Residual Stresses in Thick Welded Plates

SURVEY OF

UTILIZATION AND MANUFACTURE

OF HEAVY COLUMNS

by

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This work has been carried out as part of an investigation sponsored jointly by the American Iron and Steel Institute, the American Institute of Steel Construction, the National Science Foundation, and the Column Research Council.

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October 1970

Fritz Engineering Laboratory Report No. 337.7
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ABSTRACT

This report presents the results of a survey on the use, design, and manufacture of heavy columns for structural purposes. The survey was carried out in conjunction with other phases of the research project "Residual Stresses in Thick Welded Plates".

A number of companies responded to a questionnaire submitted to them, and a total of 94 different projects in the United States and Canada was recorded. The majority of these structures was multistory and low-rise buildings, but several plants, hangars, and other structures were also represented. About two-thirds of the multistory and low-rise buildings surveyed had a number of stories less than 30, but two of the tallest structures in the nation are also included.

A variety of shapes was used for the heavy columns, with rolled WF, welded H, and box sections being the most frequent ones. A very common steel grade was ASTM A36,
although a large number of other grades also had been utilized. High strength steels were not employed to any large extent.

The welded heavy columns were fabricated mainly by means of the automatic submerged arc method. Some fabricators had developed special welding procedures in order to accommodate the particular demands of the welding of heavy components. Several replies indicated that distortions and other defects occurred due to the extensive welding, and sometimes created severe problems for the proper erection of the structure.

Almost 50% of the structures had been designed according to the AISC Specifications only, but other standards and codes were applied wherever any particular problems made it necessary. Special or refined analyses were made in a limited number of cases, and some replies also mentioned that model and wind tunnel tests had been performed. There is no reason to believe, however, that any special design considerations have been employed for the heavy columns.
Residual stress measurements were carried out for two projects only, and were confined to minor portions of the structure. These measurements were done with the intention of showing whether any stress-relieving processes were warranted.

In general, it can be stated that the survey shows heavy columns to be frequently used today. This utilization may increase as the number of multistory buildings and other heavily-loaded structures increases. The survey is indicative only, but it does give some idea of the problems encountered in the design and fabrication of heavy columns, as well as methods used to overcome them.
1. INTRODUCTION

Heavy elements have been used to an ever-increasing extent in the development of steel structures lately. This has been due mainly to the fact that the buildings have grown increasingly taller, which has resulted in substantially increased dead and live loads. Even more significant is the importance of the wind loads on tall structures.

There also seems to be a trend among designers towards preferring unbraced frames, which leaves the beams and the columns to carry the loads alone. This will have a larger influence as the structure gets taller.

Since the present design rules are based primarily on results from investigations on small or medium-sized members, and because the larger types may behave significantly different structurally, it was considered of interest to carry out a survey on the actual utilization of heavy columns. This study was part of a major project on residual stresses in thick welded plates.
The survey was aimed at finding which types of heavy columns were in practical use, how the columns had been designed, whether or not any particular problems had arisen due to the usage of heavy members, and how these problems had been solved. The survey provided background information for the structural shapes tested in the experimental part of the overall project.
2. **OUTLINE OF SURVEY**

The survey was initiated by mailing a questionnaire to several companies in the architectural, engineering, fabricating and contracting business. The following questions, intended to cover the most important features, were contained in the questionnaire:

1. Name and location of project.
2. Name and address of architect.
3. Name and address of structural engineer.
4. Name and address of steel fabricator.
5. Name and address of general contractor.
6. Number of stories (if applicable).
7. Total building height.
8. Typical story height (if applicable).
9. Heavy column sections used.
10. Basis of design (specifications or otherwise).
11. a) Residual stress measurements performed.
    b) How did these measurements affect the design?
12. Type of steel used.
13. Type of welding used.
14. Special problems before, during or after construction.
The first five questions were aimed at discovering whether any companies were working particularly much with heavy members, and if they had developed special skills for handling problems of this nature. The rest of the questions were technically oriented. To answer question no. 9, a definition of a heavy member was needed, and it was chosen by defining a column as heavy whenever any one of its component plates was thicker than one inch (1""). This definition proved very convenient.

Questions 6, 7, and 8 were made in reference to the loads on the structure and to the effective lengths of the columns. Number 9 asked for exact information about the column cross section that had been used, and No. 10 was intended to find if any special design procedures had been employed. This was also the reason for questions 11a and b; since residual stresses influence the load-carrying capacity of columns. It was necessary to know the steel grade that had been used in the heavy columns, and question 13 was meant to establish both the type of weld and welding method used for the fabrication of the member. The last question in the questionnaire intended to cover all problems...
that had arisen due to the size of the column, such as structural misfit due to various reasons, distortions of the shape, and application of straightening. The questionnaire is shown in the Appendix.
3. **UTILIZATION OF HEAVY COLUMNS**

3.1 Companies Responding to Survey

The questionnaire was mailed to a total of 434 different architects, structural engineers, fabricators and general contractors. Ninety-eight positive replies were received, representing 94 different projects. The number of replies was larger than the number of projects because some of the projects employed more than one fabricator.

The distribution of answers among the various company-types is shown in Table 1; indicating that the fabricators showed the largest response. It was noted that in 41 of the projects, the architectural and the engineering design had been done by the same company. Thirty of these 41 structures were multistory buildings, while the remaining 11 were of other types.

No particular engineering firm was handling these projects significantly more than others, contrary to the case for architects and fabricators. Table 2 illustrates
the results of this investigation, with the companies in question designated A, B, etc. It was found that one architectural firm had designed 10 of the total of 94 structures. This tendency was even more pronounced for the fabricators, for which it was found that one company was responsible for 18 and another for 13 projects, totaling 31 projects of 94 for only two fabricators. Among the contractors, one particular firm was working with 7 structures.

It may therefore be concluded that some companies, especially within the fabricating industry, have developed special skills in handling heavy columns and erecting structures utilizing them.

3.2 Structures with Heavy Columns

The survey showed that structures where heavy columns had been used were mainly of the multistory building type. Table 3 summarizes this information, and Table 4 shows the geographic locations of the projects included in the survey.

For this purpose a multistory building was defined as a structure with more than 10 stories.
Table 3 indicates that multistory buildings accounted for 62 projects, or approximately two thirds of the sum of replies. It is also interesting to note that heavy columns had been used in low-rise buildings such as post-offices and libraries.

Twenty-four of the American states were represented in the survey, with the largest number of projects located in California and Illinois. Although only one reply came from Canada, there are definite indications that heavy columns are used extensively there. As a matter of fact, columns heavier than any of the types found in the U.S. have been used in Canada. There does not seem to be any particular reason for this.

Table 5 illustrates the distribution of the number of stories for the multistory and the low-rise buildings, indicating that nearly 60% of these structures had a number of stories between 10 and 30. Two of the tallest structures in the nation, the John Hancock Building in Chicago and the World Trade Center in New York, with 100 and 110 stories, respectively, are included in the survey.
In relation to the number of stories, it was important to find the range of total building heights, especially because the story heights varied between 10'-6" and 15'-0". Comparison of Tables 5 and 6 indicates that the trend given by Table 5 is confirmed by Table 6, and it may also be noted that 59 of 86 structures had total heights less than 400'. Eight answers did not include data on this question.

For buildings other than multistory buildings, "story" heights up to 80' were recorded.

3.3 Heavy Column Sections Used

It was considered important to categorize the heavy columns used in the various structures. This would indicate to what extent regular sections were utilized, and whether any special sections had been introduced. Regular sections refer to WF, welded H (later designated only as H), box and circular tubes.

The information is summarized in Table 7, where it may be seen that the two types mostly used are WF- and
H-shapes. Box-sections also seem to have some importance, whereas all the other types are used almost equally, and to a relatively small extent. It is worth while noting that the combination of WF-shapes and various kinds of cover plates seems to be fairly common. The cover plates were usually placed on top of the flanges, but there were cases where the cover plates were oriented parallel to the web and welded to the flange tips or only to the web.

It was found that only one type of shape was used in most of the structures. Some buildings, however, and particularly the more complex ones, utilized up to 5 or 6 different section types. This information is given in Table 8. Comparing Tables 7 and 8 indicates that projects with only one column type mostly used WF- or H-shapes. This may be because these types are most readily available, and do not require special design or manufacturing procedures.

Figure 1 illustrates some of the typical heavy column shapes utilized in the structures included in the survey. The range of the dimensions of the H-shapes is particularly wide; with the component plate thickness varying from $\frac{1}{2}"$ to $6\frac{1}{2}"$, and the flange widths and section heights varying from 10" to 40", and from 20" to 43", respectively.
Also notable are the variety of box shapes, and a number of the more special sections, such as the cruciform type. The heaviest box shape recorded had dimensions 52" x 22", with plate thickness up to 8".

Although no specific information is included in this report, the trend for the utilization of extremely heavy columns in some Canadian structures must be mentioned. Columns heavier than any found in the U.S. have been made in Canada, and the heaviest shape used so far has a weight of 2,700 lb/ft,\(^1\) with shapes up to 4,000 lb/ft under fabrication.

3.4 Material Used for Heavy Columns

With the wide variety of steel grades commercially available, it was of particular interest to find which, if any, grades were utilized most for the heavy columns. This information is summarized in Table 9.

The results show that steel grade ASTM A36 is by far the one most used. It has been employed in 84 different projects, equivalent to 90% of all of the recorded structures.
Apart from ASTM A441, which has been used in 26 buildings (approximately 30%), the high strength steels have not been utilized to any large extent. The reasons for this are not deduced from the information available, although it is possible that cost and lack of construction experience may have played a role.

Analogous to the data given in Table 8, the extent to which different steel grades had been used for the heavy columns in the same project was investigated. Table 10 illustrates the collected data, and it is seen that although it is most common to have all columns manufactured from the same steel grade, a significant number of structures had columns of more than one grade. Some of the more complex buildings used several grades. An illustration of this is given in Fig. 1, which also contains information about the steel grades used for some of the column types.

In general it was found that columns made of higher strength steels were located in the lower portions of the structure, or in other heavily-loaded areas.
None of the projects included in the survey had utilized hybrid columns, that is, columns where the component plates are made of different steel grades.

3.5 Manufacturing Procedures for Heavy Columns

One phase of the overall research program on residual stresses in thick welded plates was concerned with the study of the manufacture and fabrication of heavy welded plate and shape specimens. For this investigation, the procedures employed by one fabricator were studied, and part of the survey was aimed at finding whether these procedures represented common practice.

Items of interest to the survey were, as indicated above:

1. Welding methods
2. Weld types
3. Location of welds
4. Use of preheating and postheating
5. Application of straightening

The findings on each of these features are discussed in the following paragraphs.
1. **Welding Methods**

Table 11 presents the results of this investigation. A substantial part of the replies (45 projects) did not include information on this topic, but the data available indicate that the automatic submerged arc method is the most common. This is probably due to the fact that many fabricators have only one type of equipment available, which usually is of the submerged arc type.

The use of methods like MIG and special procedures were reported, and almost exclusively by the larger fabricators. It may be noted that specially developed methods seem to be quite common, some employing combinations of two or more regular techniques, and others emphasizing the importance of a proper welding sequence. Several replies stressed the necessity for such methods, due to factors like multiple-pass, large-size welds, and subsequent distortions, bridging of large gaps between component plates, and field welding.

Reference to gas-shield methods was made only in a few replies, and seemed mostly to be applied for small-scale work.
2. **Weld Types.**

The questionnaire (see Appendix) asked for data concerning the use of fillet, groove and butt welds, and Table 12 shows the categorized answers. One difficulty became evident, however, in that the questionnaire did not define the terms groove and butt welds. It was therefore decided to follow the definitions given by the joint recommendations of AISC and AWS\(^3\). The recommendations clearly define a fillet weld, whereas they do not differ between groove and butt welds.

Table 12 indicates that usually all weld types had been used within the same structure (57 projects), but it was also rather common that only fillet welds were employed. A description of typical locations of the various weld types is given in the next paragraph.

3. **Location of Welds**

Only 30 of the 98 replies included information on where the various welds had been used within the structure and its components. However small this figure may be, it did provide some useful information for the survey.
The 30 answers available were subdivided as follows:

a. Seventeen of the projects reported on welds used for welding together column component plates. Except for the box sections and some special sections, where the welds used were of the partial penetration single or double bevel groove type, all welds for this purpose were fillet welds.

b. The remaining 13 projects reported welds being used for column splices (square groove, single or double bevel groove), beam-to-column connections (fillet welds only), stiffeners and diaphragms to web (fillet, single or double full penetration groove), and column base plates to column (fillet, partial or full penetration single bevel groove).

In one case fillet welds had to bridge large gaps between the component plates in H-sections and WF + cover plate sections. This involved a rather complicated welding procedure, employing a triple head welding equipment. The first pass was done with CO₂-welding, and
the second and third passes completed the operation with a regular automatic submerged arc process. There are no indications, however, why CO$_2$-welding was chosen for the first pass.

4. **Use of Preheating and Postheating**

   The American Welding Society's "Code for Welding in Building Construction"(4) specifies the procedure for heat treatment of welded assemblies, when such is required either by contract or specifications. Depending on certain conditions, the AISC 1969 Specifications(5) also specify the use of preheating for welded construction. However, only five of the questionnaires returned mentioned heat treatment, and in addition one reply stated that it had not been performed. The answers are not believed to be representative in any form as far as the extent of application of heat treatment is concerned, but some of the data received are quite interesting, and one method will be described briefly below.

   A project that utilized box columns with integrated gusset plates (steel grade A 242 Cor-Ten, thickness 2$\frac{1}{4}$")
at various locations, reported some cracking in the gusset plates after welding. The problem was alleviated by annealing the plates after rolling, and instituting strict heat control during fabrication.

All of the four other projects that reported the use of heat treatment applied preheating for fabrication of box sections, following the requirements of the AWS Code. (4)

Postheating was not reported in any of the projects.

5. **Application of Straightening**

Straightening is required by the various codes and specifications\(^4,5\) whenever the distortions or the out-of-straightness exceed the allowable limits. Regardless of this, only three of the projects reporting indicated that straightening was utilized. It is hardly likely that this reflects the actual situation, since considerable deformations normally will occur during welding of heavy shapes and assemblies.
One of the projects that reported on the use of straightening did not specify why, where and by which method it had been done. Both of the other two projects used it for the straightening of box section component plates after the plates had been cut. Gagging of the plates was performed in one case, while heat straightening was used for the other one.

6. Other Features of the Manufacturing Process

A few other points are worth mentioning concerning the fabrication of heavy columns. Several replies referred to the necessity for strict assembly and welding sequence rules, in order to maintain the required tolerances. This was particularly emphasized for assemblies with extensive welding, and for members where several weld beads were either intersecting or located close to each other.

Many references were made to expected and actual distortions due to heavy welding. As discussed later (see Sect. 3.6, items 4 and 5), the distortions that occurred sometimes caused severe problems for the proper
erection of the structure, supporting the views expressed above on the need for straightening.

The precautions taken by one fabricator for the manufacture of box columns present a good example. The columns in question were the heaviest to be used in the particular structure, and were equipped both with or without single or double longitudinal diaphragms. The component plates were flame-cut to final detail width, regardless of whether the original material had been purchased as universal mill or flame-cut. The length of the plates was sufficient to allow trimming and milling to final length after the welding of the columns had been completed.

Several plates were more or less curved due to the cutting operation. This was taken care of by flattening them with hydraulic jacks, and tack welding the assembly, thus ensuring proper straightness of the columns. The final longitudinal welds were subsequently deposited by tandem submerged arc machines. The plates had been preheated in accordance with the AWS requirements.
The welding sequence for the columns with internal diaphragms was as follows:

1. Welding of diaphragm(s) and "flanges" into an H-shape.
2. Tack welding of remaining box plates to the flange tips of the "H-shape". Proper fit was ensured before this was carried out.
3. Completing the welds required for the box section, using tandem submerged arc electrodes.

3.6 Miscellaneous Information

1. Design Bases for Heavy Columns

The design bases for the heavy columns were of particular importance to the survey. Besides asking for information on which specifications or codes had been employed, it was of significance to learn whether any special or refined analyses had been performed, whether any model or full scale tests accompanied the design, and so on.

Table 13 shows the information received on this topic. It is seen that almost 50% of the structures had been designed by using the AISC Specifications only, and that these
specifications together with local building codes and other standards constituted the design basis for about two thirds of the projects.

The AWS and AASHO Specifications were used mainly for special purposes. Some of the fabricators indicated that the AWS Specifications were utilized for the manufacture and partly also for erection items, whereas the AASHO Specifications formed the design basis for bridges and bridge-like structures. Local building codes were applied when this was required by the authorities, mainly to establish loading data, fire ratings and other locally specified design data. For projects located in California the codes also included design procedures with regard to earthquake loading.

Many designers indicated that computer solutions had been used extensively, which in some cases were accompanied by various types of tests. One reply mentioned specifically that a plexiglass model of a typical column base had been tested (64-story building), and two structures were examined in wind tunnel tests. These particular buildings had 35 and 64 stories with cruciform and box columns. Tests were also
referred to in other answers, but the kind of testing that had been done was not stated.

2. Residual Stress Measurements

Residual stress measurements may also be classified as design information.

Such measurements were reported only for two projects, and in both cases the measurements were carried out in order to determine whether the use of stress-relieving treatment was warranted.

One of the buildings was a 35-story structure with welded H-columns (double web). The residual stress measurements showed that no particular heat treatment was necessary. The other structure was the John Hancock Building in Chicago, where measurements were made on the unusually shaped corner joints. The results convinced the designer that stress relieving of the joints was necessary.

3. Testing of Welds

Testing of welds includes ultrasonic testing, X-ray testing, magnetic particle testing, and other methods that
are commonly used. For most of the projects where weld testing was reported, it was done in conjunction with studies of the welding procedures or to examine the quality of the welds. This implied detecting and locating cracks, and determining effects due to changes in the welding procedures.

Ultrasonic testing was more commonly used than other methods, and was reported in most of the cases where weld testing was indicated. X-ray testing was reported in much fewer cases. Other testing methods were reported in some cases. Among these were checks for surface cracks (magnetic particle testing), and for hardness of welds.

4. **Damage to Columns and Welds**

The instances reported of damage to columns and welds occurred almost only during the manufacturing stage. The information given here must therefore be studied in conjunction with Sect. 3.5, which gives a better picture of the manufacturing techniques. This paragraph outlines how the fabricators and the contractors solved problems of this type.
Damage to columns were mainly distortions, caused by extensive welding. It will be discussed below how these distortions affected the erection of the structure. Usually the distortions were diminished by altering the welding sequence, but in some cases, the distorted columns were actually installed in the structure, using shimming to alleviate the problem.

Several fabricators reported weld cracking, particularly in full-penetration groove welds. In one case, where girder flange plates were welded in the trough of the H-columns, delayed cracking occurred in the full-penetration welds. The problem was solved by changing the welding sequence, such that the girder flange was welded to the column web before being welded to the flanges.

Slag inclusions and other similar defects were found in some welds. Laminations were detected in some of the thickest plates, agreeing with the findings reported in Ref. 2.

Generally speaking, many fabricators indicated difficulties in meeting weld defect limitations; however, the amount of repair of improper welds was not stated in any replies.
5. Erection Problems

Many replies indicated that erection problems were caused by column distortions. In a few cases the distortions were so severe that considerable reworking of the connections had to be made. Usually, however, problems like these were solved by shimming, either at the column ends or at the splices, even if large gaps had to be bridged sometimes. The shimming was checked as the erection of the structure above proceeded. Some of the fabricators mentioned that revised erection plans would be used for future buildings, in order to avoid problems of this type, but did not indicate how it would be done, and which revisions this would involve.

Other fabricators reported that small tolerances caused difficulties for the erection. This was partly structure-dependent, and would require close cooperation with the structural engineer if similar problems were to be avoided in the future.

Problems with field welding were reported for a few projects, especially where two different steel grades had to be joined.
Only for very few projects did the fabricator or contractor indicate a smooth erection operation. It is obvious that many of the problems described above were caused by the use of heavy structural elements.
4. SUMMARY AND CONCLUSIONS

The information obtained from the survey can be summarized as follows:

1. A number of architectural, engineering, fabricating and contracting companies are working with structures employing heavy columns. Some of the companies in the fabricating business seem to have developed special skills and methods for handling the problems that arise due to the use of heavy elements.

2. 94 different projects were included in the survey. 70 of these structures were multistory and low-rise buildings, and the other 24 projects represented various types of plants, hangars, transit structures and research and art centers.

3. All projects except one were located in the United States. Of the remaining 93 buildings, 25 were located in California, 14 in Illinois, and the rest distributed all over the U.S. A total of 24 different states had projects included in the survey.
4. Of the 70 multistory and low-rise buildings, 47 had a number of stories less than 30. Correspondingly, 59 of these structures had total building height less than 400 ft. Two of the tallest buildings in the nation are included in the survey.

5. The heavy column sections mostly used are rolled WF, welded H, and box, although many other shapes also are utilized. Usually, only one type of shape is used for the columns in a structure, but buildings employing up to 6 or 7 different types are not uncommon.

6. Steel grade ASTM A36 by far constitutes the material mostly used for heavy columns. ASTM A441 had been used in 26 cases, but other steel grades, including the high strength steels, were utilized to an extent much smaller than expected. Usually all columns were manufactured from the same steel grade, but projects employing 2 or 3 different grades were quite common.

7. Although many replies did not include information on this topic, the data available indicate that the automatic submerged arc welding method is more used than all other
methods. Some fabricators have developed their own welding procedures in order better to meet the special demands of heavy column manufacture.

8. The AISC Specifications formed the only design bases for a major portion of the buildings included. Other codes and standards were used as supplements to the AISC Specifications in a number of cases, whereas special analyses, tests, and other methods of arriving at more exact design data were applied only for a limited number of structures. Very few, if any, designers seem to have taken any special measures to account for the use of heavy structural elements.

9. Residual stress measurements were reported for two structures only. In both cases the measurements were carried out in order to establish whether stress relieving was necessary.

10. Application of heat treatment and straightening was reported only for very few projects. It is believed that this does not reflect the actual picture, since many specifications and contracts require such treatment.
This assumption is further justified by the statements of several fabricators and contractors, concerning column distortions and structural misfit.

11. Weld testing was reported in a few cases. It has not been stated to which extent this made weld repair necessary. The ultrasonic testing method seems to be more commonly used than others.

12. Damage to columns and welds was indicated for a number of projects. This caused several problems during erection of the steel structures, particularly when column distortions occurred. Many fabricators indicated size of columns and welds as a major reason for the distortions, and stated that special erection procedures would be developed for future work of this kind.

13. The results of the survey indicate that heavy columns are frequently used in steel structures today. The utilization is expected to increase as tall buildings and other heavily-loaded structures become more numerous. While the findings in this report are by no means exhaustive, they do indicate some of the problems encountered and the solutions made.
5. ACKNOWLEDGEMENTS

This report presents the results of a survey that formed part of the research project "Residual Stresses in Thick Welded Plates". The research program is being carried out at Fritz Engineering Laboratory, Lehigh University, Bethlehem, Pennsylvania, of which Dr. Lynn S. Beedle is Director. Dr. D. A. VanHorn is the Chairman of the Civil Engineering Department.

The investigation was sponsored jointly by the American Iron and Steel Institute, the American Institute of Steel Construction, the National Science Foundation, and the Column Research Council. The technical guidance of Task Group 1 of Column Research Council under the chairmanship of John A. Gilligan is gratefully acknowledged.

The information given by the responding companies, without which the survey could not have been done, is sincerely appreciated. Special thanks are due Angel Lazaro III, who carried out much of the work done during the first phases of the survey.
The authors also wish to acknowledge the assistance of Miss Joanne Mies for typing the manuscript, and of John M. Gera for preparing the drawings.
6. APPENDIX

SAMPLE OF SURVEY QUESTIONNAIRE.
QUESTIONNAIRE
SURVEY OF DESIGN AND FABRICATION PROCEDURES OF HEAVY COLUMN SHAPES

I. Name and location of project: ________________________________

II. Name and address of architect: ______________________________

III. Name and address of structural engineer: ______________________

IV. Name and address of steel fabricator: __________________________

V. Name and address of general contractor: _________________________

VI. Number of stories: _________________________________________

VII. Total building height: _____________________________________
VIII. Typical story height: ____________________________________________

IX. Heavy column sections used (section in which any element exceeds 1" in thickness) ____________________________________________

X. Basis of design (AISC code, tests, more refined analysis, etc.) ____________________________________________

XI. Were there any residual stress measurements and how did this affect the design? ____________________________________________

XII. Material (check appropriate item/s): A7____ A36____ A242____ A441____ A572____ A514/517____ Others ____________________________________________

XIII. Type of welding used (check appropriate item/s):
Fillet_____ Groove_____ Butt_____ Submerged arc_____ M.I.G._____ Others ____________________________________________

XIV. Any special problems concerning the columns before, during, or after construction?: ____________________________________________

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XV. Remarks: ____________________________________________

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7. **TABLES AND FIGURES**
TABLE 1

Distribution of Answers Among Companies

<table>
<thead>
<tr>
<th>Type of Company</th>
<th>No. of Answers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Architect</td>
<td>3</td>
</tr>
<tr>
<td>Engineer</td>
<td>17</td>
</tr>
<tr>
<td>Architect/Engineer</td>
<td>20</td>
</tr>
<tr>
<td>Fabricator</td>
<td>51</td>
</tr>
<tr>
<td>Contractor</td>
<td>5</td>
</tr>
<tr>
<td>Not Known</td>
<td>2</td>
</tr>
<tr>
<td><strong>Sum</strong></td>
<td><strong>98</strong></td>
</tr>
</tbody>
</table>
TABLE 2

Distribution of Projects in Companies

<table>
<thead>
<tr>
<th>Company</th>
<th>No. of Projects</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Architectural:</strong></td>
<td></td>
</tr>
<tr>
<td>Company A</td>
<td>10</td>
</tr>
<tr>
<td>Company B</td>
<td>6</td>
</tr>
<tr>
<td>Others</td>
<td>1-3</td>
</tr>
<tr>
<td><strong>Engineering:</strong></td>
<td></td>
</tr>
<tr>
<td>Company C</td>
<td>5</td>
</tr>
<tr>
<td>Others</td>
<td>1-3</td>
</tr>
<tr>
<td><strong>Fabricators:</strong></td>
<td></td>
</tr>
<tr>
<td>Company D</td>
<td>18</td>
</tr>
<tr>
<td>Company E</td>
<td>13</td>
</tr>
<tr>
<td>Company F</td>
<td>6</td>
</tr>
<tr>
<td>Others</td>
<td>1-3</td>
</tr>
<tr>
<td><strong>Contractors:</strong></td>
<td></td>
</tr>
<tr>
<td>Company G</td>
<td>7</td>
</tr>
<tr>
<td>Others</td>
<td>1-3</td>
</tr>
</tbody>
</table>
### TABLE 3

Structural Types Included in Survey

<table>
<thead>
<tr>
<th>Structural Type</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multistory buildings</td>
<td>62</td>
</tr>
<tr>
<td>Low-rise buildings</td>
<td>8</td>
</tr>
<tr>
<td>Power plants</td>
<td>5*</td>
</tr>
<tr>
<td>Steel mills</td>
<td>4</td>
</tr>
<tr>
<td>Subway structures</td>
<td>3</td>
</tr>
<tr>
<td>Hangars</td>
<td>2</td>
</tr>
<tr>
<td>Research centers</td>
<td>2</td>
</tr>
<tr>
<td>Chemical (paper) plant</td>
<td>1</td>
</tr>
<tr>
<td>Transit structure</td>
<td>1</td>
</tr>
<tr>
<td>Subterranean structure</td>
<td>1</td>
</tr>
<tr>
<td>Viaduct</td>
<td>1</td>
</tr>
<tr>
<td>Mine plant</td>
<td>1</td>
</tr>
<tr>
<td>Rubber plant</td>
<td>1</td>
</tr>
<tr>
<td>Brewery</td>
<td>1</td>
</tr>
<tr>
<td>Art center</td>
<td>1</td>
</tr>
<tr>
<td><strong>Sum</strong></td>
<td><strong>94</strong></td>
</tr>
</tbody>
</table>

* Three of these were nuclear power plants.
## TABLE 4

Geographical Locations and Types of Structures.

<table>
<thead>
<tr>
<th>State</th>
<th>No. of Project</th>
<th>Structure Types</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alabama</td>
<td>2</td>
<td>1 chem. plant, 1 res. center</td>
</tr>
<tr>
<td>Arkansas</td>
<td>2</td>
<td>2 multi-story buildings</td>
</tr>
<tr>
<td>California</td>
<td>25</td>
<td>18 multi-story buildings, 1 8-st. build., 3 subway str., 2 hangars, 1 nucl. pow. pl.</td>
</tr>
<tr>
<td>Colorado</td>
<td>1</td>
<td>Nuclear power plant</td>
</tr>
<tr>
<td>Florida</td>
<td>2</td>
<td>2 power plants (1 nuclear)</td>
</tr>
<tr>
<td>Georgia</td>
<td>1</td>
<td>Power plant</td>
</tr>
<tr>
<td>Illinois</td>
<td>14</td>
<td>10 multi-st. build., 1 5-st. build., 1 steel mill, 1 transit str., 1 subterr. str.</td>
</tr>
<tr>
<td>Kansas</td>
<td>1</td>
<td>Multi-story building</td>
</tr>
<tr>
<td>Louisiana</td>
<td>1</td>
<td>Multi-story building</td>
</tr>
<tr>
<td>Massachusetts</td>
<td>4</td>
<td>3 multi-st. build., 1 viaduct</td>
</tr>
<tr>
<td>Michigan</td>
<td>5</td>
<td>3 multi-st. build., 1 9-st. build., 1 steel mill</td>
</tr>
<tr>
<td>Minnesota</td>
<td>4</td>
<td>2 multi-st. build., 1 9- &amp; 1 7-st.</td>
</tr>
<tr>
<td>Missouri</td>
<td>1</td>
<td>4-story building</td>
</tr>
<tr>
<td>Nebraska</td>
<td>1</td>
<td>Multi-story building</td>
</tr>
<tr>
<td>New York</td>
<td>8</td>
<td>7 multi-st. build., 1 4-st. build.</td>
</tr>
<tr>
<td>North Carolina</td>
<td>1</td>
<td>Mine plant</td>
</tr>
<tr>
<td>Ohio</td>
<td>4</td>
<td>2 multi-st. build., 2 steel mills</td>
</tr>
<tr>
<td>Pennsylvania</td>
<td>6</td>
<td>5 multi-st. build., 1 res. center</td>
</tr>
<tr>
<td>Tennessee</td>
<td>1</td>
<td>Rubber plant</td>
</tr>
<tr>
<td>Texas</td>
<td>2</td>
<td>2 multi-story buildings</td>
</tr>
<tr>
<td>Virginia</td>
<td>1</td>
<td>Multi-story building</td>
</tr>
<tr>
<td>Washington</td>
<td>3</td>
<td>2 multi-st. build., 1 brewery</td>
</tr>
<tr>
<td>West Virginia</td>
<td>1</td>
<td>Multi-story building</td>
</tr>
<tr>
<td>Wisconsin</td>
<td>2</td>
<td>1 3-st. build., 1 art center</td>
</tr>
<tr>
<td>Canada</td>
<td>1</td>
<td>Multi-story building</td>
</tr>
<tr>
<td>Sum projects</td>
<td>94</td>
<td></td>
</tr>
</tbody>
</table>
### TABLE 5

Distribution of Number of Stories in Multistory- and Low-Rise Buildings.

<table>
<thead>
<tr>
<th>Range of Stories</th>
<th>No. of Buildings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Below 10 (low-rise)</td>
<td>8</td>
</tr>
<tr>
<td>10 - 19</td>
<td>16</td>
</tr>
<tr>
<td>20 - 29</td>
<td>23</td>
</tr>
<tr>
<td>30 - 39</td>
<td>8</td>
</tr>
<tr>
<td>40 - 49</td>
<td>4</td>
</tr>
<tr>
<td>50 - 59</td>
<td>6</td>
</tr>
<tr>
<td>60 - 69</td>
<td>3</td>
</tr>
<tr>
<td>70 - 79</td>
<td>0</td>
</tr>
<tr>
<td>80 - 89</td>
<td>0</td>
</tr>
<tr>
<td>90 - 99</td>
<td>0</td>
</tr>
<tr>
<td>100 - 109</td>
<td>1</td>
</tr>
<tr>
<td>110 - 119</td>
<td>1</td>
</tr>
<tr>
<td><strong>Sum</strong></td>
<td><strong>70</strong></td>
</tr>
</tbody>
</table>
TABLE 6

Distribution of Total Building Heights.
(All Structures Included.)

<table>
<thead>
<tr>
<th>Range of Heights</th>
<th>No. of Buildings</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 100'</td>
<td>12</td>
</tr>
<tr>
<td>100' - 200'</td>
<td>19</td>
</tr>
<tr>
<td>200' - 300'</td>
<td>16</td>
</tr>
<tr>
<td>300' - 400'</td>
<td>12</td>
</tr>
<tr>
<td>400' - 500'</td>
<td>8</td>
</tr>
<tr>
<td>500' - 600'</td>
<td>5</td>
</tr>
<tr>
<td>600' - 700'</td>
<td>5</td>
</tr>
<tr>
<td>700' - 800'</td>
<td>4</td>
</tr>
<tr>
<td>800' - 900'</td>
<td>3</td>
</tr>
<tr>
<td>900' - 1000'</td>
<td>0</td>
</tr>
<tr>
<td>1000' - 1100'</td>
<td>0</td>
</tr>
<tr>
<td>1100' - 1200'</td>
<td>1</td>
</tr>
<tr>
<td>1200' - 1300'</td>
<td>0</td>
</tr>
<tr>
<td>1300' - 1400'</td>
<td>1</td>
</tr>
<tr>
<td>Sum</td>
<td>86*</td>
</tr>
</tbody>
</table>

*8 replies did not indicate total building height.
TABLE 7

Heavy Column Sections Used.

<table>
<thead>
<tr>
<th>Section Type</th>
<th>No. of Projects</th>
</tr>
</thead>
<tbody>
<tr>
<td>WF</td>
<td>47</td>
</tr>
<tr>
<td>H</td>
<td>33</td>
</tr>
<tr>
<td>Welded Box</td>
<td>21</td>
</tr>
<tr>
<td>Circular tube</td>
<td>0</td>
</tr>
<tr>
<td>WF + Cover Plates</td>
<td>12</td>
</tr>
<tr>
<td>H + Cover Plates</td>
<td>0</td>
</tr>
<tr>
<td>H with double web</td>
<td>1</td>
</tr>
<tr>
<td>□ with diaphragm(s)</td>
<td>6</td>
</tr>
<tr>
<td>Cruciform</td>
<td>2</td>
</tr>
<tr>
<td>Special sections</td>
<td>3</td>
</tr>
<tr>
<td>Not known sections</td>
<td>9</td>
</tr>
</tbody>
</table>

Note:
Many structures have used more than one type of shape, and total number appearing above is therefore larger than the number of projects included.
### TABLE 8

Number of Different Column Shapes (WF, H, etc.) Used in Each Structure.

<table>
<thead>
<tr>
<th>No. of Different Shapes</th>
<th>No. of Projects</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 type</td>
<td>59</td>
</tr>
<tr>
<td>2 types</td>
<td>25</td>
</tr>
<tr>
<td>3 types</td>
<td>4</td>
</tr>
<tr>
<td>4 types and more</td>
<td>3</td>
</tr>
<tr>
<td>Not known</td>
<td>7</td>
</tr>
<tr>
<td><strong>Sum</strong></td>
<td><strong>98</strong></td>
</tr>
</tbody>
</table>

Note:

*Sum = 98 is larger than the actual number of projects (94), because one structure has been included more than once.*
TABLE 9

Steel Grades Used for Heavy Columns.

<table>
<thead>
<tr>
<th>Steel Grade*</th>
<th>No. of Projects</th>
</tr>
</thead>
<tbody>
<tr>
<td>A 7</td>
<td>2</td>
</tr>
<tr>
<td>A 36</td>
<td>84</td>
</tr>
<tr>
<td>A 242</td>
<td>8</td>
</tr>
<tr>
<td>A 441</td>
<td>26</td>
</tr>
<tr>
<td>A 514</td>
<td>6</td>
</tr>
<tr>
<td>A 572</td>
<td>12</td>
</tr>
<tr>
<td>Other grades**</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Sum 148+</td>
</tr>
</tbody>
</table>

* According to ASTM designation. (6)

** Other grades include: A441 with modified yield strength, A588, USS T1A and T1B, USS Cor-Ten, and Beth. Steel Mayari-R.

+ The total number of projects is larger than 94, because many structures have employed more than one steel grade.
### TABLE 10

Number of Steel Grades Used in the Various Projects.

<table>
<thead>
<tr>
<th>No. of grades</th>
<th>No. of projects</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 grade</td>
<td>57</td>
</tr>
<tr>
<td>2 grades</td>
<td>24</td>
</tr>
<tr>
<td>3 grades</td>
<td>10</td>
</tr>
<tr>
<td>More than 3 grades</td>
<td>3</td>
</tr>
<tr>
<td>Not known</td>
<td>4</td>
</tr>
<tr>
<td><strong>Sum</strong></td>
<td><strong>98</strong>*</td>
</tr>
</tbody>
</table>

*See note, Table 8.
TABLE 11

Welding Methods Used.

<table>
<thead>
<tr>
<th>Method</th>
<th>No. of projects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Submerged arc</td>
<td>47</td>
</tr>
<tr>
<td>MIG</td>
<td>7</td>
</tr>
<tr>
<td>Special procedures*</td>
<td>8</td>
</tr>
<tr>
<td>Not known</td>
<td>45</td>
</tr>
<tr>
<td><strong>Sum</strong></td>
<td><strong>107</strong></td>
</tr>
</tbody>
</table>

* Special procedures include: Lincoln Squirt welding, Gas Shield methods (CO₂, etc.), modified versions of MIG, Lincoln Inner-shield method, and procedures developed by the fabricators.

** This number indicates that some projects employed more than one method.
TABLE 12

Weld Types Used.

<table>
<thead>
<tr>
<th>Type of weld*</th>
<th>No. of projects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fillet</td>
<td>21</td>
</tr>
<tr>
<td>Groove/Butt</td>
<td>12</td>
</tr>
<tr>
<td>Fillet and groove/butt</td>
<td>57</td>
</tr>
<tr>
<td>Not known</td>
<td>8</td>
</tr>
<tr>
<td>Sum</td>
<td>98**</td>
</tr>
</tbody>
</table>

* Designation according to Ref. 3.

** See note, Table 8.
TABLE 13

Use of Design Specifications, Codes, or Otherwise.

<table>
<thead>
<tr>
<th>Method, code, tests</th>
<th>No. of projects</th>
</tr>
</thead>
<tbody>
<tr>
<td>AISC Spec. only (Various ed.)</td>
<td>46</td>
</tr>
<tr>
<td>AISC + Codes or other standards*</td>
<td>18</td>
</tr>
<tr>
<td>Other standards or codes</td>
<td>11</td>
</tr>
<tr>
<td>Any of above specs., codes, etc., + tests and special analyses.**</td>
<td>14</td>
</tr>
<tr>
<td>Not known</td>
<td>9</td>
</tr>
<tr>
<td>Sum</td>
<td>98+</td>
</tr>
</tbody>
</table>

*Codes and other standards include: Local Building Codes, AWS Specs., AASHO Specs., and the Canadian code CSA-SIG 1961 and -65.

**Tests and special analyses include: Model tests, residual stress measurements, refined analyses, etc.

+See note, Table 8.
Fig. 1 Some Typical Heavy Column Shapes.
Fig. 1 (Continued) Some Typical Heavy Column Shapes.

WELDED BOX
Steel Grades Used:
A36, A572

WELDED BOX WITH
LONGITUDINAL DIAPHRAGMS
Steel Grades Used:
A36

CRUCIFORM
B ≤ 60"
\( t_1 \leq 6" \)
\( t_2 \leq 6" \)
Steel Grades Used:
A36, A242

Horizontal Stiffener
(Used in Some Cases)
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