were made continuous.

Typical details are shown in figs. 9 and 10, which illustrate connections to columns, and details of beam splices across girders. The heavy box column section, as first used on the Imperial Oil Building, should be noted. It is of course apparent that cumulative errors in beam lengths and column thicknesses ordinarily tolerable in riveted or conventional welded construction (where connections in effect overlap members) would not be permissable in this building where very accurate fitting-up was required for the butt welded connections. The answer to the problem of accuracy lay in first cutting and

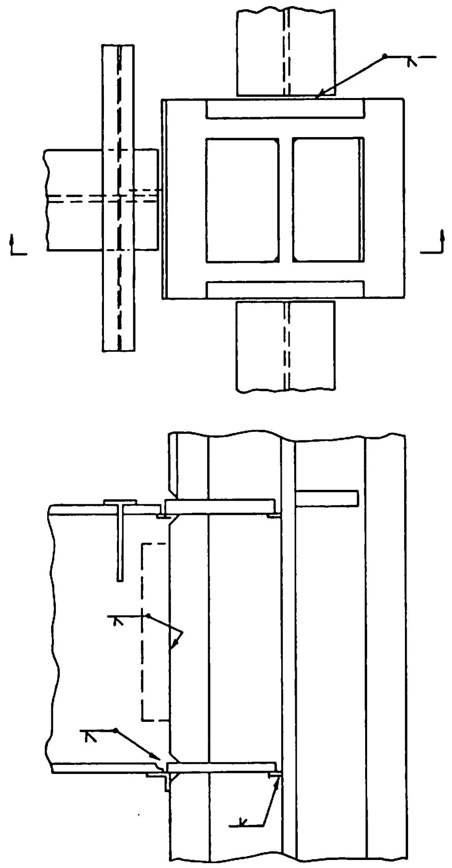

Fig. 9. Detail of Rigid Butt-Welded Beam-Column Connections in Sun Life Building (1959).

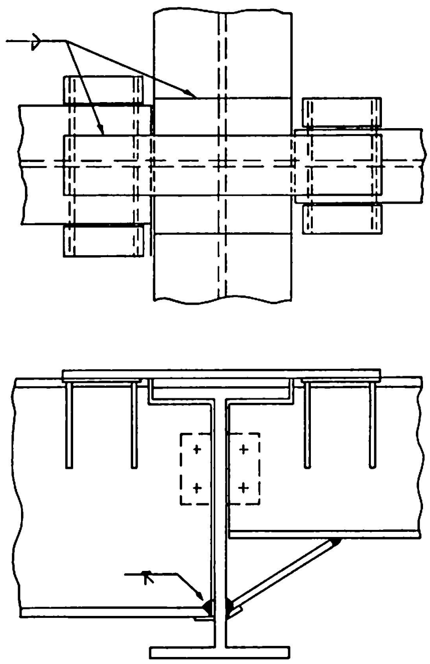

Fig. 10. Detail of Rigid Beam-Girder Connections in Sun Life Building (1959).

then measuring all the column sections for the building. Tolerable mill errors, such as slight longitudinal curvatures, lack of parallelism between flanges, etc. were all carefully determined before any flexural members were fabricated. With this information the beams could be properly dimensioned to fit the actual columns in the building at each connection. This operation, though markedly different from usual fabricating practice, was in fact completed successfully without special difficulty, or lack of economy.

Fig. 15 shows a view of the overall structure. J. B. PARKIN and Associates were architects and engineers, and the 2,200 tons of steel work were fabricated and directed by the Disher Steel Company Limited.

Summary

Starting in 1948 with the provision of adequate codes and specifications, significant progress has been made in Canada in the use of welding in multi-storey steel skeleton buildings. Vigorous commercial activity has led to the construction of many new structures, and has provided opportunity for the application of new techniques and procedures.

The use of welding in steel skeleton construction commenced first with applications to "flexible" connections, similar to those used in riveted construction. Later, semi-rigid connections were employed, using reduced-section top plates, etc. Fully rigid connections were also introduced, though still using detail metal (supplementary plates and angles). Finally fully-rigid direct butt-welded connections were introduced, with direct metal-to-metal stress transfer, avoiding all secondary material save temporary seats.

When first used, semi-rigid and rigid connections were applied only in the weak directions (for wind) of high buildings. Later, rigid connections were applied in both directions, but with detail metal to aid in fitting-up. Latest developments are typified by a seventeen-storey office building, welded fully rigid in both directions, with all joints made as direct butt welds. This accomplishment is the fruit of ten years' efforts and indicates clearly the high level of accomplishment in fabrication and erection operations achieved with welding.

Along with the general development of rigid connections, other innovations have been made. Heavy welded, box-columns, comprising broadflange sections with plates up to four inches thick, have been used. These facilitate the butt-welding of connections to beams and girders, and reduce column dimensions significantly in high buildings. Column splices in multi-storey buildings are made with simple butt-welds, even when such heavy column sections are used. Low-hydrogen electrodes are used almost universally to facilitate the deposition of high quality weld metal. Special control and inspection methods have also been established to assure safety, etc.

It is felt that the advances noted above represent, for multi-storey steel skeleton buildings, some of the most advanced techniques yet used anywhere in the world.

Résumé

Depuis que des normes et des règlements bien adaptés ont été établis en 1948, de notables progrès ont été réalisés au Canada dans l'emploi de la soudure pour la construction des ouvrages à ossature métallique à plusieurs étages. Par suite de l'intense activité économique, on a construit de nombreux bâtiments nouveaux et on a eu ainsi l'occasion d'utiliser des techniques et des procédés nouveaux.

L'application de la soudure aux bâtiments à ossature métallique a débuté avec les assemblages «flexibles», analogues à ceux utilisés dans les constructions rivées. Par la suite, on a réalisé des assemblages semi-rigides, en employant par exemple des semelles de continuité de section réduite. Les assemblages entièrement rigides à la flexion ont été également introduits, mais toujours avec adjonction de pièces de renforcement (couvre-joints et cornières supplémentaires). Enfin, on a exécuté des assemblages entièrement rigides soudés bout à bout, assurant la transmission directe des contraintes, sans aucune pièce intermédiaire d'attache à l'exception des appuis provisoires de montage.

Au début, on a prévu des assemblages semi-rigides et des assemblages rigides uniquement dans la direction la moins sollicitée (pour le vent). Ultérieurement, on a adopté pour les deux directions des assemblages rigides à la flexion, avec pièces additionnelles pour faciliter le montage. Les progrès les plus récents ont été réalisés sur un immeuble de dix-sept étages, à usage de bureaux, dans lequel tous les assemblages, rigides à la flexion, ont été réalisés par soudage direct en bout dans les deux directions. Cette réalisation constitue le fruit de longues années d'efforts et met nettement en évidence le niveau élevé atteint actuellement par la technique du soudage, dans la fabrication en atelier et au montage.

Parallèlement au développement général des assemblages soudés, d'autres innovations ont été introduites. C'est ainsi que l'on a pu réaliser de gros poteaux soudés en caissons, formés de profilés à larges ailes et de semelles d'épaisseur allant jusqu'à 4″ (10 cm environ). Cette disposition facilite le soudage en bout des joints des poutres et des cadres et réduit l'encombrement des poteaux, tout particulièrement dans les bâtiments de grande hauteur. Dans les bâtiments à plusieurs étages, les joints des poteaux sont exécutés par simples soudures en bout, même lorsque l'on emploie des poteaux aussi massifs. Les électrodes basiques ont été presque partout adoptées, pour obtenir un métal déposé de haute qualité. Pour assurer une sécurité suffisante, des méthodes spéciales de contrôle et d'essai ont été mises au point.

On peut considérer que les innovations mentionnées ci-dessus ont permis

de réaliser une technique parmi les plus poussées utilisées à l'heure actuelle dans le monde entier pour la construction des ossatures métalliques à étages.

Zusammenfassung

Seit im Jahre 1948 angemessene Normen und Vorschriften aufgestellt wurden, sind in Kanada bedeutende Fortschritte in der Anwendung von Schweißverbindungen beim Bau von mehrstöckigen Stahlskelettbauten gemacht worden. Eine lebhafte Geschäftstätigkeit führte zur Erstellung vieler neue Bauten und gab dadurch Gelegenheit, neue Verfahren und Konstruktionen anzuwenden.

Die Verwendung der Schweißtechnik in Stahlskelettbauten begann zuerst mit «flexiblen» Verbindungen, welche in der Ausführung ähnlich denjenigen der genieteten Bauweise waren. Später wurden halbsteife Verbindungen vorgesehen, die zum Beispiel Kopfplatten mit reduziertem Querschnitt verwendeten. Ebenso wurden völlig biegesteife Verbindungen eingeführt, wobei aber immer noch Stoßdeckteile beigezogen wurden (zusätzliche Laschen und Winkel). Endlich kam die Verwendung völlig starrer, mit Stumpfstoßnähten ausgeführter Verbindungen, die direkte Spannungsübertragung gewährleisten und jegliches sekundäre Stoßmaterial, ausgenommen provisorische Setzvorrichtungen, vermeiden.

Als man zur Verwendung geschweißter Verbindungen überging, wurden halbstarre und starre Verbindungen einzig in der weniger beanspruchten Richtung vorgesehen (für Wind). Später wurden für beide Richtungen biegungssteife Verbindungen mit Zusatzteilen zur Montagehilfe gebraucht. Die jüngste Entwicklung kann an einem 17-stöckigen Bürogebäude betrachtet werden, wo alle Verbindungen biegungssteif mit direkten Stumpfstoßnähten in beiden Richtungen verschweißt wurden. Diese Ausführung ist das Ergebnis zehnjähriger Anstrengungen und zeigt deutlich den hohen Standard, der bei der Herstellung und bei der Montage in der Schweißtechnik erreicht worden ist.

Parallel zur allgemeinen Entwicklung starrer Verbindungen sind auch andere Neuerungen eingeführt worden. Schwere, geschweißte Kastenprofilstützen aus Breitflanschträgern und bis zu 4 Inch starken Lamellen wurden ausgeführt. Dies erleichtert die Stumpfstöße der Träger- und Rahmenanschlüsse und reduziert die Säulenprofile besonders in hohen Gebäuden. Die Stöße der Stützen in mehrstöckigen Bauten werden ebenso mit einfachen Stumpfstoßnähten ausgeführt, sogar wenn solche äußerst starken Profile verwendet wurden. Basische Elektroden wurden fast überall eingesetzt, um das Anbringen hochwertigen Schweißgutes zu ermöglichen. Damit eine genügende Sicherheit erlangt werden konnte, wurden spezielle Kontrollen und Prüfverfahren entwickelt.

Man kann annehmen, daß die obenerwähnten Neuerungen im Bau mehrstöckiger Stahlskelettbauten zu einer der fortschrittlichsten Bauweisen der ganzen Welt geführt haben.